DUKE COGEMA
STONE & WEBSTER

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555

02 July 2003
DCS-NRC-000147

Subject: Docket Number 070-03098
Duke Cogema Stone & Webster
Mixed Oxide (MOX) Fuel Fabrication Facility
Criticality Validation Report – Revision 3 of Part I, Revision 2 of Part II, and Revision 1 of Part III
Response to DSER Open Item NCS-04

References:

(1) P. S. Hastings (DCS) to NRC Document Control Desk, DCS-NRC-000124, *Mixed Oxide Fuel Fabrication Facility Criticality Validation Report – Revision 2 of Part I, Revision 1 of Part II and Original Issue of Part III*, 09 January 2003

(2) P. S. Hastings (DCS) to NRC Document Control Desk, DCS-NRC-000144, *Mixed Oxide (MOX) Fuel Fabrication Facility Response to DSER Open Item NCS-04*, 13 June 2003

(3) A. Persinko (NRC) to P. S. Hastings, *Request for Additional Information – Mixed Oxide (MOX) Fuel Fabrication Facility Nuclear Criticality Safety*, 25 June 2003

This letter transmits the latest versions of Parts I, II, and III of the Criticality Validation Report for the Mixed Oxide Fuel Fabrication Facility. Reference 1 transmitted prior revisions to Parts I-III. The attached revisions implement the changes discussed in Reference 2 and address, in part, NRC Staff questions contained in Reference 3.

The Criticality Validation Report documents the validation of the nuclear criticality safety codes to be used in the design of the MFFF, and are being transmitted at this time to provide justification for selection of administrative margin for construction authorization.

Part I validates Areas of Applicability (AOAs) related to AOA(1), Pu-nitrate aqueous solutions, and AOA(2), MOX pellets, fuel rods, and fuel assemblies. The enclosed revision clarifies the definition of areas of applicability and reflects additional evaluation of fixed absorbers.

Part II covers AOA(3), PuO_2 powders, and AOA(4), MOX powders. It defines areas of applicability based on key parameter ranges of input design applications used in sensitivity and uncertainty analysis. It also removes waste store and laboratory from typical design applications for AOA(3) since these units can be analyzed using ANSI-ANS-8.1 limits.

NMSS01

Part III covers AOA(5), PuO_2 powder-polystyrene mixtures and Pu nitrate. Revision 1 clarifies the applicability of validation for design application with $H/Pu < 30$.

In addition, please find enclosed a summary of the extent to which the revised Parts I, II, and III of the validation report is responsive to the Staff's 25 June 2003 letter (Reference 3), and discussion of DCS' response to other issues raised in that letter. As was agreed to by the Staff in a conference call that preceded their letter, and in the interest of expediting the Staff's review of the changes implementing DCS' 13 June 2003 letter (Reference 2), these validation report revisions do not yet address all of the Staff's questions (from Reference 3).

As indicated in the original transmittal of Part I, the MOX Standard Review Plan states that the validation report should be maintained at DCS' facility, the implication being that, should the NRC Staff wish to review it, the review would take place at DCS' facility. However, DCS presumes that the Staff's review of the validation report will be facilitated by making the report available directly. DCS considers the attached Criticality Validation Report to be a technical report that backs up conclusions in the Construction Authorization Request (CAR), but does not consider it to be part of the CAR.

DCS requests NRC review and comment on these reports, and will be prepared to discuss its conclusions at your convenience. If you have any questions, please feel free to contact me at (704) 373-7820.

Sincerely,

Peter S. Hastings, P.E.
Manager, Licensing & Safety Analysis

Enclosures:
(1) Response to NRC Staff Request for Additional Information (Persinko to Hastings, 25 June 2003)
(2) MFFF Criticality Validation Report – Revision 3 of Part I
(3) MFFF Criticality Validation Report – Revision 2 of Part II
(4) MFFF Criticality Validation Report – Revision 1 of Part III

xc (with enclosure):
David Alberstein, NNSA/HQ
Kenneth L. Ashe, DCS
Andrew Persinko, USNRC/HQ
Donald J. Silverman, Esq., DCS
PRA/EDMS: Corresp\Outgoing\NRC\2003 NRC\DCS-NRC-000147

xc (without enclosure):
Marc Arslan, DCS
David A. Ayres, USNRC/RII
Timothy S. Barr, NNSA/CH
Jean-Marc Belmont, DCS
Edward J. Brabazon, DCS
James R. Cassidy, DCS
Sterling M. Franks, III, NNSA/SR
Kathy H. Gibson, USNRC/HQ
Robert H. Ihde, DCS
James V. Johnson, NNSA/HQ
Eric J. Leeds, USNRC/HQ
J. David Nulton, NNSA/HQ
Robert C. Pierson, USNRC/HQ
Luis A. Reyes, USNRC/RII
Patrick T. Rhoads, NNSA/HQ
Brian W. Smith, USNRC/HQ
Thomas E. Touchstone, DCS
Martin J. Virgilio, USNRC/HQ

Enclosure 1

Response to NRC Staff Request for Additional Information
(Persinko to Hastings, 25 June 2003)

Following is a summary of the extent to which the current revisions of Parts I, II, and III of the MFFF Validation Report address the questions asked in the NRC Staff's Request for Additional Information (RAI) dated 25 June 2003. Also included is additional discussion on issues raised in those RAIs. Further information will be forthcoming in response to the Staff's questions.

Background

On 20 March 2003, DCS and NRC Staff conducted a public meeting on the subject of validation reports. As discussed in that meeting, there was general agreement that the Staff's questions would be addressed through a clearer definition of the parameter ranges for each of the five Areas of Applicability (AOAs) discussed in the three parts of the MFFF Validation Report, along with clarification of the methodology to be employed when criticality calculations exceeded those parameter ranges.

On 13 June 2003, DCS submitted Reference 2 responding to the questions raised in the prior public meeting, and proposed corresponding actions to revise the validation reports accordingly. On 18-19 June 2003, a telephone conference call was held between DCS and NRC Staff to discuss the Reference 2 letter. In that telephone call, DCS agreed to expedite the revisions of the validation reports which were the subject of the actions in the DCS letter and, with an expected submittal date of 02 July 2003. (The letter to which this summary is an enclosure transmits the revised Parts I-III of the MFFF Validation Report, implementing the actions as described in Reference 2.)

During the 18-19 June 2003 conference calls, the Staff indicated they also had additional questions on previous versions validation reports (transmitted in January 2003 by Reference 1). The Staff proposed that, even though the issuance of the revised versions of the validation reports was imminent, that they would send the list of questions the following week (those questions were transmitted in Reference 3 on 25 June 2003). As discussed during the 18-19 June 2003 calls, the revised validation report then in final review obviously would not address the additional NRC questions from Reference 2; the Staff acknowledged that the questions would be addressed subsequently.

Reference 3 consists of six questions requesting clarification and justifications of certain aspects of the (previous) validation report parts transmitted by Reference 1, one question not related to the validation report (i.e., associated with normal k_{eff} methodology), and a request for data.

Question 1

As discussed in the 20 March 2003 public meeting and responded to by DCS in Reference 2, the Staff requested the range of parameters under which DCS considers the criticality code to be validated. Parts I-III of the MFFF Validation Report transmitted by this letter include a clear definition of the parameter ranges under which DCS considers the code to be validated, as indicated by a new column labeled "Validated AOA" in the tables of section 5 of the report parts. Also shown in those tables, as before, are columns showing the ranges of the parameters of the anticipated criticality calculations (labeled "Design Applications") and the corresponding parameter ranges of the benchmarks (labeled "Benchmarks").

The detailed tables of anticipated calculations (in section 4) on which the "Design Application" columns are based have been updated with the latest expectations of parameters. (It should be noted that calculations upon which the information in the "Design Applications" column is based have not yet been completed; thus, the information is indeed "anticipated," and subject to future change.)

Comparison of the corresponding information in the "Validated AOA" columns and the "Design Applications" shows very good agreement. Generally, the resulting validated AOAs contain the corresponding key parameters of the anticipated design applications for which the code system will be used to determine reactivity. In some cases, parameter values for design applications may fall outside the validated area of applicability. In these cases, DCS has committed to identifying additional margin, referred to as AOA margin, in the associated calculations or NCSEs, consistent with the approach described in NUREG-6698. The required margin is typically quantified by extrapolating observed trends in the bias as a function of the parameter. This commitment is made in each of the three parts of the validation report.

Thus, Question 1 has essentially been addressed.

Question 2

The revised validation report parts partially address Question 2. This question deals with details of the new approach to benchmark selection (Sensitivity and Uncertainty [S/U] methodology) used by Oak Ridge National Lab (ORNL), and upon which DCS has based the treatment of AOA(3) and AOA(4) in Part II of the validation report. The information in Part II is based exclusively on the methodology and its application by ORNL, as published in ORNL/TM-2001/262. DCS will provide the requested justifications requested in this question in a subsequent response to Reference 3 (as discussed above, this issue is not addressed in the current revisions of the validation report).

One sub-part of Question 2 requests that DCS show the design applications are representative of the entire range of parameters covered by the AOA. The information associated with Question 1 addresses this issue, including a commitment to address the need for the validated AOA parameter ranges to cover corresponding ranges in the calculations. Thus the revised validation report parts partially address Question 2.

Enclosure 1

Response to NRC Staff Request for Additional Information (Persinko to Hastings, 25 June 2003)

Question 3

The revised validation report parts partially address Question 3. This question deals with "data clusters." DCS will provide the justifications requested in this question in a subsequent response to Reference 3. However, some of the AOAs which showed this effect are included in Part II of the validation report.

As noted previously, DCS has used the new S/U methodology for Part II. In this case, the applicability of the benchmarks is mainly dependent upon the characteristics of the typical design applications, and not on the appearance – or lack of – such "data clusters." Additionally, as recommended by the validation handbook, NUREG-6698, the non-parametric method (NPM) has been used in these cases. The NPM uses the most pessimistic value of applicable benchmark to determine the bias of the calculational result, and thus the appearance of the results of the benchmark experiments are no longer relevant. Thus the revised validation report parts partially address Question 3.

Question 4

Question 4 deals with the differing methodologies used in the various validation reports. DCS will provide the requested justifications requested in this question in a subsequent response.

Question 5

Question 5 requests information on the relationship between the calculational uncertainty Δk_s and the statistical Monte Carlo uncertainty σ_k. DCS will provide the justifications requested in this question in a subsequent response.

Question 6

Question 6 requests a justification that the data presented in Part III is normally distributed. DCS will provide the justifications requested in this question question in a subsequent response.

Question 7 and Request for Data

Question 7 is associated with normal k_{eff} methodology and is not addressed in the revised validation report parts. Additionally, the Staff have requested specific data to facilitate further review of the validation report. DCS will provide responses to both Question 7 and the data request in a subsequent response.

DUKE COGEMA
STONE & WEBSTER

Mixed Oxide Fuel Fabrication Facility

Criticality Code Validation
Part I

Revision 3

Docket Number 070-03098

Prepared by
Duke Cogema Stone & Webster

June 2003

Under
U.S. Department of Energy
Contract DE-AC02-99-CH10888

REVISION DESCRIPTION SHEET

REVISION NUMBER	DESCRIPTION
0	Initial Issue June 2001
1	Additional experiments added to AOA(1) Correct typographical errors Address non-normality issue Add results for PC platform (SCALE 4.4a) Correct USLSTATS input to include experimental uncertainties Provide justification for administrative margin
2	Address non-normality issue by performing non parametric analysis of AOA(1) data. Affected pages: 18-19, 31, 33, 46. Editorial and typographical corrections: various pages.
3	Clearly define areas of applicability Additional analysis of fixed absorbers Affected pages: 25-27, 29-30, 110, 112, 114, 124-131. Editorial and typographical corrections: various pages.

TABLE OF CONTENTS

ATTACHMENT 1 CRITICALITY CALCULATION RESULTS FOR AOA (1)

ATTACHMENT 2 CRITICALITY CALCULATION RESULTS FOR AOA (2)

ATTACHMENT 3 OUTPUT LISTING OF USLSTATS V1.0 PROGRAM FOR PC PLATFORM

ATTACHMENT 4 OUTPUT LISTING OF USLSTATS V1.0 PROGRAM FOR SUN PLATFORM

ATTACHMENT 5 BORATED CONCRETE REFLECTORS

ATTACHMENT 6 CONCRETE AND CD/WATER REFLECTORS

ATTACHMENT 7 INPUT AND OUTPUT FILES

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

ANS	American Nuclear Society
ANSI	American National Standards Institute
AOA	area of applicability
CFR	Code of Federal Regulations
DCS	Duke Cogema Stone & Webster
DOE	U.S. Department of Energy
EALF	energy of average lethargy causing fission
FA	fuel assembly
LTB	lower tolerance band
MFFF	Mixed Oxide Fuel Fabrication Facility
MOX	mixed oxide
NRC	U.S. Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
RSICC	Radiation Safety Information Computational Center
USL	upper safety limit

EXECUTIVE SUMMARY

This report documents the validation of the nuclear criticality safety codes to be used in the design of the Mixed Oxide (MOX) Fuel Fabrication Facility (MFFF), to be owned by the U.S. Department of Energy (DOE) and operated by the licensee, Duke Cogema Stone & Webster (DCS). This report is applicable to the validation of the SCALE 4.4 and SCALE 4.4a code packages [1] using the CSAS26 (KENOVI) sequence and the 238 energy group cross section library 238GROUPNDF5.

Title 10 Code of Federal Regulations (CFR) §70.61(d) requires that all nuclear processes remain subcritical under all normal and credible abnormal conditions. In order to establish that a system or process will be subcritical under all normal and credible abnormal conditions, it is necessary to establish acceptable subcritical limits for the operation and then show that the proposed operation will not exceed those values. In order to comply with this requirement, the *American National Standard for Nuclear Criticality Safety in Operations with Fissionable Material Outside Reactors ANSI/ANS–8.1–1998* [2] and the U.S. Nuclear Regulatory Commission (NRC) *Standard Review Plan for the Review of an Application for a Mixed Oxide (MOX) Fuel Fabrication Facility* [3], require that a validation be performed that (1) demonstrates the adequacy of the margin of subcriticality for safety by assuring that the margin is large compared to the uncertainty in the calculated value of k_{eff} and (2) determines the area(s) of applicability (AOA) and use of the code within the AOA, including justification for extending the AOA by using trends in the bias.

A number of design AOAs are established to cover the range of processes and fissile materials in the MFFF. AOAs covering Pu and MOX applications are as follows: (1) Pu-nitrate aqueous solutions (homogeneous systems), (2) MOX pellets, fuel rods, and fuel assemblies (heterogeneous systems), (3) PuO_2 powders, (4) MOX powders, and (5) aqueous solutions of Pu compounds (e.g., Pu-oxalate solutions). The present report addresses only the first two areas of applicability: (1) Pu-nitrate aqueous solutions and (2) MOX pellets, fuel rod, and fuel assemblies. The AOA(3) and AOA(4) areas are validated in the Part II report [16]. AOA(5) is addressed in the Part III [17].

The report concludes that the upper safety limit (USL) for the first design area of applicability (i.e., Pu-nitrate solutions) is 0.9370, and the USL for the second design area of applicability (i.e., MOX pellets, rods, and fuel assemblies) is 0.9321. The USL accounts for computational bias, uncertainties, and a 0.05 administrative margin. The final USL in each case is the more conservative of the USLs calculated separately for SCALE versions 4.4 and 4.4a.

1. INTRODUCTION

1.1 PURPOSE

The purpose of this report is to validate the criticality codes and determine the upper safety limit (USL) to be used for performing nuclear criticality safety calculations and analyses of the Mixed Oxide (MOX) Fuel Fabrication Facility (MFFF), to be owned by the U.S. Department of Energy (DOE) and operated by the licensee, Duke Cogema Stone & Webster (DCS).

1.2 SCOPE

The scope of this report is limited to the validation of the KENO VI module and CSAS26 driver in the SCALE 4.4 and SCALE 4.4a code packages [1] for use with the 238 energy group cross-section library 238GROUPNDF5 for nuclear criticality safety calculations of the MFFF.

1.3 APPLICABILITY

The following areas of applicability (AOAs) are identified to cover a range of processes and fissile materials in the MFFF:

- Pu-nitrate aqueous solutions (homogeneous systems)
- MOX pellets, fuel rods, and fuel assemblies (heterogeneous systems)
- PuO_2 powders
- MOX powders
- Aqueous solutions of Pu compounds (e.g., Pu-oxalate solutions).

This report addresses the first two AOAs:

- Pu-nitrate aqueous solutions (homogeneous systems),
- MOX pellets, fuel rods, and fuel assemblies (heterogeneous systems).

1.4 BACKGROUND

1.4.1 Overall MFFF Design

The MFFF is designed to produce MOX fuel assemblies on an industrial scale from a mixture of depleted uranium and plutonium oxides for use in mission light-water reactors. The MFFF will be constructed on a DOE site and will be licensed by the U.S. Nuclear Regulatory Commission (NRC) under Title 10 Code of Federal Regulations (CFR) Part 70. The facility is designed to applicable U.S. codes and standards and operated by DCS, a private consortium under contract to DOE. The goal of the contract is to design, construct, and operate a facility to fabricate MOX fuel based on existing technology from the COGEMA MELOX and La Hague plants in France. To maximize the benefit of the existing technology, process and equipment designs from the MELOX and La Hague plants are duplicated, to the maximum extent possible, in the design of the new plant.

The feed material is depleted uranium dioxide and surplus plutonium dioxide (from the Pit Disassembly and Conversion Facility) supplied by DOE. The impurities in the plutonium dioxide feed are extracted by the Aqueous Polishing process. The MOX fuel fabrication process blends this "polished" plutonium dioxide with depleted uranium dioxide to form mixed oxide pellets. These pellets are loaded into fuel rods, which are integrated into fuel assemblies. The nuclear fuel assemblies are transported for use in specific U.S. commercial reactors as nuclear fuel. The MFFF is designed to process 3.5 metric tons annually, for a total disposition of 33 metric tons of plutonium (as dioxide).

1.4.2 Regulatory Requirements, Guidance, and Industrial Standards

Title 10 CFR §70.61(d) requires that "*under normal and credible abnormal conditions, all nuclear processes are subcritical, including use of an approved margin of subcriticality for safety.*" In order to comply with this requirement, NUREG 1718 [3] and ANSI/ANS-8.1 [2] require a validation report that (1) demonstrates the adequacy of the margin of subcriticality for safety by assuring that the margin is large compared to the uncertainty in the calculated value of keff and (2) determines the AOAs and use of the code within the AOA, including justification for extending the AOA by using trends in the bias.

NUREG 1718 [3] further states that the validation report should contain:

> A description of the AOA that identifies the range of values for which valid results have been obtained for the parameters used in the methodology. As defined in ANSI/ANS 8.1–1983, the AOA is the range of material compositions and geometric arrangements within which the bias of a calculational method is established. Other variables that may affect the neutronic behavior of the calculational method should also be specified in the definition of the AOA. Particular attention should be given to validating the code for calculations involving mixed oxides of differing isotopics and defining the isotopic ranges covered by the available benchmark experiments. In accordance with the provisions in ANSI/ANS 8.1–1983 (applicable section is Section 4.3.2), any extrapolation of the AOA beyond the physical range of the data should be supported by an established mathematical methodology.

2. CALCULATIONAL METHOD

The SCALE 4.4 and SCALE 4.4a code packages [1] are the computational systems used for MFFF criticality analyses. The two code packages are available from the Radiation Safety Information Computational Center (RSICC). The SCALE 4.4 code package is installed and verified on the SGN Sun hardware platform [4], and the SCALE 4.4a code package is installed and verified on the SGN PC hardware platform [5].

SCALE 4.4 and SCALE 4.4a are a collection of modules designed to perform nuclear criticality, shielding, and thermal calculations. Each SCALE functional module may be run individually, or a sequence of functional modules may be executed using a special module referred to as a control module. For criticality analyses, various criticality safety analysis sequence (CSAS) control modules are available which differ in the specific functional modules executed and in the processing of cross sections used as input. In general, MFFF criticality analyses are performed using the CSAS26 control module and the 238 energy group cross-section library 238GROUPNDF5, based on ENDF/B-V data. These modules perform cross section processing using the BONAMI and NITAWL-II functional modules, and the calculation of k_{eff} is performed using the KENO VI Monte Carlo transport code.

3. CRITICALITY CODE VALIDATION METHODOLOGY

In order to establish that a system or process will be subcritical under all normal and credible abnormal conditions, it is necessary to establish acceptable subcritical limits for the operation and then show that the proposed operation will not exceed those values.

Figure 3–1 shows how the validation process fits within the overall MFFF nuclear criticality analysis process. The first step involves the procurement, installation, and verification of the criticality software on a specific computer platform. For the MFFF, the SCALE 4.4 and SCALE 4.4a code packages were procured, installed, and verified on the SGN Sun [4] and PC [5] hardware platforms, respectively. This step is followed by the validation of the criticality software, which is the purpose of this report. The final step involves the criticality safety design analysis calculations, which are performed and presented in separate reports.

The criticality code validation methodology can be divided into four steps:

- Identify general MFFF design applications
- Select applicable benchmark experiments and group them into AOAs
- Model and calculate k_{eff} values of selected critical benchmark experiments
- Perform statistical analysis of results to determine computational bias and upper safety limit (USL).

The first step is to identify the MFFF design applications and key parameters associated with the normal and upset design conditions. Table 3-2 lists some of the key parameters for the MFFF.

The second step involves several substeps. First, based on the key parameters, the AOA and expected range of the key parameter are identified. ANSI/ANS-8.1 [2] defines the AOA as "*the limiting range of material composition, geometric arrangements, neutron energy spectra, and other relevant parameters (such as heterogeneity, leakage interaction, absorption, etc.) within which the bias of a computational method is established.*" AOAs covering Pu and MOX applications are as follows: (1) Pu-nitrate solutions; (2) MOX pellets, fuel rods, and fuel assemblies; (3) PuO_2 powders; (4) MOX powders; and (5) aqueous solutions of Pu compounds. These AOAs are defined and presented in Section 4. After identifying the AOAs, a set of critical benchmark experiments is selected. Benchmark experiments for the AOAs are selected from the references listed in the *International Handbook of Evaluated Criticality Safety Benchmark Experiments [6]*, the *Guide to Verification and Validation of the SCALE-4 Criticality Safety Software [7]*, and the *Neutronics Benchmarks for the Utilization of Mixed-Oxide Fuel [8]*. A description of all relevant experiments used for each AOA considered here is provided in Section 5.

The third step involves modeling the critical experiments and calculating the k_{eff} values of the selected critical benchmark experiments[1]. Attachments 1 and 2 present calculated results.

The final step involves the statistical analysis of the results in order to calculate the computational bias and USL. Section 6 presents the computational bias and USL results.

---

[1] Note that these models contain simplifications of critical experiments geometry. These simplifications lead to additional uncertainties, included in the statistical analysis of the results.

3.1 DETERMINATION OF BIAS

ANSI/ANS–8.1–1998 [2] requires a determination of the calculational bias by "*correlating the results of critical and exponential experiments with results obtained for these same systems by the calculational method being validated.*" The correlation must be sufficient to determine if major changes in the bias can occur over the range of variables in the operation being analyzed. The standard permits the use of trends in the bias to justify extension of the area of applicability of the method outside the range of experimental conditions.

Calculational bias is the systematic difference between experimental data and calculated results. The simplest technique is to find the difference between the average value of the calculated results of critical benchmark experiments and 1.0. This technique gives a constant bias over a defined range of applicability.

Another technique is to find the difference between a regression fit of the calculated results of critical benchmark experiments and 1.0, as a function of an independent variable (e.g., enrichment, moderator-to-fuel ratio, etc.). As a rule, the bias is not a constant, but is dependent upon an independent variable, usually the degree of moderation of the neutrons. For example, the bias for an unmoderated system in which fission occurs with fast neutrons would not be expected to be the same as for a moderated system in which fission occurs with thermal neutrons. The AOA for the bias is the limiting range of material composition, geometric arrangement, etc., over which the bias is collectively established.

The recommended approach for establishing subcriticality based on numerical calculations of the neutron multiplication factor is prescribed in Section 5.1 of ANSI/ANS–8.17–1984 [9]. The criteria to establish subcriticality requires that for a design application (system) to be considered as subcritical, the calculated multiplication factor for the system, k_s, must be less than or equal to an established maximum allowed multiplication factor based on benchmark calculations and uncertainty terms that is:

$$k_s \leq k_c - \Delta k_s - \Delta k_c - \Delta k_m \qquad \text{(Eq. 3.1)}$$

where:

k_s = the calculated allowable maximum multiplication factor, (k_{eff}) of the design application (system)
k_c = the mean k_{eff} value resulting from the calculation of benchmark critical experiments using a specific calculation method and data
Δk_s = the uncertainty in the value of k_s
Δk_c = the uncertainty in the value of k_c
Δk_m = the administrative margin to ensure subcriticality.

Sources of uncertainty that determine Δk_s include:

- statistical and/or convergence uncertainties
- material and fabrication tolerances
- limitations in the geometric and/or material representations used.

Sources of uncertainty that determine Δk_c include:

- uncertainties in critical experiments
- statistical and/or convergence uncertainties in the computation
- extrapolation outside of the range of experimental data
- limitations in the geometric and/or material representations used.

An assurance of subcriticality requires the determination of an acceptable margin based on known biases and uncertainties. The USL is defined as the upper bound for an acceptable calculation.

Critical benchmark experiments used to determine calculational bias (β) should be similar in composition, configuration, and nuclear characteristics to the system under examination. The range of applicability may be extended beyond the range of conditions represented by the benchmark experiments by extrapolating the trends established for the bias. β is related to k_c as follows:

$$\beta = k_c - 1 \qquad \text{(Eq. 3.2)}$$

$$\Delta\beta = \Delta k_c \qquad \text{(Eq. 3.3)}$$

Using this definition of bias, the condition for subcriticality in Eq. 3.1 is rewritten as:

$$k_s + \Delta k_s \leq 1 - \Delta k_m + \beta - \Delta\beta \qquad \text{(Eq. 3.4)}$$

A system is acceptably subcritical if a calculated k_{eff} plus calculational uncertainties lies at or below the USL.

$$k_s + \Delta k_s \leq \text{USL} \qquad \text{(Eq. 3.5)}$$

The USL can be written as:

$$\text{USL} = 1 - \Delta k_m + \beta - \Delta\beta \qquad \text{(Eq. 3.6)}$$

Bias is negative if $k_c < 1$ and positive if $k_c > 1$. For conservatism, a positive bias is set equal to zero for the purpose of defining the USL. $\Delta\beta$ is typically determined at the 95% confidence level.

The USL takes into account bias, uncertainties, and administrative and/or statistical margins such that the calculated configuration will be subcritical with a high degree of confidence.

β is related to system parameters and may not be constant over the range of a parameter of interest. If k_{eff} values for benchmark experiments vary as a function of a system parameter, such as enrichment or degree of moderation, then β can be determined from a best fit as a function of the parameter upon which it is dependent. Extrapolation outside the range of validation must take into account trends in the bias.

Both $\Delta\beta$ and β can vary with a given parameter, and the USL is typically expressed as a function of the parameter. Normally, the most important system parameter that affects bias is the degree of moderation of the neutrons. This parameter can be expressed in several different ways, such as the energy of average lethargy causing fission (EALF), moderator-to-fuel volume ratio (v^m/v^f), or moderator-to-fuel atomic ratio (H/Pu ratio).

In general, the "bias" can be broken down into components caused by system modeling error, code modeling inaccuracies, cross-sectional inaccuracies, etc. Biases associated with individual inaccuracies are usually combined into a total bias to represent the combined effect from all sources that prevent code and cross-sections from calculating the experimental value of k_{eff} (see Section 0).

One or two calculations are insufficient to determine calculational bias. In practice, it is necessary to determine the "average bias" for a group of experiments. A statistical analysis of the variation of biases around this average value is used to establish an uncertainty associated with the bias value when it is applied to a future calculation of a similar critical system. The lower limit of this band of uncertainty establishes an upper bound for which a future calculation of k_{eff} for a similar critical system can be considered subcritical with a high degree of confidence.

NUREG/CR-6361 [10] describes two statistical methods for the determination of an USL from the bias and uncertainty terms associated with the calculation of criticality. The first method applies a statistical calculation of the bias and its uncertainty, plus an administrative margin, to a linear fit of critical experimental benchmark data. The second method applies a statistical calculation to determine a combined lower confidence band and subcritical margin. Both methods assume that the distribution of data points is normal. The following discussion of each method is taken from NUREG/CR-6361 [10] and is based on equations and techniques described in Dryer, Jordan, and Cain [11], Easter[12], Bowden and Graybill [13], Johnson [14], and Cain [15].

3.2 USL METHOD 1: CONFIDENCE BAND WITH ADMINISTRATIVE MARGIN

This method applies a statistical calculation of the bias (β) and its uncertainty (Δβ) plus an administrative safety margin (Δk_m) to a linear fit of calculated results for a selected set of critical experiments. A confidence band (W) is determined statistically based on the existing data and a specified level of confidence; the greater the standard deviation in the data or the larger the confidence desired, the larger the band width will be. This confidence band, W, accounts for uncertainties in the experiments, the calculational approach, and calculational data (e.g., cross sections) and is therefore a statistical basis for Δβ, the uncertainty in the value of β. W is defined for a confidence level of ($1-\gamma_1$) using the relationship:

$$W = \max\{w(x)|_{x\ min,\ x\ max}\} \qquad \text{(Eq. 3.7)}$$

where

$$w(x) = t_{1-\gamma_1} s_p \left[1 + \frac{1}{n} + \frac{(x-\bar{x})^2}{\sum\limits_{i=1,n}(x_i-\bar{x})^2} \right]^{\frac{1}{2}} \qquad \text{(Eq. 3.8)}$$

and

n = the number of critical calculations used in establishing $k_c(x)$

$t_{1-\gamma_1}$ = the Student - t distribution for $1-\gamma_1$ and n - 2 degrees of freedom

$\bar{x}$ = the mean value of parameter x in the set of calculations

s_p = the pooled standard deviation for the set of criticality calculations.

The function w(x) is a curvilinear function. For simplicity, it is desirable to obtain a constant width margin. Therefore, for conservatism, the confidence band, W, is defined as the maximum of *(w(x$_{min}$), w(x$_{max}$))*, where x_{min} and x_{max} are the minimum and maximum values of the independent parameter x, respectively. Typically, W is determined at a 95% confidence level.

The pooled standard deviation is obtained from the pooled variance $S_p = \sqrt{S_p^2}$, where S_p is given as:

$$s_p^2 = s_{k(x)}^2 + s_w^2 \qquad \text{(Eq. 3.9)}$$

Where $S_{k(x)}^2$ is the variance (or mean square error) of the regression fit, and is given by:

$$s_{k(x)}^2 = \frac{1}{(n-2)}\left[\sum_{i=1,n}(k_i-\bar{k})^2 - \frac{\left\{\sum_{i=1,n}(x_i-\bar{x})(k_i-\bar{k})\right\}^2}{\sum_{i=1,n}(x_i-\bar{x})^2}\right] \qquad \text{(Eq. 3.10)}$$

and S_w^2 is the within-variance of the data:

$$s_w^2 = \frac{1}{n}\sum_{i=1,n}\sigma_i^2 \qquad \text{(Eq. 3.11)}$$

where σ_i is the standard deviation associated with k_i for a Monte Carlo calculation. It is recommended that the individual standard deviations for Monte Carlo calculations be roughly uniform in value for the best results. For deterministic codes that do not have a standard deviation associated with a computed value of k, the standard deviation is zero. However, this term can also be used as a mechanism to include known uncertainties in experimental data.

In USL Method 1, Δk_m is given an arbitrary administrative value. NUREG-1718 [3] states that a "minimum subcritical margin (Δk_m) of 0.05 is generally considered acceptable without additional justification when both the bias and its uncertainty are determined to be negligible." The MFFF criticality analyses use a value of 0.05. Section 7.1 provides further justification of the 0.05 administrative margin.

Having determined the constant W and substituting for Δβ in equation 3.6, the expression for the USL may be written as:

$$USL_1(x) = 1.0 - \Delta k_m - W + \beta(x). \qquad \text{(Eq. 3.12)}$$

3.3 USL METHOD 2: SINGLE-SIDED UNIFORM WIDTH CLOSED INTERVAL APPROACH

In USL Method 2, sometimes referred to as a lower tolerance band (LTB) approach, statistical techniques are applied to determine a combined lower confidence band plus subcritical margin. In USL Method 1, Δk_m and Δβ are determined independently, and in USL Method 2 (LTB method), a combined statistical lower bound is determined.

The purpose of this method is to determine a uniform tolerance band over a specified closed interval for a linear least-squares model. The level of confidence in the limit being calculated is α and is typically in the range of 0.90 to 0.999.

The USL Method 2 is defined as:

$$USL_2(x) = 1.0 - (C_{\alpha/P} \cdot s_p) + \beta(x) \qquad \text{(Eq. 3.13)}$$

where s_p is the pooled variance of k_c described earlier. The term $C_{\alpha/P} \cdot s_p$ provides a band for which there is a probability *P* with a confidence α that an additional calculation of k_{eff} for a critical system will lie within the band. For example, a $C_{95/99.5}$ multiplier produces a USL for which there is a 95% confidence that 995 out of 1000 future calculations of critical systems will yield a value of keff above the USL.

The analysis is over the closed interval from $x = a$ to $x = b$. $C_{\alpha/P}$ is calculated according to the following equations:

$$g = \sqrt{\frac{1}{n} + \frac{(a-\bar{x})^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}} \qquad \text{(Eq. 3.14)}$$

$$h = \sqrt{\frac{1}{n} + \frac{(b-\bar{x})^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}} \qquad \text{(Eq. 3.15)}$$

$$\rho = \frac{1}{gh} \cdot \left\{ \frac{1}{n} + \frac{(a-\bar{x})(b-\bar{x})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \right\} \qquad \text{(Eq. 3.16)}$$

$$A = \frac{g}{h} \qquad \text{(Eq. 3.17)}$$

A, ρ, and (n-2) are used to determine the value of D from Table 3 in Bowden [13], which covers values of $0.5 \leq A \leq 1.5$. The procedure to follow when A is in this range is:

$$C^* = D \cdot g. \qquad \text{(Eq. 3.18)}$$

When A is outside the above range, A is replaced by $1/A$ for the determination of D, and C^* is given by:

$$C^* = D \cdot h. \qquad \text{(Eq. 3.19)}$$

Next,

$$C_{\alpha/P} = C^* + z_p \cdot \sqrt{\frac{n-2}{\chi^2}}, \qquad \text{(Eq. 3.20)}$$

where

z_p = the Student t statistic depending on n and P
χ^2 = the chi square distribution, a function of n-2 and α

This approach provides a statistically based subcritical margin, Δk_m which can be determined as the difference ($C_{\alpha/P} \cdot s_p$)-W. In criticality safety applications, such a statistically determined approach generally, but not necessarily, yields a margin of less than 0.05, which serves to illustrate the adequacy of the administrative margin specified in USL Method 1. The recommended purpose of USL Method 2 is to apply it in tandem with USL Method 1 to verify that the administrative margin is conservative relative to a purely statistical basis.

3.4 NON-NORMAL DISTRIBUTIONS

In cases where the benchmark results fail the χ^2 test for normality, the non-parametric technique described in NUREG-6698 [18] is applied to the data. This statistical technique is based on a rank order analysis of the data. The USL is established according to

USL = Smallest k_{eff} value – Uncertainty for smallest k_{eff} – Nonparametric margin – Δk_m (Eq. 3.21)

Where the non-parametric margin is an additional margin intended to account for small sample size. Recommended values for the non-parametric margin as a function of the degree of confidence are obtained from Table 2.2 of NUREG-6698, which is reproduced in Table 3-1.

The degree of confidence β that a fraction q of the population is greater than the lowest observed value is established for a given sample size n according to

$$\beta = 1 - q^n \qquad \text{(Eq. 3.22)}$$

For a desired population fraction of 95%, this becomes

$$\beta = 1 - 0.95^n \qquad \text{(Eq. 3.23)}$$

In order to obtain a 95% confidence that 95% of the population is larger than the smallest observed sample, at least 59 critical experiments are required.

Table 3-1 Recommended Non-Parametric Margin Values from NUREG-6698

Degree of Confidence for 95% of the Population	Non-parametric Margin (NPM)
>90%	0.00
>80%	0.01
>70%	0.02
>60%	0.03
>50%	0.04
>40%	0.05
≤40%	Additional data needed. (This corresponds to less than 10 data points.)

3.5 UNCERTAINTIES

Uncertainties, as used in this report, refer to the uncertainty in k_{eff} associated with experimental unknowns or assumptions and to the uncertainty values associated with Monte Carlo analyses.

Experimental uncertainty (σ_e) – Modeling of validation experiments frequently result in assumptions about experimental conditions. In addition, experimental uncertainties (such as measurement tolerances) influence the development of a computer model. Recent efforts by the OECD – NEA [6] have resulted in the quantification of these uncertainties in validation experiments.

Statistical uncertainty (σ_s) – Monte Carlo calculation techniques result in a statistical uncertainty associated with the actual calculation. This type of uncertainty is dependent upon many factors, including number of neutron generations performed, variance reduction techniques employed, and problem geometry. For this document, σ_s refers to the statistical Monte Carlo uncertainty associated with the computer modeled validation experiment.

Total uncertainty –This is the total uncertainty associated with a calculated k_{eff} on a benchmark experiment. The total uncertainty for an individual benchmark is the combined error of the experimental and statistical uncertainties:

$$\sigma_i = \sqrt{\sigma_{e,i}^2 + \sigma_{s,i}^2} \qquad \text{(Eq. 3.24)}$$

where the subscript (i) refers to an individual benchmark calculation.

3.6 NORMALIZING K_{EFF}

In many instances, benchmark experiments used for validation may not be exactly critical. Experimental results may show that the experiment is slightly above or below a k_{eff} = 1.0. For these cases, the calculated k_{eff} values should be normalized to the experimental value. This assumes that any inherent bias in the calculation is not affected by the normalization, which is valid for small differences in k_{eff}. To normalize k_{eff}, the following formula applies:

$$k_{eff}\text{ (normalized)} = k_{eff}\text{ (calculated)} / k_{eff}\text{ (experimental)} \qquad \text{(Eq. 3.25)}$$

The normalized k_{eff} values are to be used in the determination of the USL. Since only small adjustments to the calculated k_{eff} value are made as a result of normalization, no adjustment to the total uncertainty, σ_i, is made.

3.7 APPLICATION OF THE USL

The equations for USL Methods 1 and 2 (equations 3.12 and 3.13) represent an upper bound to assure subcriticality for a given configuration when the calculated k_{eff} plus uncertainty for the configuration is less than the USL. USLs may be calculated for a number of independent parameters for a given system. Here, the subcritical limit is taken as the minimum of all USLs computed for the specific parameters of the system. This approach is conservative with respect to the guidance provided in NUREG/CR-6361 [10] in which the USL is determined based on the statistical results for the parameter "*with the strongest correlation to the calculated k_{eff} values.*"

Another advantage of the USL is that it may also be used to establish guidelines for quantitatively determining the applicability of the bias (or validation) to specific applications. For a given parameter, the USL is valid over the range of that parameter in the set of calculations used to determine the USL. However, ANSI/ANS-8.1 [2] allows the range of applicability to be extended beyond this range by extrapolating the trends established for the bias. No precise guidelines are specified for the limits of extrapolation. Thus, engineering judgment should be applied when extrapolating beyond the range of the parameter bounds.

Appendix C in NUREG/CR-6361 [10] documents the USLSTATS computer program that was developed to perform the required statistical analysis and calculate USLs based on USL Methods 1 and 2.

In this validation report, USLSTATS is used to trend the following parameters:

- Moderator to fuel atomic ratio (H/Pu)
- Energy of Average Lethargy Causing Fission (EALF)
- Moderator to Fuel Volume Ratio (v^m/v^f)
- ^{240}Pu and PuO_2 content

The H/Pu ratio is a parameter that describes the moderation of the neutrons in the fissile medium. The moderator to fuel volume ratio, v^m/v^f, has a similar meaning for fuel rod lattices. The EALF parameter is a measure of the energy dependent fission efficiency of the fissile medium.

The administrative margin, Δk_m, is fixed in order to have a sufficient confidence that the calculated results are subcritical.

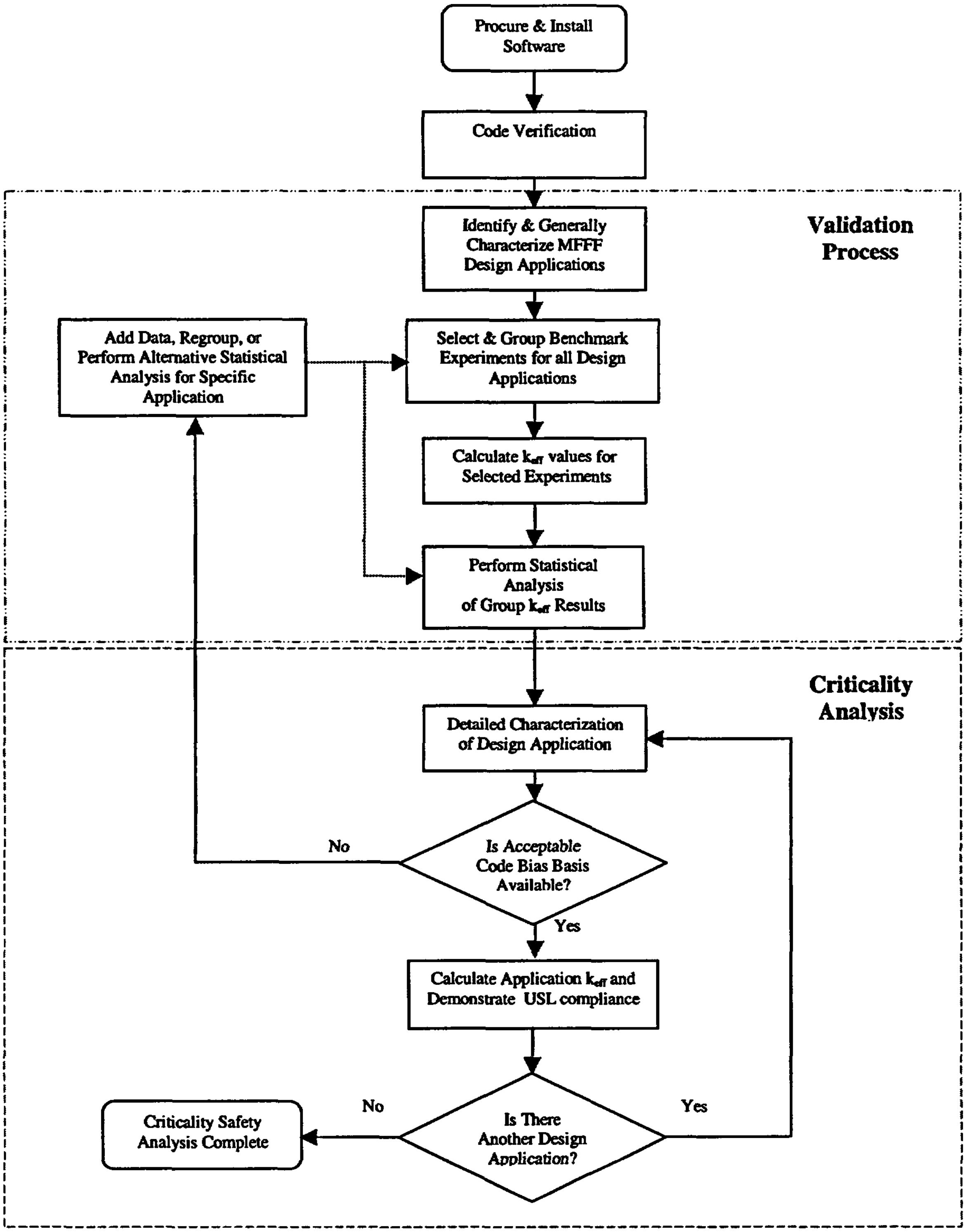


Figure 3–1 Overview of the Criticality Analysis Process of the MFFF

Table 3-2 Characteristics of the MFFF Application Areas*

Parameter	Pu-nitrate solution	MOX pellets, fuel rods, FAs	PuO_2 powder/water mixtures	MOX powder/water mixtures	Aqueous solutions of Pu compounds
Fissile Material Physical/Chemical Form	Pu-nitrate	MOX green and sintered pellets, MOX Rods and FAs	PuO_2 powder	MOX powder	(a) Pu-oxalate (b) PuO_2F_2
Isotopic composition of fissile material **	96% ^{239}Pu 4% ^{240}Pu	96% ^{239}Pu 4% ^{240}Pu depleted U	96% ^{239}Pu 4% ^{240}Pu	96% ^{239}Pu 4% ^{240}Pu depleted U	96% ^{239}Pu 4% ^{240}Pu
Pu/(U+Pu)	100 %	≤ 6.3 %	100 %	6.3% – 22%	100 %
Maximum oxide density [g/cm^3]	-	7.0, 11.0	3.5, 7.0, 11.46	4.1, 5.5	-
Pu concentration [g/liter]	125 – 237	–	–	–	(a) 242 (b) 696
Type of moderation	Homogeneous	Heterogeneous	Homogeneous	Homogeneous	Homogeneous
Optimum moderation ***	H/Pu=100–200	v^m/v^f = 1.9 – 9	H/Pu= 0.3 – 6 and 700 – 1900	H/Pu=1.6 – 291	(a) H/Pu=100 (b) H/Pu=30
Low density moderation [wt.% H_2O]	-	≤ 5 ****	≤ 5	≤ 5	-
Anticipated absorber/reflector materials	Water Cd/water Concrete Borated concrete	Water Concrete Borated concrete	Water Borated concrete	Water	Water Cd/water Concrete
Typical geometry	Annular cylinders Cylinders Slabs	Cylinders Arrays Cuboids	Various configurations	Various configurations	Annular cylinders Cylinders Slabs

[*] Characteristics presented typically refer to optimal or bounding values or ranges associated with respective AOAs

[**] Bounding design isotopic composition from Aqueous Polishing System basis of design

[***] Per calculation

[****] Green Pellets (i.e., unsintered pellets) < 5; sintered pellets < 1

4. MFFF DESIGN APPLICATION CLASSIFICATION

This section describes the characteristics of the established AOAs based on the various fuel configurations encountered in the MFFF. AOAs covering Pu and MOX applications are as follows (see Table 3-2):

- Pu-nitrate aqueous solution
- MOX pellets, fuel rods, and fuel assemblies (FA)
- PuO_2 powders
- MOX powders
- Aqueous solutions of Pu compounds (e.g., Pu-oxalate solution).

4.1 DESIGN APPLICATION (1) – PU-NITRATE SOLUTION

Table 4-1 summarizes the anticipated criticality calculations to be performed for the design of the Aqueous Polishing process of the MFFF in which Pu-nitrate will be processed. The table provides the relevant parameters (i.e., chemical form, isotopic vector, moderator to fuel atomic ratio (H/Pu), and EALF) for each criticality design application.

Since geometry control is expected to be used for all the equipment listed in Table 4-1, the calculations are performed at optimum moderation taking into account full water reflection. In some applications (e.g., mixer-settler tanks), the reflector is modified by cadmium/water materials and borated concrete materials.

4.2 DESIGN APPLICATION (2) – MOX PELLETS, FUEL RODS, AND FUEL ASSEMBLIES

Table 4-2 summarizes the anticipated criticality calculations to be performed for the design of the MOX process pellet, fuel rod, and fuel assembly lines. In addition, the table provides the relevant parameters (i.e., chemical form, fuel concentration C(Pu), isotopic vector, moderator to fuel volume ratio (v^m/v^f), and EALF) for each criticality design application.

In the pellet and fuel rod area, a conservative value of 6.3% Pu content is used to bound the design limit of 6.0%. The maximum assembly-averaged Pu content in the fuel assembly area is less than 6.0%. The value depends on the FA type that is specified by the MFFF customers (i.e., utility reactors) and will be incorporated into the criticality design application calculations.

Table 4-1 Anticipated Characteristics for the Design Application Involving Pu-nitrate Solutions

Fuel Configuration	**Reflector Conditions**	**Chemical Form**	**Pu/ (U+Pu)**	**Pu Isotopic Composition**	**H/Pu**	**C(Pu) [g/l]**	**EALF [eV]**
AP: Purification							
Mixer-settler tank	Slab with Cd/water reflector	$Pu(NO_3)_3$	100%	4% ^{240}Pu	100	237	0.20
Active gallery	Array of interacting cylinders	$Pu(NO_3)_3$	100%	4% ^{240}Pu	150	164	0.14
Pulsed columns	Cylinder with water reflector	$Pu(NO_3)_3$	100%	4% ^{240}Pu	150	194	0.14
Tanks in cell	Annular cylinder with concrete reflector Slab with Cd/water reflector	$Pu(NO_3)_3$	100%	4% ^{240}Pu	200	125	0.18
AP: Oxalic Precipitation Oxidation							
Tanks in cell	Annular cylinder with concrete reflector	$Pu(NO_3)_3$	100%	4% ^{240}Pu	200	125	0.18
Dosing wheels	Rectangular solid with steel water reflector	$Pu(NO_3)_3$	100%	4% ^{240}Pu	150	164	0.25
Expected Range of Design Application	**Various configurations**	**$Pu(NO_3)_3$**	**100%**	**4% ^{240}Pu**	**100 – 200**	**125 – 237**	**0.14 – 0.25**

Table 4-2 Anticipated Characteristics for the Design Application Involving MOX Pellets, Fuel Rods, Fuel Assemblies

Fuel Configuration	Reflector Condition	Chemical Form	Pu/(U+Pu) wt. %	Pu Isotopic Composition	v^m/v^f	EALF [eV]
MP: Pellet area						
Sintering furnace[1] Heterogeneous Array	Water and concrete	MOX	6.3%	4% ^{240}Pu	2 – 10	0.19-0.41
Pellets boats in the return glove box of the sintering furnace Heterogeneous Array	Water	MOX	6.3%	4% ^{240}Pu	2 – 10	0.10-0.26
Glove boxes Heterogeneous Array	Water	MOX	6.3%	4% ^{240}Pu	2 – 10	0.12-0.41
Pellet boats and boxes store[2] Heterogeneous Array	Water	MOX	6.3%	4% ^{240}Pu	2 – 10	0.18-0.62
Pellets stored in tray baskets[2] Heterogeneous Array	Water, concrete	MOX	6.3%	4% ^{240}Pu	2 – 10	0.11-0.66
MP: Rod area						
Rod store[2] Rectangular array	Water	MOX	6.3%	4% ^{240}Pu	2 – 5	0.1 – 0.5
MP: Fuel Assembly Area						
MOX FA store Rectangular array	Water and concrete	MOX	6.3%	4% ^{240}Pu	~1.9	0.1 – 0.5
Expected Range of Design Application	**Various**	**MOX**	**6.3%**	**4% ^{240}Pu**	**1.9 – 10**	**0.1 – 0.66**

[1] Random orientation of pellets modeled as regular arrays with hexagonal or rectangular pitch

[2] Boron shields are actually employed, but no credit for the boron is required in the safety analysis of the system.

5. BENCHMARK EXPERIMENTS

5.1 AOA (1) – PU-NITRATE SOLUTION

Fifteen benchmark experiments, consisting of a total of 191 critical configurations, with Pu-nitrate solution are selected from the ICSBEP Handbook [6] for AOA(1). One or more of the following criteria are used for selecting an experiment:

- Moderator-to-fuel atomic ratio H/Pu appropriate for the area of applicability.
- The presence of a water reflector, cadmium/water reflector, or concrete reflector.
- Neutron interaction between bare cylinders arranged in an array.
- Bare spheres without significant reflectors in order to represent the normal unreflected design application.

The identification numbers of the benchmarks selected from Reference [6] are listed below:

PU_SOL_THERM_001, 002, 003, 004, 005, 006, 008, 011, 014, 015, 016, 017, 020, 025, 026.

A description of the key parameters of these experiments is presented in Table 5-1. Table 5-2 provides a comparison of the key AOA parameters for the critical benchmark experiments and the design applications. The validated AOA is established based on the more limiting (smaller range) of the design application and benchmark experiment values as shown in Table 5-2. Although no experiments are available with borated concrete, a justification for validated use of borated concrete reflectors is provided in Attachment 5.

The validation methodology described in this validation report requires that consistent code options be employed in modeling both benchmark experiments and design applications. Due to the multigroup energy treatment employed in KENO-VI, the most important such option is the resonance treatment employed in the Material Information Processor (MIP) of SCALE. The validation performed here employs applies to the INFHOMMEDIUM model. This model must be used in design application analyses considered applicable to this AOA.

Generally, the resulting validated AOA contain the corresponding key parameters of the anticipated design applications for which the code system will be used to determine reactivity. In some cases, parameter values for design applications may fall outside the validated area of applicability. In these cases, DCS commits to identifying additional margin, referred to as AOA margin, in the associated calculations or NCSEs, consistent with the approach described in NUREG-6698. The required margin is typically quantified by extrapolating observed trends in the bias as a function of the parameter.

5.2 AOA (2) – MOX-PELLETS, FUEL RODS, FUEL ASSEMBLIES

Five benchmark experiments are selected from the ICSBEP-Handbook [6] for AOA(2). These benchmarks include 36 critical configurations performed with lattices of MOX fuel rods in water having various Pu contents and moderating ratios (v^m/v^f).

The ID numbers of the selected benchmarks are listed below :

MIX_COMP_THERM_002, 003, 004, 005, 009.

A description of the key parameters of these experiments is presented in Table 5-3. Table 5-4 provides a comparison of the key AOA parameters for the critical benchmark experiments and the design applications. The validated AOA is established based on the more limiting (smaller range) of the design application and benchmark experiment values as shown in Table 5-4. Although no experiments are available with borated concrete, a justification for validated use of borated concrete reflectors is provided in Attachment 5.

The validation methodology described in this validation report requires that consistent code options be employed in modeling both benchmark experiments and design applications. Due to the multigroup energy treatment employed in KENO-VI, the most important such option is the resonance treatment employed in the Material Information Processor (MIP) of SCALE. The validation performed here employs applies to the LATTICECELL model. This model must be used in design application analyses considered applicable to this AOA.

Generally, the resulting validated AOA contain the corresponding key parameters of the anticipated design applications for which the code system will be used to determine reactivity. In some cases, parameter values for design applications may fall outside the validated area of applicability. In these cases, DCS commits to identifying additional margin, referred to as AOA margin, in the associated calculations or NCSEs, consistent with the approach described in NUREG-6698. The required margin is typically quantified by extrapolating observed trends in the bias as a function of the parameter.

Note that some previously anticipated design applications fell outside the validated range of EALF. However, additional calculations have been made and the tables (4-2 and 5-4) have been updated accordingly.

Table 5-1 Critical Experiments Selected for AOA(1)

Case ID From [6]	H/Pu	EALF [eV]	Reflector/ Geometric form	^{240}Pu wt. %	Description
PU-SOL-THERM-001	87–353	0.09–0.35	Water reflected sphere	4.67	11.5" diameter sphere
PU-SOL-THERM-002	299–508	0.07–0.10	Water reflected sphere	3.12	12" diameter sphere
PU-SOL-THERM-003	545–774	0.06–0.07	Water reflected sphere	1.76, 3.12	13" diameter sphere
PU-SOL-THERM-004	573–982	0.05–0.07	Water reflected sphere	0.54 to 3.43	14" diameter sphere
PU-SOL-THERM-005	557–866	0.06–0.07	Water reflected sphere	4.05, 4.40	14" diameter sphere
PU-SOL-THERM-006	911–1028	0.05–0.06	Water reflected sphere	3.12	15" diameter sphere
PU-SOL-THERM-008	85–867	0.06–0.55	Concrete reflected and concrete/Cd reflected sphere	4.67	14" diameter sphere
PU-SOL-THERM-011	551–1157	0.05–0.08	Bare sphere	4.2	Bare 16" and 18" diameter spheres
PU-SOL-THERM-014	210	0.17	Unreflected array of cylinders	4.23	Interacting cylinders in air (115.1gPu/l)
PU-SOL-THERM-015	155	0.24	Unreflected array of cylinders	4.23	Interacting cylinders in air (152.5gPu/l)
PU-SOL-THERM-016	155–210	0.17–0.24	Unreflected array of cylinders	4.23	Interacting cylinders in air with (152.5 gPu/l and 115.1 gPu/l)
PU-SOL-THERM-017	210	0.17	Unreflected array of cylinders	4.23	Interacting cylinders in air (115.1gPu/l)
PU-SOL-THERM-020	341–754	0.06–0.11	Water reflected, Water/Cd reflected sphere	4.67	14" diameter sphere
PU-SOL-THERM-025 Case 1 to 6	424	0.08	Water-reflected slab	4.67	Isolated slab tank in water (58 gPu/l)
PU-SOL-THERM-026 Case 1 to 3	425–430	0.09	Unreflected slab	4.67	Isolated slab tank in air (57.3 and 57.7 gPu/l)

Table 5-2 AOA (1) – Comparison of Key Parameters and Definition of Validated AOA

Parameter	Design application (cf. Table 4-1)	Benchmark (cf. Table 5-1)	Validated AOA
Geometric shape	Cylinder Slab Annular cylinder Array of cylinders	Sphere Slab Array of cylinders	Cylinder Slab Annular cylinder Array of cylinders
Reflector conditions	Full water Cd/water Borated concrete	Full water Cd/water Concrete	Full water Cd[1]/water Borated concrete[2]
Chemical form	Pu nitrate solution	Pu nitrate solution	Pu nitrate solution
Pu/(U+Pu)	100 wt. %	100 wt. %	100 wt. %
Isotopic composition [wt. % ^{240}Pu]	4.0	0.54–4.67	4.0
H/Pu	100–200	85–1157	100-200
C(Pu) [g/l]	125–237	22–269	125-237
EALF [eV]	0.14–0.25[3]	0.05–0.55	0.14–0.25

[1] Cadmium sheet of 0.05 cm thickness (clad in 0.1 cm stainless steel) outside of a slab tank of 4.5-9.5 cm fissile material thickness.

~~1~~[2] Refer to Attachment 5 for justification of validation for borated concrete.
Borated concrete (colmanite concrete) of 15 cm thickness (clad in 0.5 cm stainless steel) inside and outside of an annular tank of 7.0-7.5 cm fissile material thickness, separated from the tank by 1.8-2.0 cm conservatively assumed to be filled with water and having the following characteristics:

Colemanite concrete (density = 1.5055 g/cm^3)

Elements	Number densities [10^{24} at/cm^3]
^{10}B	1.59E-03
^{11}B	7.04E-03
Ca	4.65E-03
Fe	5.01E-04
Si	1.66E-04
H	2.17E-02
Al	1.96E-03
O	3.25E-02

Note: Only 5% of the above boron values are required to meet the conservatively modeled USL.

[3] At the optimum of moderation

Table 5-3 Critical Experiments Selected for AOA(2)

Case No. [6]	v^m/v^f	EALF [eV]	Reflector/ geometric form	PuO_2 wt. %	^{240}Pu wt. %	Description
MIX-COMP-THERM-002	1.19–3.64	0.14–0.77	Water	2.04	8.0	Rectangular Lattices of Water-moderated UO_2–PuO_2 Fuel Rods
MIX-COMP-THERM-003	1.7–10.75	0.10–0.91	Water radial	6.6	8.6	Rectangular Lattices of Water-Moderated UO_2–PuO_2 Fuel Rods
MIX-COMP-THERM-004	2.4–5.6	0.08–0.15	Water radial	3.0	22	Rectangular Lattices of UO_2-PuO_2 Fuel Rods in Water
MIX-COMP-THERM-005	1.9–10.1	0.09–0.39	Water	4.0	18	Water-Moderated Mixed UO_2-PuO_2 Pins in Hexagonal Lattices
MIX-COMP-THERM-009	1.1–5.6	0.09–0.55	Water	1.5	8.0	Mixed Oxide Fuel Pin Hexagonal Lattice, Depleted Uranium

Table 5-4 AOA (2) – Comparison of Key Parameters and Definition of Validated AOA

Parameter	Design application (cf. Table 4-2)	Benchmark (cf. Table 5-3)	Validated AOA
Geometrical shape	Heterogeneous lattices, Rectangular lattices	Rectangular lattices Hexagonal lattices	Heterogeneous lattices, Rectangular lattices
Absorber / Reflector	Water	Water	Water
Chemical form	Mixed oxide	Mixed oxide	Mixed oxide
$PuO_2/(UO_2+PuO_2)$ [wt. %]	6.3	1.5–6.6	6.3
Isotopic composition [wt. % ^{240}Pu]	4.0	8–22	4.0[1]
v^m/v^f	1.9–10	1.1–10.75	1.9–10
EALF [eV]	0.1–0.66	0.08–0.91	0.1–0.66

[1] In accordance with the guidance provided in LA-12683 [21], permissible variations of ± 4% on ^{240}Pu content are considered within the acceptable values for defining AOA for this parameter.

6. ANALYSIS OF VALIDATION RESULTS

6.1 DESIGN APPLICATION (1) - AQUEOUS SOLUTIONS OF PU-NITRATE

One hundred ninety-one critical experiments are modeled with CSAS26/KENO VI using the 238 energy group cross sections library 238GROUPNDF5 on both the Sun and PC platform. These experiments include the following geometries:

- Bare (unreflected) spheres,
- Water reflected spheres,
- Concrete reflected spheres,
- Interacting cylinders,
- Water reflected slabs,
- Unreflected slabs,
- Cadmium/concrete reflected spheres,
- Cadmium/water reflected spheres.

The calculated k_{eff} values are presented in Attachment 1A and 1B for the Sun and PC platforms, respectively. Figure 6–1 shows the distribution of the calculated k_{eff} values for the AOA(1) design application (Pu-nitrate solutions) for SCALE 4.4 on the Sun platform and SCALE 4.4a on the PC platform. The results are analyzed statistically with the USLSTATS computer code using three trending parameters: H/Pu, EALF and ^{240}Pu content. In all cases, the calculated k_{eff} values are normalized by the handbook experimental k_{eff} values (see Section 3.5) in order to provide a consistent basis of comparison among the experiments.

Although the USLSTATS approach is the preferred statistical technique for determining the USL, the method is based on an assumption that the distribution of benchmark critical values is normal. The data analyzed here does not pass the χ^2 test for normality employed in the USLSTATS code. Hence, an additional analysis of the data is performed using the non-parametric (NPM) technique described in Section 3.4. The final USL is determined based on the more conservative of the USLs established separately using the USLSTATS approach and the NPM technique. The USLSTATS approach leads to a more conservative USL and this result is maintained as the USL for AOA(1) in order to maintain consistency with previous analysis.

The EALF parameter of the selected experiments ranges from 0.05 eV to 0.55 eV and the range of H/Pu atomic ratios goes from 85 to 1157, cf. Table 5-1.

Table 6-1 and Table 6-2 summarize the statistical results of the USLSTATS program for Sun and PC platforms, respectively. It can be noted that the range of EALF obtained with these experiments covers the EALF values of AOA(1), cf. Table 4-1. Figure 6–2 through Figure 6–4 show the results graphically. All positive biases are conservatively set to zero.

6.1.1 USL with EALF and H/Pu ratio

Figure 6–2 and Figure 6–3 show the k_{eff} values calculated on each platform and the values of USL-1 and USL-2 versus the trending parameters EALF and H/Pu, respectively. The corresponding USLSTATS output listings are presented in Attachment 3 for PC values and in Attachment 4 for Sun values.

Note that the data does not pass the normal distribution test for the full set of experiments (See the USLSTATS outputs in Attachments 3 and 4). The non-normality of the data can be observed in Figure 6–1. Evaluation of the data indicates that the non-normality is due to acceptable differences in the benchmark experiments. Consequently, all the data is used to establish the USL. By performing a graphical analysis of the data in Figure 6–2 through Figure 6–4 it is apparent that the minimum normalized k_{eff} value is bounded by a value of 0.9900. With the application of a 0.05 administrative margin, the graphical analysis of the data indicates that a USL of 0.9400 is adequate.

In addition, the results of the USLSTATS analysis of the data are shown in Table 6-1 and Table 6-2 for each trending parameter. For AOA(1), the minimum USL-1 with a 0.05 administrative margin is 0.9370(a)/0.9372(b)[2]. The USL-2 analysis indicates that a suitable minimum margin of subcriticality for this AOA is 0.029(a)/0.029(b) (See Section 3.3). This indicates that the administrative margin (Δk_m =0.05) applied to the USL-1 value is adequate for the AOA(1) application provided the EALF and H/Pu ratio fall within the applicable range.[3] Since the USL calculated with USLSTATS is less than that determined by performing a graphical analysis of the data, the USL calculated with USLSTATS is used for conservatism.

The two versions of SCALE running on different hardware platforms show no statistically significant differences in results. Taking the minimum computed USL for each platform, a USL of 0.9370 is justified for both SCALE 4.4 and SCALE4.4a for the Pu-nitrate solution area of applicability.

6.1.2 USL with ^{240}Pu content in Plutonium

Forty-six experiments were selected from PU_SOL_THERM_001, 002, 003, 004, 005 and 006 to evaluate the effect of the ^{240}Pu ratio on the calculational bias. The ^{240}Pu content in the fissile solutions of Pu-nitrate used in the experiments varied from 0.54 wt. % to 4.67 wt. %. This reduced set of experiments is selected because the experiments have otherwise very similar characteristics, therefore exposing ^{240}Pu effect to the greatest extent:

- Plutonium nitrate solution,
- Spherical geometry, water reflected.

---

[2] Note: In the following sections, results tagged with "(a)" correspond to SCALE 4.4 on the Sun platform; those tagged "(b)" correspond to SCALE 4.4a on the PC platform.

[3] ANSI/ANS-8.1–1998 allows the range of applicability to be extended beyond this range by extrapolating the trends established for the bias; however, no precise guidelines are specified for the limits of extrapolation. Therefore, engineering judgment must be applied when extrapolating beyond the range of the parameter bounds. If extrapolation is necessary, it will be discussed on a case-by-case basis in the individual criticality calculations.

Figure 6–4 shows the calculated k_{eff} values and the parameters for the determination of USL-1 and USL-2 based on trending with ^{240}Pu content. This figure shows that the bias (k_{eff}-1.0) is positive and remains constant with an increase in ^{240}Pu content.

The corresponding USLSTATS output listings are included in Attachment 3 for PC values and in Attachment 4 for Sun values.

Table 6-1 and Table 6-2 show that the minimum USL-1 with a 0.05 administrative margin is 0.9402(a)/0.9408(b). The minimum USL-2 is 0.9746(a)/0.9760(b) and the corresponding minimum margin of subcriticality is 0.016(a)/0.015(b) as determined using Method 2 (See Section 3.3). This indicates that the administrative margin (Δk_m=0.05) applied to the USL-1 value is adequate for the AOA(1) application.

6.1.3 Effect of reflectors and absorbers

Concrete, cadmium/water layers and borated concrete materials are used for some AOA(1) design applications as reflector materials or absorbers to reduce the reflector effectiveness or neutron interaction between adjacent fission zones. Experiments with concrete or cadmium/water reflector are included in the full set of experiments used in the calculation of the USL for the AOA(1). Justification for use of this USL is provided in Attachment 6.

For design applications using borated concrete reflectors, the discussion in Attachment 5 provides justification for use of the USL developed here.

6.1.4 Non-parametric analysis

With 191 critical benchmark values, the degree of confidence β for the non-parametric technique described in Section 3.4 is, according to Eq. 3.23:

$$\beta = 1 - 0.95^{191} = 99.994\%$$

Hence, according to Table 3-1, no additional non-parametric margin is required. The smallest computed k_{eff} values for the collection of experiments is 0.9968±0.006282 for the Sun platform and 0.9948±0.006152 for the PC platform. The resulting USLs determined according to the non-parametric technique (Eq. 3.21) with a 5% administrative margin are

$$\text{NPM USL for Sun} = 0.9386$$

$$\text{NPM USL for PC} = 0.9405$$

The non-parametric results are less limiting than those obtained using the USLSTATS methodology. In order to remain consistent with previous analysis, it is recommended that the more conservative USLSTATS results be used in determining the final USL for AOA(1).

6.1.5 Summary of USL for AOA(1) Aqueous Solutions of Pu-nitrate

The minimum USL for the AOA(1) systems is 0.9370. This value reflects a 0.05 administrative margin and 0.0130 calculational bias. The 0.05 administrative margin is adequate since there is a sufficient number of representative benchmark experiments which cover the range of applicability for the design conditions. This administrative margin is further justified by the results of the USL-2 analysis, which indicates that the 0.05 administrative margin is justified.

Note that the minimum USL has been selected from the essentially identical results from the PC and Sun platforms and from the trending values from the three correlated parameters. However, [10] suggests that the parameter "*with the strongest correlation to the calculated k_{eff} values is to be used for the determination of USL.*" As can be seen from the USLSTATS results in Attachment 3, this approach would result in a higher USL value for AOA(1). The conservative approach adopted here represents additional margin in the validation for this AOA.

6.2 DESIGN APPLICATION (2) – MOX-PELLETS, FUEL RODS, FUEL ASSEMBLIES

Thirty-six experiments are evaluated for this design application. The calculated k_{eff} values are presented in Attachment 2.

Figure 6–5 shows the distribution of the calculated k_{eff}-values for the design application (Group AOA(2) – MOX pellets, fuel rods, and fuel assemblies) for SCALE 4.4 on the Sun platform and SCALE 4.4a on the PC platform. The results are analyzed statistically with the USLSTATS computer code using three trending parameters: v^m/v^f, EALF and PuO_2 content. In all cases, the calculated k_{eff} values are normalized by the handbook experimental k-effective values (see Section 3.5).

The EALF range of selected experiments goes from 0.08 eV to 0.91 eV and the range of v^m/v^f goes from 1.1 to 10.75, cf. Table 5-3.

Table 6-3 and Table 6-4 summarize the statistical results of the USLSTATS program. Figure 6–6 through Figure 6–8 show the results graphically.

6.2.1 USL with EALF and v^m/v^f Ratio

Figure 6–6 and Figure 6–7 show the calculated k_{eff} and the values of USL-1 and USL-2, versus the trending parameters EALF and v^m/v^f, respectively.

The corresponding USLSTATS output listings are attached in Attachment 3 for PC values and in Attachment 4 for Sun values.

Table 6-3 and Table 6-4show that the minimum USL-1 with a 0.05 administrative margin is 0.9321(a)/0.9327(b) for trending with EALF and v^m/v^f (EALF from 0.08 to 0.91 and v^m/v^f ratio from 1.1 to 10.75). The minimum USL-2 is 0.9640(a)/0.9659(b) and the corresponding minimum margin of subcriticality is 0.018(a)/0.017(b) as determined using Method 2 (See Section 3.3). This indicates that the administrative margin (Δk_m=0.05) applied in the USL-1 analysis is adequate for the AOA(2) application provided the EALF and v^m/v^f ratio fall within the applicable range.[4]

---

[4] ANSI/ANS-8.1 allows the range of applicability to be extended beyond this range by extrapolating the trends established for the bias. If extrapolation is necessary, it will be discussed on a case-by-case basis in the individual criticality calculations.

6.2.2 USL with PuO_2 content in MOX

The 36 experiments are also analyzed as a function of the $PuO_2/(UO_2+PuO_2)$ ratio to evaluate the effect of PuO_2 content on the calculational bias. These 36 experiments cover a range from 1.5 wt. % to 6.6 wt. % in $PuO_2/(UO_2+PuO_2)$. Figure 6–8 shows the calculated k_{eff} values and the USL parameters for the determination of USL-1 and USL-2 based on trending with PuO_2 content.

Table 6-3 and Table 6-4 show that the minimum USL-1 with a 0.05 administrative margin is 0.9378(a)/0.9378(b). This administrative margin is further justified by the results of the USL-2 analysis which indicates that an adequate minimum margin of subcriticality for this AOA is 0.018(a)/0.017(b), significantly less than the 0.05 administrative margin actually used.

6.2.3 Effect of reflectors and absorbers

Concrete and borated shields are used for some AOA(2) design application as reflectors or to reduce reflector effectiveness and neutron interaction between adjacent fission zones. For these design applications, a case-by-case argument will be provided in the respective calculation justifying use of the USL.

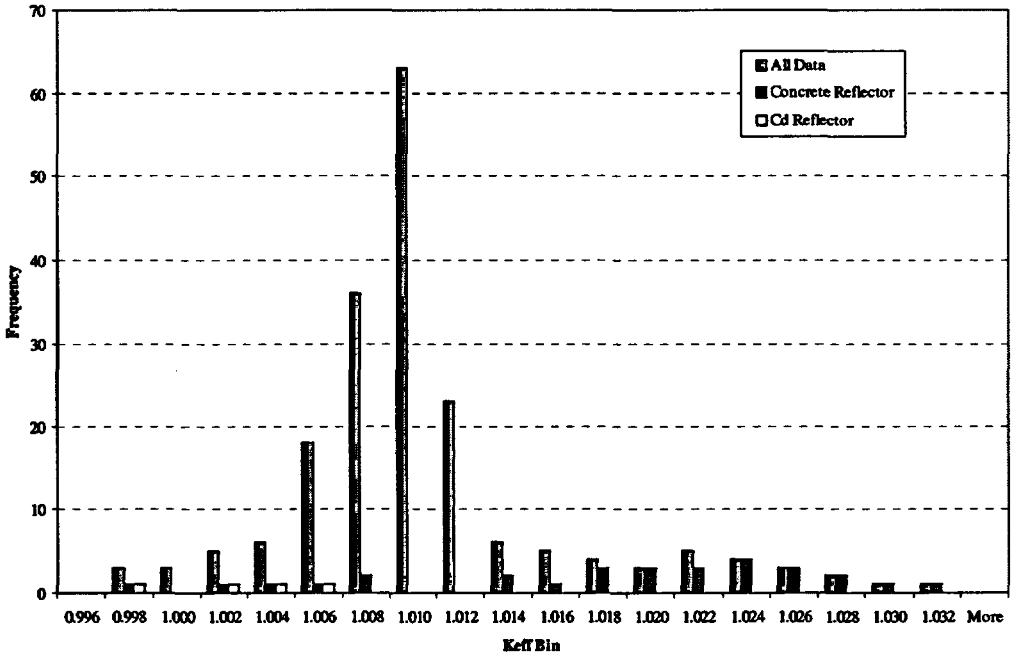
6.2.4 Summary of USL for AOA(2) MOX pellets, fuel rods, and fuel assemblies

The minimum USL for the AOA(2) systems is 0.9321. This value reflects a 0.05 administrative margin and 0.0179 calculational bias. The 0.05 administrative margin is more than adequate since there is an adequate number of representative benchmark experiments which cover the range of applicability for the design conditions.

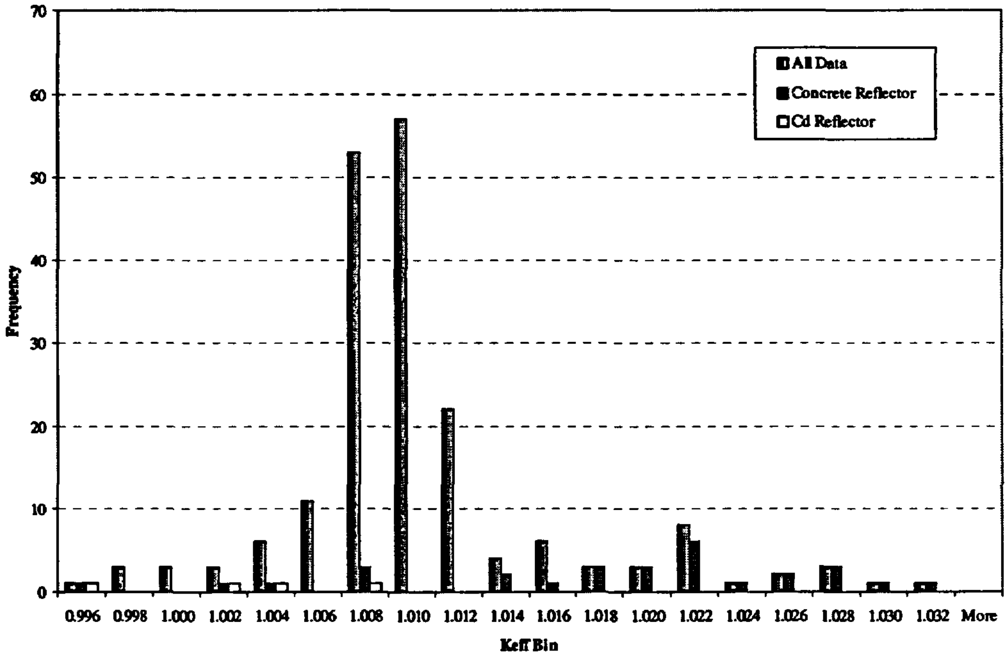
This administrative margin is further justified by the results of the USL-2 analysis which indicates that an adequate minimum margin of subcriticality for this AOA is 0.018, significantly less than the 0.05 administrative margin actually used.

Note that the minimum USL has been selected from the essentially identical results from the PC and Sun platforms and from the trending values from the three correlated parameters. However, [10] suggests that the parameter "*with the strongest correlation to the calculated k_{eff} values is to be used for the determination of USL.*" As can be seen from the USLSTATS results in Attachment 4, this approach would result in a higher USL value for AOA(2). The conservative approach adopted here represents additional margin in the validation for this AOA.

Note that the benchmark experiments for clad fuel pellets are directly applicable to the production of fuel assemblies and configurations involving loose rods. The application calculations for these configurations are within the AOA as derived from the benchmark experiments. These benchmark experiments are also directly applicable to unclad fuel pellets or loose pellets since the cladding effects (neutronic absorption in the epithermal and thermal regions) are negligible. The cladding configuration (material, position and thickness) in these experiments changes the epithermal and thermal neutron flux distribution by less than 1% at the surface of the pellet (comparison of clad pellets as compared to unclad pellets). A 1% change in the epithermal and thermal flux distribution at the surface of the pellet leads to a significantly smaller change in the k_{eff} of the system since all neutrons transgressing the surface of the pellet do not lead to fission. The neutron flux difference would generally result in a Δk_{eff} (between clad and unclad pellets) of 0.005, which is on the order of the KENO variance. Based on this difference, the AOA for clad fuel pellets, fuel assemblies or loose rods is directly applicable to unclad pellets. Pellet configurations and application calculations within the AOA range established by benchmark experiments for clad rods are directly applicable to pellets and are therefore appropriately validated.

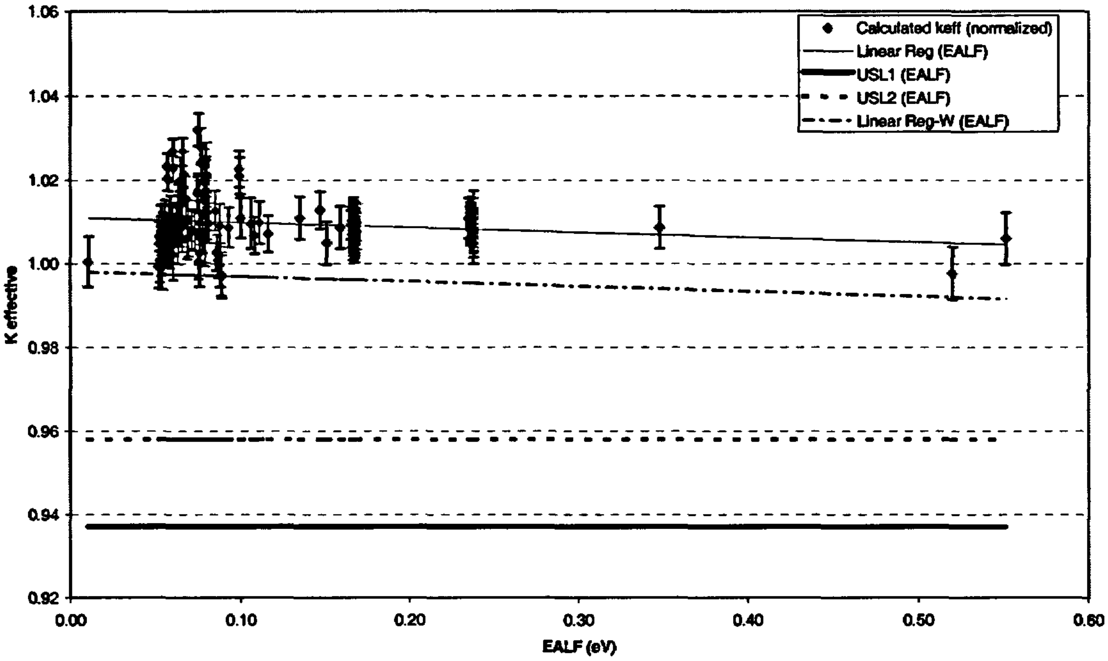


(a) Sun Platform – SCALE 4.4

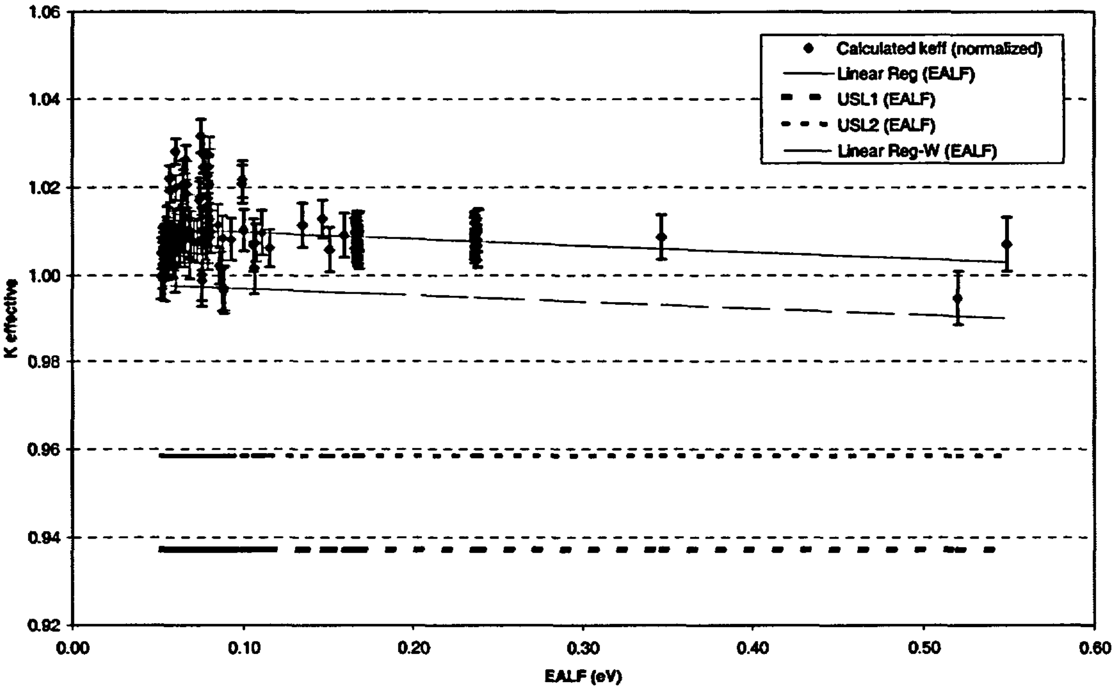


(b) PC Platform – SCALE 4.4a

Figure 6–1 Histogram of normalized k_{eff} values for AOA(1) on Sun (a) and PC (b) platforms

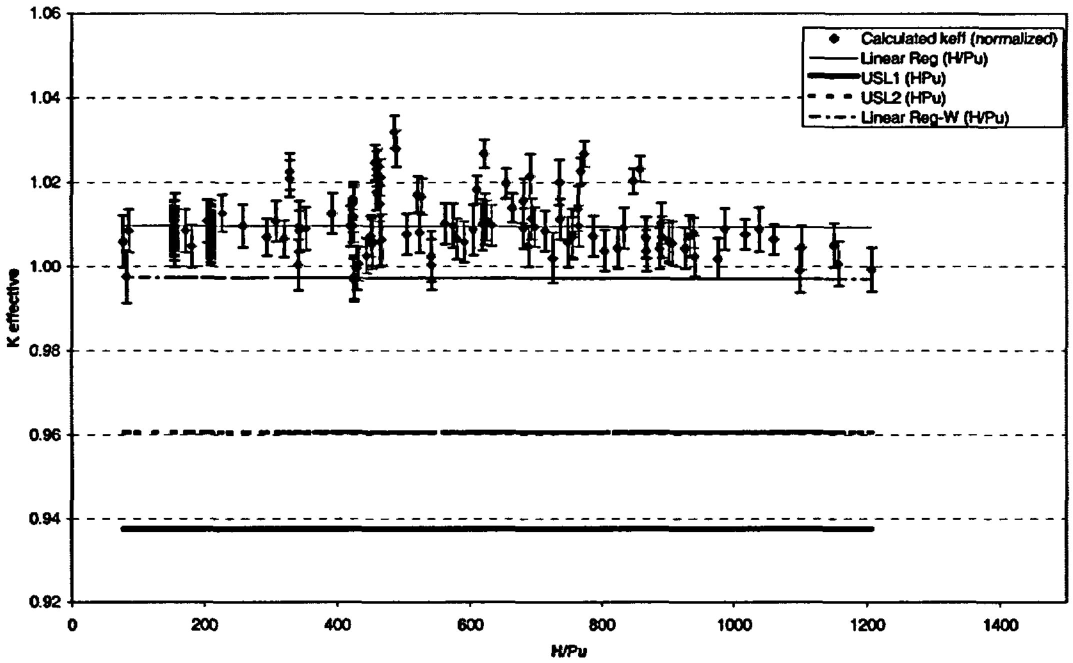


(a) Sun Platform – SCALE 4.4

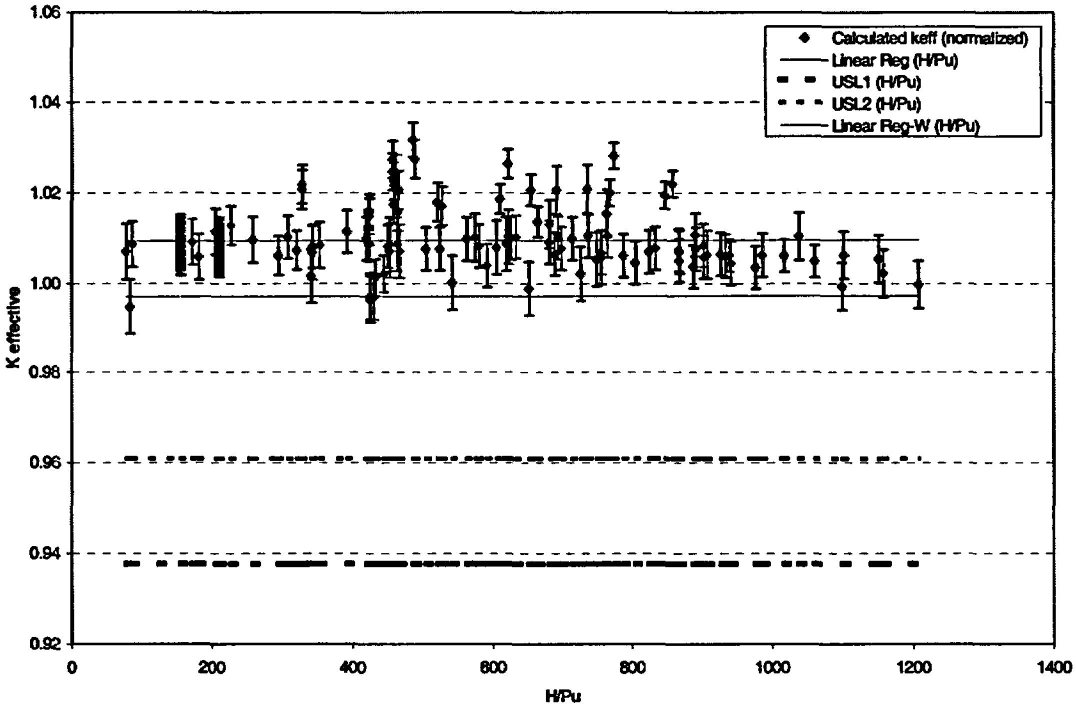


(b) PC Platform – SCALE 4.4a

Figure 6–2 AOA(1) – Pu-nitrate solution; k_{eff} as function of EALF

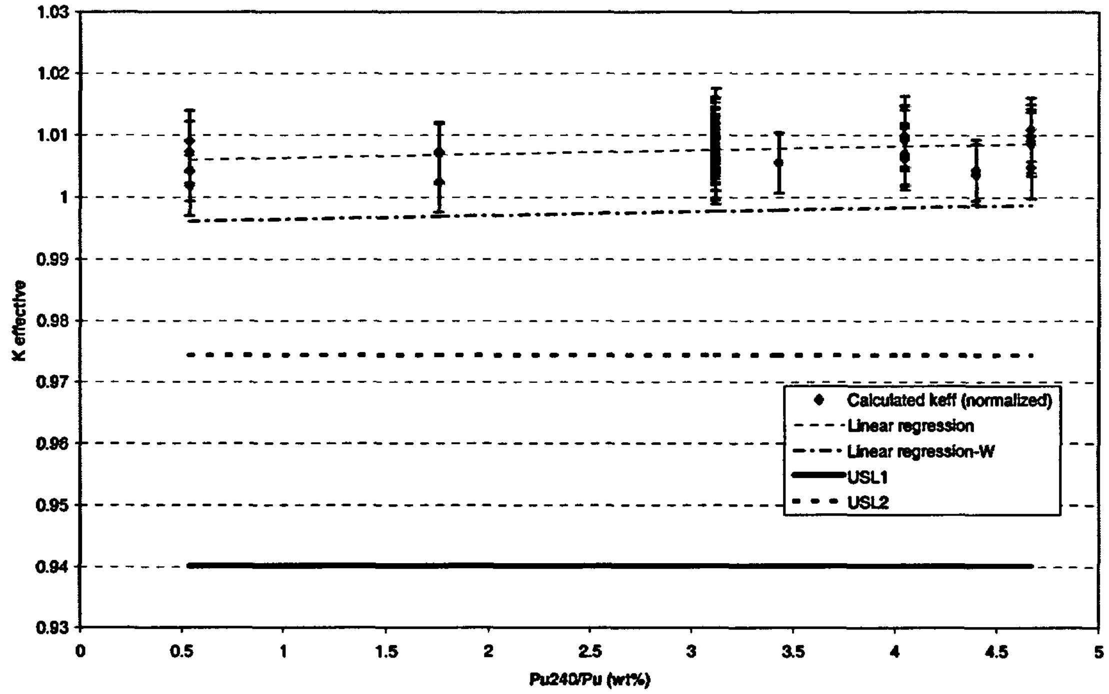


(a) Sun Platform – SCALE 4.4

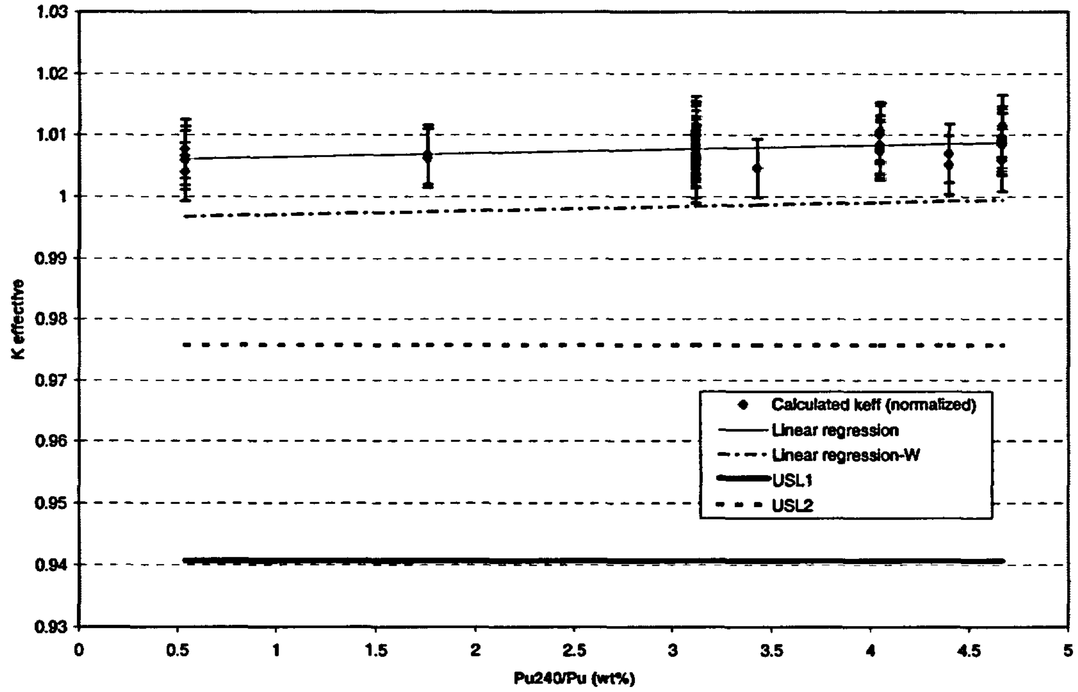


(b) PC Platform – SCALE 4.4a

Figure 6–3 AOA(1) – Pu-nitrate solution; k_{eff} as function of H/Pu

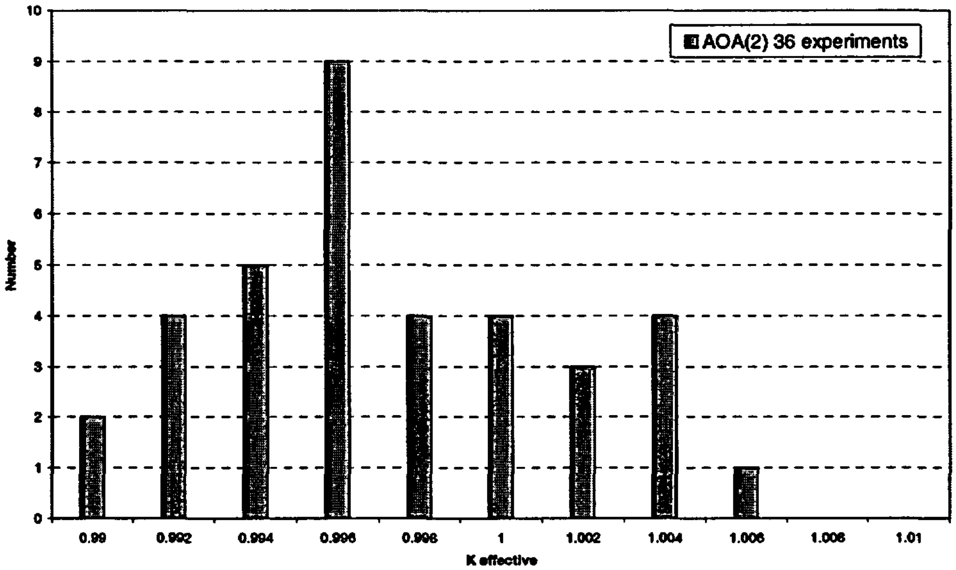


(a) Sun Platform – SCALE 4.4

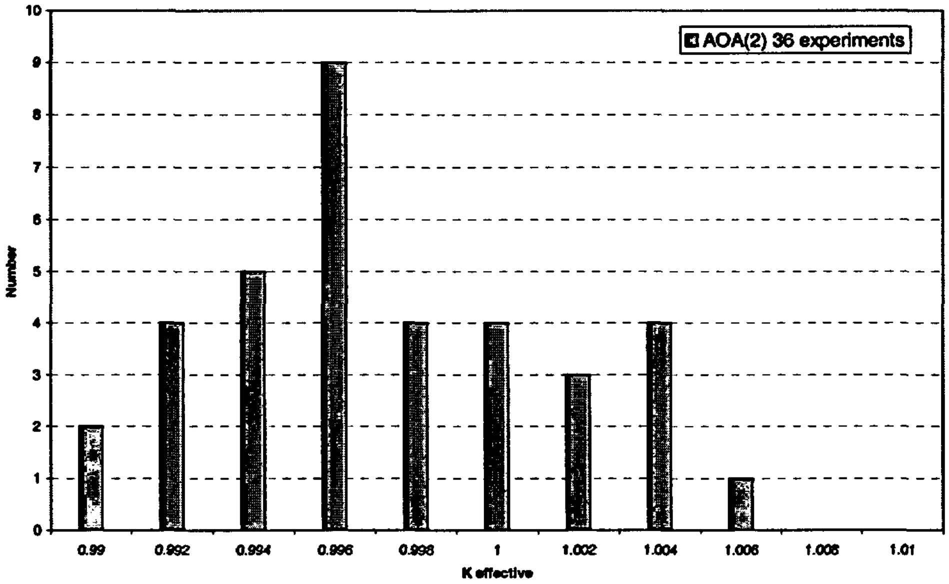


(b) PC Platform – SCALE 4.4a

Figure 6–4 AOA(1) – Calculated k_{eff} as function of ^{240}Pu content

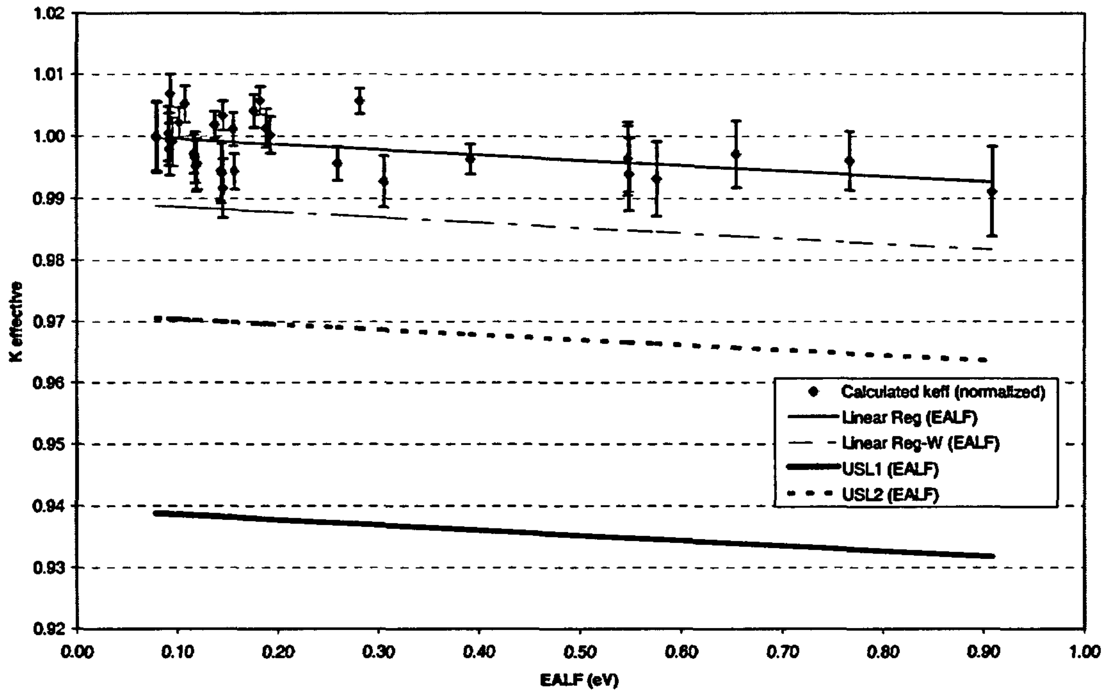


(a) Sun Platform – SCALE 4.4

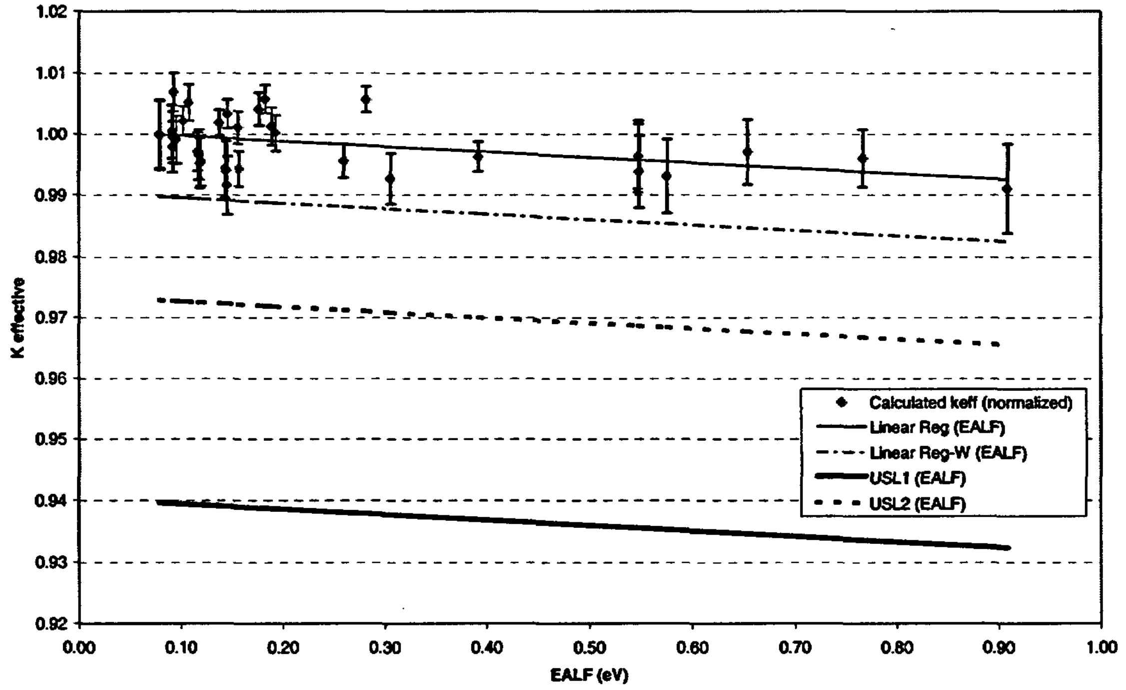


(b) PC Platform – SCALE 4.4a

Figure 6–5 Histogram of normalized k_{eff} values for AOA(2) on Sun (a) and PC (b) platforms

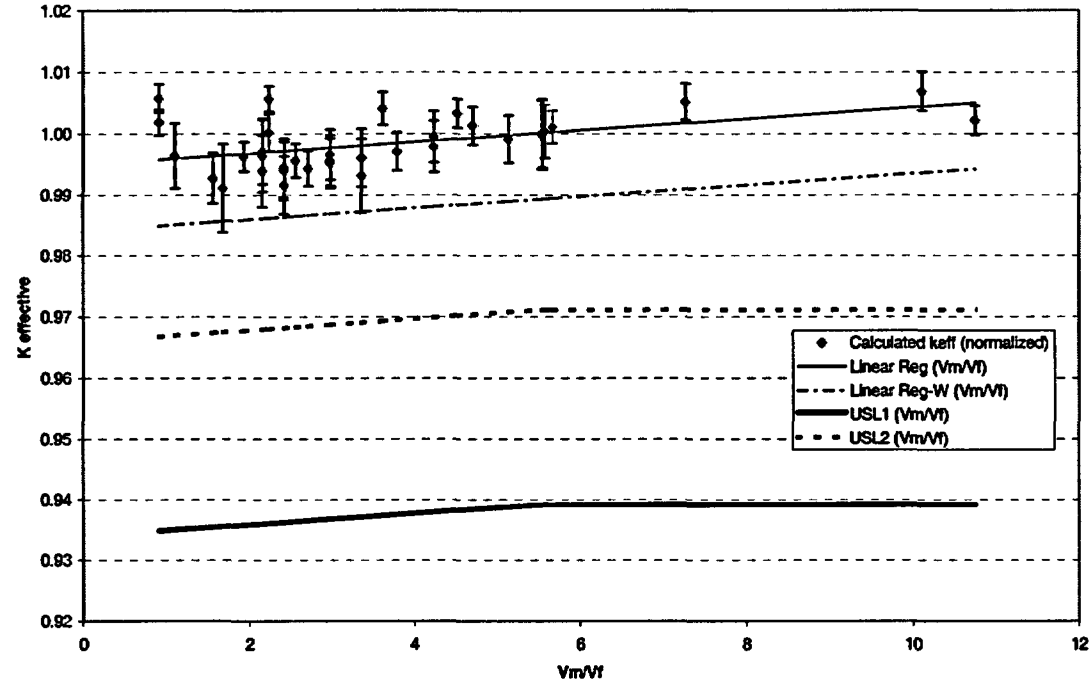


(a) Sun Platform – SCALE 4.4

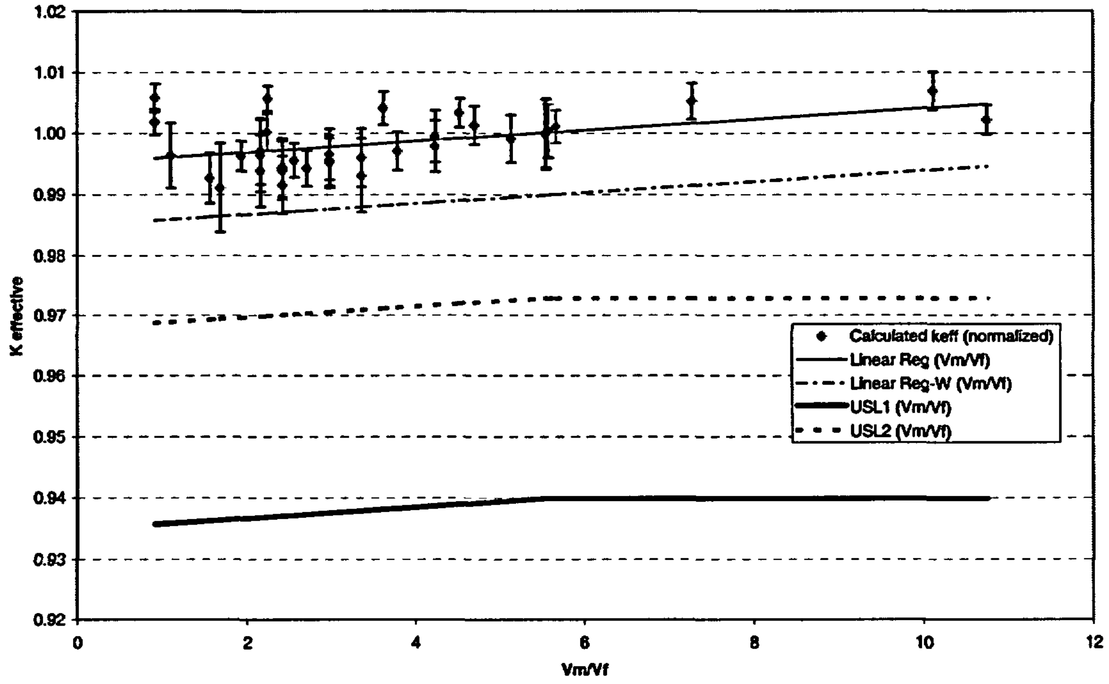


(b) PC Platform

Figure 6–6 AOA(2) – MOX pellets, fuel rods and fuel assemblies: k_{eff} as function of EALF

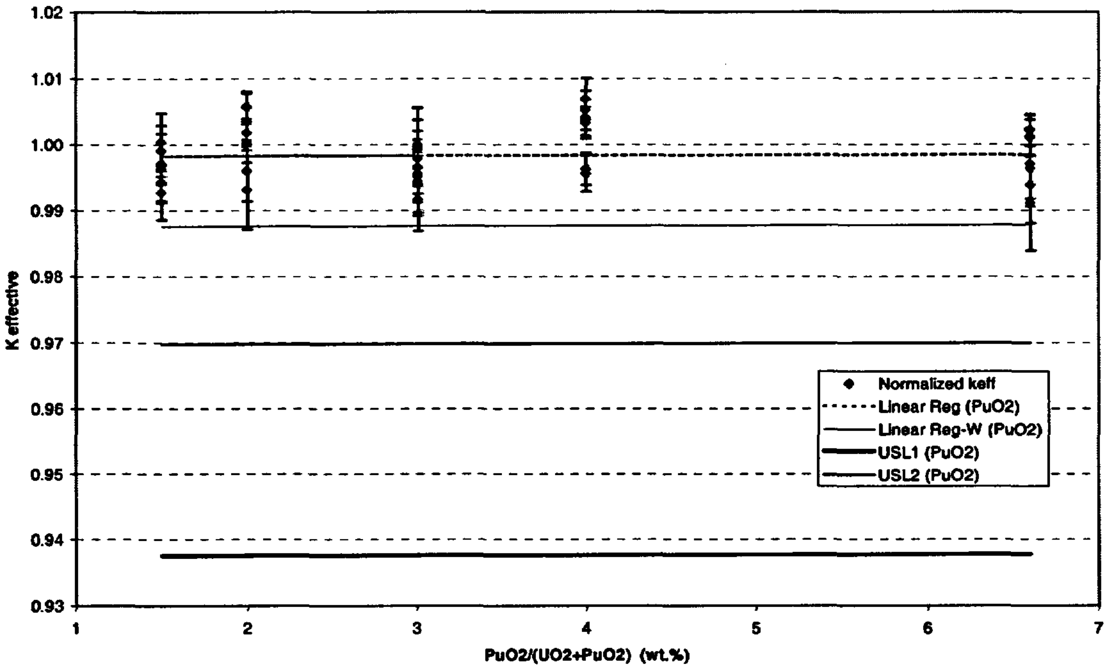


(a) Sun Platform – SCALE 4.4

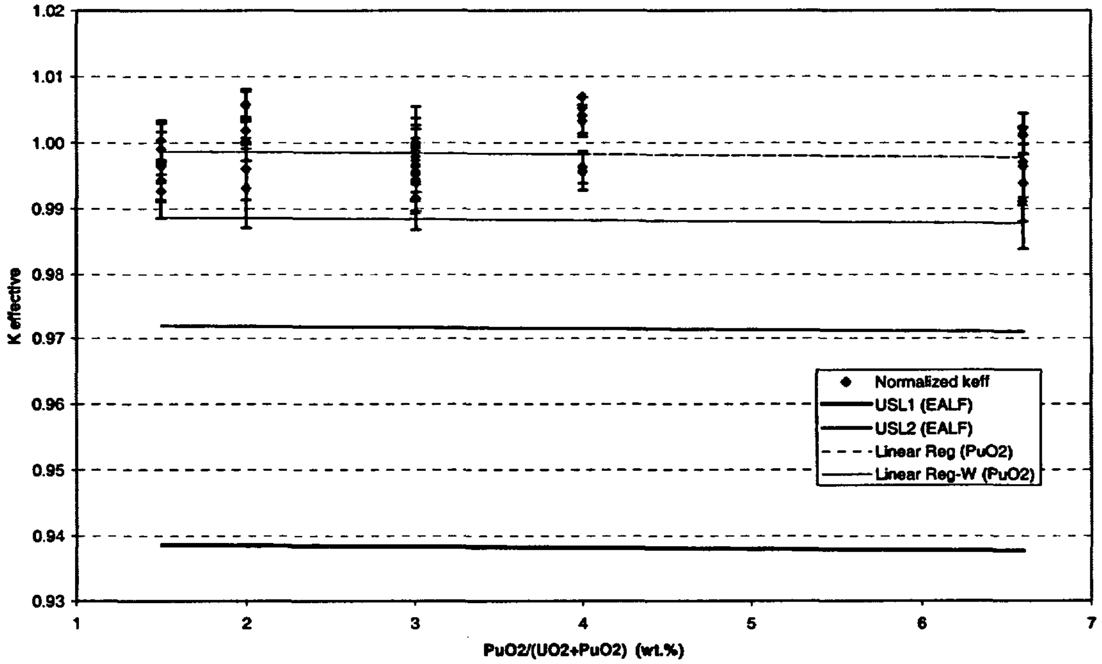


(b) PC Platform – SCALE 4.4a

Figure 6–7 AOA(2) – MOX pellets, fuel rods and fuel assemblies: k_{eff} as function of v^m/v^f



(a) Sun Platform



(b) PC Platform

Figure 6–8 AOA(2) – MOX pellets, fuel rods and fuel assemblies: k_{eff} as function of PuO_2 content

Table 6-1 Summary of USL Calculations for SCALE 4.4 on Sun Platform: AOA(1)

Correlated Parameter (x)	No. Exps.	Range of x	k_c(x) Linear Regression	Average k_c	Min USL$_1$ (Δk_m =0.05)	Min USL$_2$	Min Δk_m (USL$_2$)
EALF (eV)	191	0.05 to 0.55	1.0113 + (-1.2867E-02)*x	1.0096	0.9370	0.9581	0.029
H/Pu	191	85 to 1157	1.0096 + (1.7495E-07)*x	1.0096	0.9376	0.9607	0.027
^{240}Pu (wt. %)	46	0.54 to 4.67	1.0057 + (6.1803E-04)*x	1.0077	0.9402	0.9746	0.016

Table 6-2 Summary of USL Calculations for SCALE 4.4a on PC Platform: AOA(1)

Correlated Parameter (x)	No. Exps.	Range of x	k_c(x) Linear Regression	Average k_c	Min USL$_1$ (Δk_m =0.05)	Min USL$_2$	Min Δk_m (USL$_2$)
EALF (eV)	191	0.05 to 0.55	1.0114 + (-1.5297E-02)*x	1.0095	0.9372	0.9585	0.029
H/Pu	191	85 to 1157	1.0091 + (8.1036E-07)*x	1.0095	0.9377	0.9610	0.027
^{240}Pu (wt. %)	46	0.54 to 4.67	1.0048 + (9.2819E-04)*x	1.0078	0.9408	0.9760	0.015

Table 6-3 Summary of USL Calculations for SCALE 4.4 on Sun platform: AOA(2).

Correlated Parameter (x)	No. Exps.	Range of x	k_c(x) Linear Regression	Average k_c	Min USL$_1$ (Δk_m =0.05)	Min USL$_2$	Min Δk_m (USL$_2$)
EALF (eV)	36	0.08 to 0.91	1.0005 + (-8.4182E-03)*x	0.9984	0.9321	0.9640	0.018
v^m/v^f	36	1.1 to 10.75	0.9939 + (1.2243E-03)*x	0.9984	0.9351	0.9681	0.017
$PuO_2/(UO_2+PuO_2)$ (wt. %)	36	1.5 to 6.6	0.9985 + (-2.3845E-05)*x	0.9984	0.9378	0.9701	0.018

Table 6-4 Summary of USL Calculations for SCALE 4.4a on PC platform: AOA(2).

Correlated Parameter (x)	No. Exps.	Range of x	k_c(x) Linear Regression	Average k_c	Min USL$_1$ (Δk_m =0.05)	Min USL$_2$	Min Δk_m (USL$_2$)
EALF (eV)	36	0.08 to 0.90	1.0007 + (-8.7123E-03)*x	0.9985	0.9327	0.9659	0.017
v^m/v^f	36	1.1 to 10.75	0.9941 + (1.1733E-03)*x	0.9985	0.9359	0.9700	0.016
$PuO_2/(UO_2+PuO_2)$ (wt. %)	36	1.5 to 6.6	0.9994 + (-2.5117E-04)*x	0.9985	0.9378	0.9712	0.017

7. CONCLUSIONS

The SCALE 4.4 and SCALE 4.4a code packages using the CSAS26 (KENOVI) sequence and the 238 energy group cross section library 238GROUPDF5 have been validated to perform criticality calculations for the Mixed Oxide Fuel Fabrication Facility. The validation covers two of the facility design areas of applicability: AOA(1) Pu-nitrate solutions and AOA(2) MOX pellets, rods, and fuel assemblies.

The USL for the two design application areas are as follows:

- Design application (1) Pu-nitrate solutions	USL AOA(1) = 0.9370
- Design application (2) MOX pellets, rods, and fuel assemblies	USL AOA(2) = 0.9321

The USL accounts for the computational bias, uncertainties, and an administrative margin. The administrative margin is established at 0.05 such that $k_{eff} + 2\sigma - bias \leq 0.95$ for all normal and credible abnormal conditions. Section 7.1 contains a detailed justification of the administrative margin.

No extrapolation outside the range of applicability is expected for the AOA(1) and AOA(2) USL values; however, ANSI/ANS-8.1 [2] does allow for extrapolation outside the area of applicability by extrapolating the trends established for the bias and USL. If extrapolation is necessary, it will be discussed on a case-by-case basis in the respective calculation.

7.1 JUSTIFICATION FOR ADMINISTRATIVE MARGIN

The administrative margin applied in the determination of the USL is intended as an added level of conservatism. The code validation effort accounts for all code bias and the effects of both code and experimental benchmark uncertainties. The administrative margin is applied *in addition* to the code bias and bias uncertainty in determining the USL.

The USL values determined here are based on an administrative margin of 0.05. Based on actual process conditions, including 1) the degree to which application parameters fall within the validated Area of Applicability (AOA) of the calculational method and 2) the results of sensitivity analyses demonstrating the sensitivity of k_{eff} values to variations in controlled parameters, the USL may be adjusted. Each NCSE and criticality calculation will include a discussion of the appropriateness of the USL applied for each specific design application.

Typically, the NCSEs and criticality calculations will present k_{eff} results for various scenarios, including normal operation and credible abnormal situations. The results of these analyses permit a quantitative assessment of the degree of subcriticality of the system measured in terms of variation of one or more controlled parameters. Hence, the NCSEs/criticality calculations for specific design applications will verify the conformance with the AOA used in the validation reports.

In general, based on the discussion below, the administrative margin used in criticality analyses is 0.05. This assessment is based on a comparison against administrative margin practices at both NRC and DOE facilities, and past NRC guidance and practice, and is further substantiated by a statistical analysis of the benchmark validation results.

7.1.1 Fuel Cycle and Industry Practice

A review of NRC materials licensees and analogous DOE facilities (including plutonium facilities) indicates that administrative margins range from 0.02 to 0.05 as shown in Table 7-1. These values apply to applications within the validated AOAs; adjustments to the administrative margin are typically made for application outside the validated region.

These values are consistent with precedent information provided by the NRC Staff [20], which indicates administrative margins with a similar range to those indicated in Table 7-1.

An administrative margin of 0.05 is greater than or equal to the most conservative margins identified in Table 7-1 and other NRC precedent [20] for analysis of credible abnormal conditions.

This margin is consistent with guidance provided in NUREG-1718 [3], which supports an administrative margin of 0.05 for the MFFF. It is also consistent with past NRC-accepted practice in reactor operations (10 CFR 50) [19], and transportation (10 CFR 71) and on-site storage (10 CFR 72) of spent nuclear fuel. Examination of various precedents indicates 0.05 is a conservative administrative margin for activities falling within the validated AOA. For criticality analyses applied outside the validated AOA, specific guidance is provided in ANSI/ANS–8.1–1998 which indicates that the administrative margin may be adjusted based on established trends in the bias, if necessary.

7.1.2 USLSTATS Method 2 Quantitative Assessment

Once an administrative margin has been determined (in this case, based on NRC guidance in NUREG-1718 [3] and based on conservative comparison with applicable precedent), NUREG/CR-6361 [10] provides a quantitative method of assessing the suitability of the administrative margin based on a statistical analysis which generates a recommended minimum margin of subcriticality. NUREG/CR-6361 suggests that this minimum margin of subcriticality be compared against the administrative margin in order to verify that the administrative margin is conservative relative to a purely statistical basis[5].

This mechanism provides an independent, quantitative means of substantiating the administrative margin selected based on the statistics of the benchmarks themselves. The use of this methodology requires the specification of two important statistical parameters: α, the level of confidence in the limit being calculated and P, the probability future calculations will lie within the statistical band. The result of this methodology is the assurance that by using at least the calculated minimum margin of subcriticality, there is a probability P with a confidence α that an additional calculation of k_{eff} for a critical system will lie within the band. For example, a calculation with α=0.95 and P=0.95 would yield a USL for which there is a 95% confidence that 95 out of 100 future calculations of critical systems will yield a value of k_{eff} above the USL (which is conservative). This level of statistical treatment is consistent with the statistics usually employed in the inclusion of 2σ in the treatment of Monte Carlo criticality calculations. It is also

---

[5] See NUREG/CR-6361 §4.1.3. For example, Westinghouse is approved to use a 0.02 Δk administrative margin unless a higher margin of subcriticality is calculated using USL–2 methodology.

consistent with the statistical recommendations in NUREG/CR-6698 [18]. As can be seen in the figures in Section 6, use of this traditional statistical treatment would lead to the conclusion that, based on the usual statistical approach, a margin as low as 0.01 to 0.02 would be necessary to ensure that the USL was conservative based upon a statistical evaluation of the data.

However, this report uses USLSTATS to examine the statistics at a higher level of certainty. That is, values of α=0.95 and P=0.999 were used. This means that the derived USL–2 is such that there is a 95% confidence that 999 out of 1000 future calculations of critical systems will yield a value of k_{eff} above the USL. The resulting conclusion using 95/99.9 statistics is that the added conservatism over the 1-2% amount, which would be required using traditional statistical levels, is available to ensure that the results are conservative for other potential mechanisms for which conservatisms would be prudent.

An analysis of the benchmarks using a value of α=0.95 and P=0.999 yield the subcritical margins listed in Table 7-2. If one were to base an administrative margin solely on this very conservative statistical analysis, an administrative margin of at most 0.03 is necessary to statistically justify the use of these benchmarks. This is significantly less than the 0.05 administrative margin used for the two AOAs. Note that the administrative margin is applied in addition to the calculated bias and uncertainty for each AOA. This means that the proposed 0.05 administrative margin is still more conservative than that determined in the 95/99.9 statistical treatment and is justified in the MFFF.

7.1.3 Summary of Administrative Margin Practice

This effort involves the validation of the code to applications within one or more specific areas of applicability. There is no intent to account for or to address the uncertainties and unknowns involved in the actual design applications. This approach is consistent with NUREG/CR-6698 which states "*the subcritical margin is not intended to account for process upset conditions or for uncertainties associated with a process.*" These issues are properly addressed in the nuclear criticality safety evaluations (NCSEs). These evaluations will demonstrate that the design application falls within the required AOA, that design uncertainties and unknowns are properly and conservatively addressed, that sensitivity to controlled parameters is adequately addressed, and that the criticality models themselves are suitably conservative representations of the actual physical phenomena. In cases where calculated k_{eff} values are shown to be sensitive to controlled parameters, the NCSE will demonstrate the adequacy of the control.

In conclusion, an administrative margin of 0.05, selected on the basis of NRC guidance and conservative comparison with applicable precedent, and substantiated through statistical methods, is justified, and is sufficiently conservative to provide for an adequate margin of subcriticality.

Table 7-1 Fuel Cycle and Industry Practice

Facility	Process/Application	Material	Administrative Margin
Framatome Cogema Fuels	Fuel assembly manufacture	Low enriched U	0.05
Westinghouse Columbia Site	Fuel assembly manufacture	Low enriched U	0.02
Nuclear Fuel Services	Fuel processing (solutions, powder, pellets, etc.)	Various U enrichments	0.03 LEU 0.05 HEU
Paducah Uranium Enrichment Plant	Uranium enrichment	Low enriched U	0.02
Rocky Flats	Weapons material processing	Plutonium	0.03
BWXT	Fuel assembly manufacture	Low to High Enriched U	0.03 LEU 0.05 HEU
Savannah River Site	a) MTR fuel assemblies b) Pipe overpack material storage c) Mark 42 tube dissolution d) Ion exchange columns with fissile solutions e) DDF-1 package	a) High enriched U b) ^{239}Pu c) ^{239}Pu d) ^{239}Pu solution e) Pu metal and oxide	a) 0.02 b) 0.02 c) 0.05 d) 0.04 e) 0.05
Y-12	Weapons material processing	High enriched U	0.02 – 0.05[1]
Idaho National Engineering and Environmental Lab	Solutions/spent fuel/powders/pieces	Low to High Enriched U, including ^{233}U;some Pu	0.02 – 0.05 0.05 typical
Hanford Site	Waste tanks Packaging and transportation	Various	0.05

[1] Pending final approval of validation document.

Table 7-2 USLSTATS Method 2 Analysis Results

Area of Applicability	USL-2 Minimum Margin of Subcriticality	Administrative Margin	Factor By Which Admin Margin Exceeds Recommended Value
AOA(1)	0.029	0.050	1.7
AOA(2)	0.018	0.050	2.7

8. REFERENCES

[1] SCALE 4.4 : A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation, NUREG/CR-0200 (ORNL/NUREG/CSD-2/R6), Volumes I, II and III. Available from Radiation Shielding Information Center as CCC-545.

[2] ANSI/ANS (American National Standards Institute/American Nuclear Society), 1998. American National Standard for Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors, ANSI/ANS–8.1–1998, La Grange Park, IL.

[3] NRC (U.S. Nuclear Regulatory Commission), 2000. Standard Review Plan for the Review of an Application for a Mixed Oxide (MOX) Fuel Fabrication Facility, NUREG-1718, U.S. Nuclear Regulatory Commission, Washington, DC.

[4] DV/CDT/9003/055/V Verification of the SCALE4.4 Code Package at the Sun Work Station, SGN Document NT 12046 00 029 A.

[5] Verification of the SCALE 4.4a Code Package on SGN Pentium PCs, SGN Document NT 12046 00 028 A.

[6] Nuclear Energy Agency, 1999. International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC(95)03, Nuclear Energy Agency, Organization for Economic Co-operation and Development.

[7] Emmett, M.B., and W.C. Jordan, 1996, Guide to Verification and Validation of the SCALE-4 Criticality Safety Software, NUREG/CR-6483 (ORNL/TM-12834), Lockheed Martin Energy Research Corp., Oak Ridge National Laboratory, Oak Ridge, TN.

[8] Neutronics Benchmarks for the Utilization of Mixed-Oxide Fuel: Joint U.S./Russian Progress Report for Fiscal Year 1997, Prepared by the Staffs of the Oak Ridge National Laboratory and the Amarillo National Research Center for Plutonium, Coordinated in the U.S. by R.T. Primm III, ORNL/TM-13603/V2, March 1999.

[9] ANSI/ANS (American National Standards Institute/American Nuclear Society), 1984. Criticality Safety Criteria for Handling Storage, and Transportation of LWR Fuel Outside Reactors, ANSI/ANS-8.17, La Grange Park, IL.

[10] Lichtenwalter, J.J., S.M. Bowman, M.D. DeHart, and C.M. Hopper, 1997. Criticality Benchmark Guide for Light-Water-Reactor Fuel in Transportation and Storage Packages, NUREG/CR-6361 (ORNL/TM-13211), Lockheed Martin Energy Research Corp., Oak Ridge National Laboratory, Oak Ridge, TN.

[11] Dyer, H.R., W.C. Jordan, and V.R. Cain, 1991. A Technique for Code Validation for Criticality Safety Calculations, Trans. Am. Nucl. Soc. 63, 238 (June 1991).

[12] Easter, M.E., 1985. Validation of KENO V.a and Two Cross-Section Libraries for Criticality Calculations of Low-Enriched Uranium Systems, ORNL/CSD/TM-223, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., July 1985.

[13] Bowden D.C. and F.A. Graybill, 1966. Confidence Bands of Uniform and Proportional Width for Linear Models, Am. Stat. Assoc. J. 61, 182 (March 1966).

[14] Johnson, N.L.,1968. Ed., Query, Technometrics 10, 207-209 (February 1968).

[15] Cain, V.R., 1995. A Computer Code to Perform Analyses of Criticality Validation Results, Y/DD-574, Martin Marietta Energy Systems, Inc., Oak Ridge Y-12 Plant, September 1995.

[16] DCS01 ZJJ CG CAL H 06329 B Validation of SCALE 4.4 and SCALE 4.4a for Application to the MOX Fuel Fabrication Facility Using the 238 Group ENDF/B-V Cross Section Library Part II: AOA(3) PuO_2 powder, AOA(4): MOX powder.

[17] Validation of SCALE 4.4 and SCALE 4.4a for Application to the MOX Fuel Fabrication Facility Using the 238 Group ENDF/B-V Cross Section Library Part III: AOA(5) Aqueous solution of Pu compounds, Document in preparation.

[18] J.C. Dean, R.W. Tayloe, Jr., "Guide for Validation of Nuclear Criticality Safety Calculational Methodology," NUREG/CR-6698, Science Applications International Corporation, Oak Ridge, TN, January 2001.

[19] NRC Memorandum, L. Kopp to T. Collins, "Guidance on the regulatory requirements for criticality analysis of fuel storage at light-water reactor power plants," August, 1998.

[20] NRC Letter, A. Persinko to P.S. Hastings, "Nuclear Criticality Safety Staff Qualifications and Administrative Margins for Fuel Fabrication Facilities," 09 November 2001.

[21] Rutherford, D. A. "Forecast of Criticality Experiments and Experimental Programs Needed to Support Nuclear Operations in the United States of America: 1994-1999," LA-12683, Los Alamos National Laboratory, 1994.

ATTACHMENT NUMBER 1

CRITICALITY CALCULATION RESULTS FOR AOA(1)

ICSBEP Pu-Nitrate Solution Benchmarks

The ICSBEP Handbook [6] includes a number of experiments related to Pu-nitrate solutions. However, some of these experiments were determined to be inapplicable to MFFF design applications within AOA(1). The list below provides the reasoning for inclusion or exclusion of each candidate experiment.

PU-SOL-THERM-001: All cases are selected.

PU-SOL-THERM-002: All cases are selected.

PU-SOL-THERM-003: All cases are selected.

PU-SOL-THERM-004: All cases are selected.

PU-SOL-THERM-005: All cases are selected.

PU-SOL-THERM-006: All cases are selected.

PU-SOL-THERM-007: This benchmark is not selected because the experiment is very similar to the PU-SOL-THERM-001 benchmark experiment, except the spheres are only partly flooded. The partial flooding introduces an unnecessary geometric complexity.

PU-SOL-THERM-008: This experiment is selected, and is of interest due to the presence of concrete reflectors. Note that Case 6 is omitted since the benchmark evaluation recommends it not be used.

PU-SOL-THERM-009: This benchmark is not selected because the ICSBEP calculated k_{eff}-values are not in good agreement with the experimental k_{eff} (higher values) and the experiments do not add new relevant information (spherical geometry, ^{240}Pu ratio = 2.5 % ^{240}Pu).

PU-SOL-THERM-010: This benchmark is not selected because the ICSBEP calculated k_{eff} values are not in good agreement with the experimental k_{eff} and the experiments do not add relevant information (spherical geometry, reflected by natural uranium, ^{240}Pu ratio = 2.8 %).

PU-SOL-THERM-011: All cases are selected.

PU-SOL-THERM-012: This benchmark is not selected because the ^{240}Pu ratio is not in range (^{240}Pu ratio = 19%).

PU-SOL-THERM-013: This benchmark is not selected because the experiments do not add additional relevant information (Interacting cylinders, ^{240}Pu ratio = 4.23 %)

PU-SOL-THERM-014: All cases are selected.

PU-SOL-THERM-015: All cases are selected.

PU-SOL-THERM-016: All cases are selected.

PU-SOL-THERM-017: All cases are selected.

PU-SOL-THERM-020:	All cases except Case 4 are selected. The benchmark evaluation recommends against using Case 4: "this case is considered to be undesirable as a benchmark configuration, and is not accepted." [6, PU-SOL-THERM-020, p. 20]
PU-SOL-THERM-021:	This benchmark is not selected because the experiments do not add additional relevant information (spherical geometry, ^{240}Pu ratio = 4.57 % ^{240}Pu).
PU-SOL-THERM-022:	This benchmark is not selected because the ^{240}Pu ratio is not in range (^{240}Pu ratio = 19%).
PU-SOL-THERM-023:	Not considered for inclusion in this report due to excessive complexity in the geometric and material descriptions.
PU-SOL-THERM-024:	This benchmark is not selected because the ^{240}Pu ratio is not in range (^{240}Pu ratio = 18.4% to 23.2%).
PU-SOL-THERM-025:	Cases1 to 6 are selected (^{240}Pu = 4.67%).
PU-SOL-THERM-026:	Cases 1 to 3 are selected (^{240}Pu = 4.6%).

ATTACHMENT NUMBER 1A

AOA(1) CRITICALITY RESULTS ON SUN PLATFORM

(Sun calculation results)

Experiment	C(Pu) [g/l]	H/Pu	^{240}Pu [wt. %]	Exp. k_{eff}	Exp. uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF	GEN	NPG	NSK
PU-SOL-THERM-001											
Case 1	73.00	352.91	4.67	1.0000	0.005	1.0091	0.0011	8.79E-02	600	1500	13
Case 2	96.00	258.05	4.67	1.0000	0.005	1.0098	0.0010	1.11E-01	600	1500	15
Case 3	119.00	205.14	4.67	1.0000	0.005	1.0109	0.0011	1.35E-01	600	1500	21
Case 4	132.00	180.97	4.67	1.0000	0.005	1.0049	0.0011	1.51E-01	600	1500	20
Case 5	140.00	171.21	4.67	1.0000	0.005	1.0086	0.0010	1.59E-01	600	1500	20
Case 6	268.70	86.66	4.67	1.0000	0.005	1.0086	0.0011	3.48E-01	600	1500	22

PU-SOL-THERM-002											
Case 1	50.32	507.98	3.12	1.0000	0.0047	1.0082	0.0011	7.12E-02	600	1500	16
Case 2	51.80	489.18	3.12	1.0000	0.0047	1.0078	0.0011	7.29E-02	600	1500	19
Case 3	56.48	437.28	3.12	1.0000	0.0047	1.0073	0.0011	7.78E-02	600	1500	11
Case 4	60.14	407.45	3.12	1.0000	0.0047	1.0097	0.0011	8.15E-02	600	1500	14
Case 5	63.96	380.57	3.12	1.0000	0.0047	1.0127	0.0010	8.51E-02	600	1500	16
Case 6	70.22	333.54	3.12	1.0000	0.0047	1.0086	0.0011	9.29E-02	600	1500	85
Case 7	77.22	299.26	3.12	1.0000	0.0047	1.0109	0.0011	1.00E-01	600	1500	25

PU-SOL-THERM-003											
Case 1	33.62	774.15	1.76	1.0000	0.0047	1.0073	0.0009	5.84E-02	600	1500	12
Case 2	34.70	742.71	1.76	1.0000	0.0047	1.0070	0.0010	5.96E-02	600	1500	75
Case 3	38.05	677.17	3.12	1.0000	0.0047	1.0095	0.0009	6.18E-02	600	1500	25
Case 4	38.83	660.55	3.12	1.0000	0.0047	1.0092	0.0010	6.27E-02	600	1500	17
Case 5	40.90	607.17	3.12	1.0000	0.0047	1.0110	0.0010	6.54E-02	600	1500	22
Case 6	44.38	545.33	3.12	1.0000	0.0047	1.0103	0.0012	6.94E-02	600	1500	12
Case 7	36.27	714.83	3.12	1.0000	0.0047	1.0113	0.0011	5.91E-02	600	1500	11
Case 8	37.11	692.12	3.12	1.0000	0.0047	1.0086	0.0010	6.01E-02	600	1500	38

GEN : = Number of generations
NPG : = Number of neutrons per generation
NSK : = Number of generations skipped prior to collecting data

(Sun calculation results)

Experiment	**C(Pu) [g/l]**	**H/Pu**	**^{240}Pu [wt. %]**	**Exp. k_{eff}**	**Exp. uncertainty**	**CSAS26 238GROUP k_{eff}**	**σ**	**EALF**	**GEN**	**NPG**	**NSK**
PU-SOL-THERM-004											
Case 1	26.51	981.67	0.54	1.0000	0.0047	1.0090	0.0015	5.34E-02	610	800	46
Case 2	26.50	971.63	0.54	1.0000	0.0047	1.0019	0.0013	5.37E-02	610	800	25
Case 3	27.65	929.60	0.54	1.0000	0.0047	1.0073	0.0015	5.48E-02	610	800	27
Case 4	28.57	884.12	0.54	1.0000	0.0047	1.0043	0.0013	5.60E-02	610	800	56
Case 5	27.94	925.52	1.76	1.0000	0.0047	1.0025	0.0013	5.46E-02	610	800	31
Case 6	28.78	898.58	3.12	1.0000	0.0047	1.0044	0.0015	5.49E-02	610	800	21
Case 7	29.88	864.01	3.12	1.0000	0.0047	1.0103	0.0015	5.59E-02	610	800	19
Case 8	30.33	841.98	3.12	1.0000	0.0047	1.0069	0.0013	5.65E-02	610	800	23
Case 9	31.79	780.21	3.12	1.0000	0.0047	1.0038	0.0014	5.87E-02	610	800	10
Case 10	35.68	667.98	3.12	1.0000	0.0047	1.0049	0.0016	6.32E-02	610	800	47
Case 11	39.62	573.34	3.12	1.0000	0.0047	1.0059	0.0013	6.85E-02	610	800	13
Case 12	29.74	865.01	3.12	1.0000	0.0047	1.0070	0.0014	5.59E-02	610	800	19
Case 13	29.63	872.21	3.43	1.0000	0.0047	1.0056	0.0012	5.56E-02	610	800	18

PU-SOL-THERM-005											
Case 1	29.94	866.36	4.05	1.0000	0.0047	1.0062	0.0015	5.56E-02	610	800	13
Case 2	30.77	832.71	4.05	1.0000	0.0047	1.0070	0.0014	5.66E-02	610	800	21
Case 3	31.72	800.71	4.05	1.0000	0.0047	1.0092	0.0012	5.77E-02	610	800	17
Case 4	33.94	734.37	4.05	1.0000	0.0047	1.0097	0.0014	6.01E-02	610	800	13
Case 5	36.38	666.08	4.05	1.0000	0.0047	1.0114	0.0013	6.30E-02	610	800	21
Case 6	38.72	607.89	4.05	1.0000	0.0047	1.0099	0.0015	6.61E-02	610	800	17
Case 7	41.16	557.17	4.05	1.0000	0.0047	1.0066	0.0012	6.93E-02	610	800	55
Case 8	30.92	830.64	4.40	1.0000	0.0047	1.0037	0.0013	5.66E-02	610	800	19
Case 9	32.41	788.95	4.40	1.0000	0.0047	1.0044	0.0013	5.80E-02	610	800	11

PU-SOL-THERM-006											
Case 1	25.06	1028.16	3.12	1.0000	0.0035	1.0065	0.0008	5.24E-02	1500	1000	49
Case 2	25.83	986.18	3.12	1.0000	0.0035	1.0077	0.0008	5.34E-02	1500	1000	18
Case 3	27.05	910.90	3.12	1.0000	0.0035	1.0081	0.0008	5.52E-02	1500	1000	25

(Sun calculation results)

Experiment	C(Pu) [g/l]	H/Pu	^{240}Pu [wt. %]	Exp. k_{eff}	Exp. uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF	GEN	NPG	NSK
PU-SOL-THERM-008											
Case 1	35.5	683.88	4.67	1.0000	0.0033	1.0140	0.0010	6.48E-02	810	800	13
Case 2	45.2	495.93	4.67	1.0000	0.0040	1.0151	0.0012	7.85E-02	810	800	10
Case 3	46.4	488.55	4.67	1.0000	0.0040	1.0233	0.0010	7.94E-02	810	800	20
Case 4	46.9	486.15	4.67	1.0000	0.0040	1.0248	0.0011	8.02E-02	810	800	16
Case 5	32.8	782.40	4.67	1.0000	0.0028	1.0268	0.0012	6.03E-02	810	800	85
Case 7	29.6	867.10	4.67	1.0000	0.0028	1.0232	0.0012	5.71E-02	810	800	86
Case 8	50.9	454.50	4.67	1.0000	0.0040	1.0007	0.0012	8.73E-02	810	800	15
Case 9	232	85.03	4.67	1.0000	0.0061	1.0060	0.0012	5.51E-01	810	800	28
Case 10	43.4	521.45	4.67	1.0000	0.0037	1.0320	0.0011	7.52E-02	810	800	48
Case 11	36.6	650.83	4.67	1.0000	0.0031	1.0268	0.0011	6.62E-02	810	800	16
Case 12	67.9	344.02	4.67	1.0000	0.0041	1.0226	0.0013	9.94E-02	810	800	31
Case 13	50.4	499.92	4.67	1.0000	0.0041	1.0281	0.0013	7.68E-02	810	800	13
Case 14	75.0	328.02	4.67	1.0000	0.0042	1.0067	0.0013	1.08E-01	810	800	65
Case 15	46.4	538.18	4.67	1.0000	0.0041	1.0167	0.0012	7.46E-02	810	800	25
Case 16	36.5	673.07	4.67	1.0000	0.0033	1.0198	0.0013	6.53E-02	810	800	22
Case 17	46.4	488.55	4.67	1.0000	0.0040	1.0177	0.0011	7.95E-02	810	800	67
Case 18	46.9	486.15	4.67	1.0000	0.0040	1.0248	0.0012	8.01E-02	810	800	35
Case 19	32.9	776.81	4.67	1.0000	0.0028	1.0228	0.0012	6.05E-02	810	800	23
Case 20	30.0	856.60	4.67	1.0000	0.0028	1.0204	0.0011	5.74E-02	810	800	10
Case 21	50.9	462.99	4.67	1.0000	0.0040	1.0026	0.0013	8.60E-02	810	800	10
Case 22	232	88.43	4.67	1.0000	0.0061	0.9976	0.0015	5.20E-01	810	800	93
Case 23	44.8	496.98	4.67	1.0000	0.0037	1.0241	0.0011	7.73E-02	810	800	62
Case 24	36.8	639.34	4.67	1.0000	0.0031	1.0183	0.0012	6.68E-02	810	800	21
Case 25	67.8	344.02	4.67	1.0000	0.0042	1.0210	0.0011	9.96E-02	810	800	10
Case 26	52.1	474.90	4.67	1.0000	0.0041	1.0194	0.0014	7.93E-02	810	800	29
Case 27	106	232.01	4.67	1.0000	0.0042	1.0128	0.0014	1.47E-01	810	800	15
Case 28	81.7	301.12	4.67	1.0000	0.0042	1.0071	0.0014	1.16E-01	810	800	57
Case 29	52.4	475.39	4.67	1.0000	0.0041	1.0213	0.0014	8.03E-02	810	800	141
Case 30	47.0	531.21	4.67	1.0000	0.0041	1.0172	0.0013	7.50E-02	810	800	46

PU-SOL-THERM-011											
Case 1-16	35.0	733.00	4.17	1.0000	0.0052	1.0138	0.0013	0.0636	1003	1000	16
Case 1-18	22.4	1157.29	4.20	1.0000	0.0052	0.9993	0.0010	0.0520	1003	1000	76
Case 2-16	36.2	705.45	4.17	1.0000	0.0052	1.0201	0.0010	0.0647	1003	1000	9
Case 2-18	23.3	1103.19	4.20	1.0000	0.0052	1.0051	0.0009	0.0529	1003	1000	14
Case 3-16	38.1	662.77	4.17	1.0000	0.0052	1.0215	0.0010	0.0670	1003	1000	74
Case 3-18	23.1	1109.78	4.20	1.0000	0.0052	1.0007	0.0010	0.0529	1003	1000	69
Case 4-16	38.2	653.42	4.17	1.0000	0.0052	1.0157	0.0009	0.0678	1003	1000	36
Case 4-18	23.8	1053.74	4.20	1.0000	0.0052	0.9990	0.0009	0.0541	1003	1000	6
Case 5-16	43.4	550.66	4.17	1.0000	0.0052	1.0098	0.0010	0.0755	1003	1000	18
Case 5-18	25.2	995.41	4.20	1.0000	0.0052	1.0089	0.0010	0.0556	1003	1000	61
Case 6-18	27.5	870.37	4.20	1.0000	0.0052	1.0056	0.0009	0.0593	1003	1000	3
Case 7-18	23.9	1056.43	4.20	1.0000	0.0052	1.0045	0.0009	0.0540	1003	1000	13

(Sun calculation results)

Experiment	C(Pu) [g/l]	H/Pu	^{240}Pu [wt. %]	Exp. k_{eff}	Exp. Uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF	GEN	NPG	NSK
PU-SOL-THERM-014											
Case 1	115.10	210.18	4.23	0.9980	0.0032	1.0070	0.0010	1.68E-01	600	1800	15
Case 2	115.10	210.18	4.23	0.9980	0.0032	1.0059	0.0011	1.67E-01	600	1800	21
Case 3	115.10	210.18	4.23	0.9980	0.0032	1.0071	0.0011	1.67E-01	600	1800	65
Case 4	115.10	210.18	4.23	0.9980	0.0032	1.0066	0.0010	1.67E-01	600	1800	37
Case 5	115.10	210.18	4.23	0.9980	0.0032	1.0070	0.0011	1.67E-01	600	1800	12
Case 6	115.10	210.18	4.23	0.9980	0.0032	1.0057	0.0011	1.67E-01	600	1800	11
Case 7	115.10	210.18	4.23	0.9980	0.0032	1.0079	0.0012	1.68E-01	600	1800	42
Case 8	115.10	210.18	4.23	0.9980	0.0032	1.0061	0.0011	1.67E-01	600	1800	26
Case 9	115.10	210.18	4.23	0.9980	0.0032	1.0060	0.0009	1.68E-01	600	1800	10
Case 10	115.10	210.18	4.23	0.9980	0.0032	1.0071	0.0011	1.67E-01	600	1800	49
Case 11	115.10	210.18	4.23	0.9980	0.0032	1.0062	0.0011	1.67E-01	600	1800	44
Case 12	115.10	210.18	4.23	0.9980	0.0032	1.0083	0.0009	1.66E-01	600	1800	12
Case 13	115.10	210.18	4.23	0.9980	0.0043	1.0078	0.0010	1.69E-01	600	1800	12
Case 14	115.10	210.18	4.23	0.9980	0.0043	1.0068	0.0010	1.68E-01	600	1800	26
Case 15	115.10	210.18	4.23	0.9980	0.0043	1.0061	0.0010	1.67E-01	600	1800	16
Case 16	115.10	210.18	4.23	0.9980	0.0043	1.0062	0.0010	1.66E-01	600	1800	29
Case 17	115.10	210.18	4.23	0.9980	0.0043	1.0067	0.0012	1.67E-01	600	1800	25
Case 18	115.10	210.18	4.23	0.9980	0.0043	1.0082	0.0009	1.68E-01	600	1800	55
Case 19	115.10	210.18	4.23	0.9980	0.0043	1.0067	0.0010	1.68E-01	600	1800	24
Case 20	115.10	210.18	4.23	0.9980	0.0043	1.0058	0.0010	1.67E-01	600	1800	29
Case 21	115.10	210.18	4.23	0.9980	0.0043	1.0053	0.0010	1.67E-01	600	1800	25
Case 22	115.10	210.18	4.23	0.9980	0.0043	1.0049	0.0011	1.67E-01	600	1800	60
Case 23	115.10	210.18	4.23	0.9980	0.0043	1.0056	0.0011	1.67E-01	600	1800	17
Case 24	115.10	210.18	4.23	0.9980	0.0043	1.0082	0.0012	1.68E-01	600	1800	17
Case 25	115.10	210.18	4.23	0.9980	0.0043	1.0042	0.0011	1.68E-01	600	1800	25
Case 26	115.10	210.18	4.23	0.9980	0.0043	1.0033	0.0011	1.67E-01	600	1800	40
Case 27	115.10	210.18	4.23	0.9980	0.0043	1.0057	0.0010	1.67E-01	600	1800	10
Case 28	115.10	210.18	4.23	0.9980	0.0043	1.0056	0.0010	1.67E-01	600	1800	27
Case 29	115.10	210.18	4.23	0.9980	0.0043	1.0062	0.0012	1.67E-01	600	1800	22
Case 30	115.10	210.18	4.23	0.9980	0.0043	1.0057	0.0010	1.69E-01	1300	1000	16
Case 31	115.10	210.18	4.23	0.9980	0.0043	1.0027	0.0010	1.68E-01	1300	1000	30
Case 32	115.10	210.18	4.23	0.9980	0.0043	1.0048	0.0010	1.68E-01	1300	1000	40
Case 33	115.10	210.18	4.23	0.9980	0.0043	1.0036	0.0011	1.68E-01	1300	1000	23
Case 34	115.10	210.18	4.23	0.9980	0.0043	1.0043	0.0009	1.67E-01	1300	1000	40
Case 35	115.10	210.18	4.23	0.9980	0.0043	1.0042	0.0010	1.67E-01	1303	1000	15

(Sun calculation results)

Experiment	C(Pu) [g/l]	H/Pu	^{240}Pu [wt. %]	Exp. k_{eff}	Exp. uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF	GEN	NPG	NSK
PU-SOL-THERM-015											
Case 1	152.50	155.21	4.23	0.9980	0.0038	1.0099	0.0010	2.37E-01	600	1800	18
Case 2	152.50	155.27	4.23	0.9980	0.0038	1.0087	0.0010	2.37E-01	600	1800	17
Case 3	152.50	155.27	4.23	0.9980	0.0038	1.0076	0.0010	2.36E-01	600	1800	10
Case 4	152.50	155.27	4.23	0.9980	0.0038	1.0070	0.0012	2.36E-01	600	1800	23
Case 5	152.50	155.27	4.23	0.9980	0.0038	1.0077	0.0010	2.36E-01	600	1800	19
Case 6	152.50	155.27	4.23	0.9980	0.0038	1.0062	0.0011	2.36E-01	600	1800	18
Case 7	152.50	155.27	4.23	0.9971	0.0047	1.0097	0.0010	2.38E-01	600	1800	16
Case 8	152.50	155.27	4.23	0.9971	0.0047	1.0044	0.0011	2.38E-01	600	1800	10
Case 9	152.50	155.27	4.23	0.9971	0.0047	1.0078	0.0010	2.36E-01	600	1800	13
Case 10	152.50	155.27	4.23	0.9971	0.0047	1.0069	0.0011	2.36E-01	600	1800	128
Case 11	152.50	155.27	4.23	0.9971	0.0047	1.0034	0.0012	2.38E-01	600	1800	11
Case 12	152.50	155.27	4.23	0.9971	0.0047	1.0018	0.0011	2.38E-01	600	1800	21
Case 13	152.50	155.27	4.23	0.9971	0.0047	1.0062	0.0010	2.37E-01	600	1800	11
Case 14	152.50	155.27	4.23	0.9971	0.0047	1.0079	0.0011	2.35E-01	600	1800	49
Case 15	152.50	155.27	4.23	0.9971	0.0047	1.0078	0.0010	2.38E-01	600	1800	22
Case 16	152.50	155.27	4.23	0.9971	0.0047	1.0056	0.0011	2.38E-01	600	1800	35
Case 17	152.50	155.27	4.23	0.9971	0.0047	1.0062	0.0013	2.37E-01	600	1800	18

PU-SOL-THERM-016											
Case 1	152.50	155.27	4.23	0.9980	0.0043	1.0054	0.0011	2.38E-01	1000	1000	11
Case 2	152.50	155.27	4.23	0.9980	0.0043	1.0077	0.0010	2.37E-01	1000	1000	10
Case 3	152.50	155.27	4.23	0.9980	0.0043	1.0073	0.0012	2.36E-01	1000	1000	17
Case 4	152.50	155.27	4.23	0.9980	0.0043	1.0077	0.0011	2.37E-01	1000	1000	75
Case 5	115.10	210.18	4.23	0.9969	0.0038	1.0056	0.0012	1.68E-01	1000	1000	23
Case 6	115.10	210.17	4.23	0.9969	0.0038	1.0056	0.0012	1.67E-01	1000	1000	18
Case 7	115.10	210.17	4.23	0.9969	0.0038	1.0078	0.0011	1.67E-01	1000	1000	41
Case 8	115.10	210.17	4.23	0.9969	0.0038	1.0072	0.0010	1.67E-01	1000	1000	10
Case 9	115.10	210.17	4.23	0.9963	0.0033	1.0055	0.0012	1.65E-01	1000	1000	68
Case 10	115.10	210.17	4.23	0.9963	0.0033	1.0056	0.0012	1.66E-01	1000	1000	32
Case 11	115.10	210.17	4.23	0.9963	0.0033	1.0064	0.0012	1.67E-01	1000	1000	33

(Sun calculation results)

Experiment	C(Pu) [g/l]	H/Pu	^{240}Pu [wt. %]	Exp. k_{eff}	Exp. uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF	GEN	NPG	NSK
PU-SOL-THERM-017											
Case 1	115.10	210.18	4.23	0.9969	0.0038	1.0052	0.0011	1.67E-01	1000	1000	14
Case 2	115.10	210.18	4.23	0.9969	0.0038	1.0063	0.0012	1.67E-01	1000	1000	11
Case 3	115.10	210.18	4.23	0.9969	0.0038	1.0045	0.0012	1.67E-01	1000	1000	21
Case 4	115.10	210.18	4.23	0.9969	0.0038	1.0058	0.0011	1.67E-01	1000	1000	10
Case 5	115.10	210.18	4.23	0.9969	0.0038	1.0058	0.0010	1.67E-01	1000	1000	47
Case 6	115.10	210.18	4.23	0.9969	0.0038	1.0051	0.0011	1.67E-01	1000	1000	27
Case 7	115.10	210.18	4.23	0.9969	0.0038	1.0057	0.0012	1.67E-01	1000	1000	43
Case 8	115.10	210.18	4.23	0.9969	0.0038	1.0072	0.0011	1.67E-01	1000	1000	31
Case 9	115.10	210.18	4.23	0.9969	0.0038	1.0065	0.0011	1.67E-01	1000	1000	13
Case 10	115.10	210.18	4.23	0.9969	0.0038	1.0077	0.0013	1.67E-01	1000	1000	17
Case 11	115.10	210.18	4.23	0.9969	0.0038	1.0045	0.0010	1.67E-01	1000	1000	11
Case 12	115.10	210.18	4.23	0.9969	0.0038	1.0064	0.0011	1.67E-01	1000	1000	22
Case 13	115.10	210.18	4.23	0.9969	0.0038	1.0052	0.0011	1.67E-01	1000	1000	35
Case 14	115.10	210.18	4.23	0.9969	0.0038	1.0087	0.0012	1.67E-01	1000	1000	17
Case 15	115.10	210.18	4.23	0.9969	0.0038	1.0054	0.0012	1.67E-01	1000	1000	33
Case 16	115.10	210.18	4.23	0.9969	0.0038	1.0081	0.0011	1.67E-01	1000	1000	20
Case 17	115.10	210.18	4.23	0.9969	0.0038	1.0037	0.0011	1.67E-01	1000	1000	34
Case 18	115.10	210.18	4.23	0.9969	0.0038	1.0053	0.0011	1.67E-01	1000	1000	104
PU-SOL-THERM-020											
Case 1	39.20	603.57	4.67	1.0000	0.0059	1.0088	0.0012	6.57E-02	610	800	15
Case 2	38.40	621.12	4.67	1.0000	0.0059	1.0113	0.0015	6.47E-02	610	800	13
Case 3	33.50	747.18	4.67	1.0000	0.0059	1.0059	0.0012	5.89E-02	610	800	10
Case 5	47.90	462.51	4.67	1.0000	0.0059	1.0060	0.0014	7.63E-02	610	800	11
Case 6	49.50	451.85	4.67	1.0000	0.0059	1.0063	0.0013	7.93E-02	610	800	15
Case 7	34.40	723.85	4.67	1.0000	0.0059	1.0021	0.0013	6.04E-02	610	800	12
Case 8	69.40	342.96	4.67	1.0000	0.0059	1.0096	0.0014	1.06E-01	610	800	76
Case 9	46.90	540.11	4.67	1.0000	0.0059	1.0024	0.0013	7.58E-02	610	800	12
Case 10	38.60	617.24	4.67	1.0000	0.0059	1.0100	0.0015	6.48E-02	610	800	10
Case 11	33.20	753.99	4.67	1.0000	0.0059	1.0078	0.0012	5.85E-02	610	800	10
Case 12	47.50	465.80	4.67	1.0000	0.0059	1.0065	0.0014	7.59E-02	610	800	55
Case 13	49.50	451.85	4.67	1.0000	0.0059	1.0055	0.0013	7.92E-02	610	800	29
Case 14	46.90	540.11	4.67	1.0000	0.0059	1.0005	0.0014	7.60E-02	610	800	11
Case 15	69.00	341.17	4.67	1.0000	0.0059	1.0004	0.0015	1.07E-01	610	800	11

(Sun calculation results)

Experiment	C(Pu) [g/l]	H/Pu	^{240}Pu [wt. %]	Exp. k_{eff}	Exp. uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF	GEN	NPG	NSK
PU-SOL-THERM-025											
Case 1	58	424.34	4.671	1.0000	0.0039	1.0150	0.0004	7.87E-02	1503	1000	107
Case 2	58	424.34	4.671	1.0000	0.0039	1.0155	0.0004	7.88E-02	1503	1000	11
Case 3	58	424.34	4.671	1.0000	0.0039	1.0160	0.0004	7.91E-02	1503	1000	40
Case 4	58	424.34	4.671	1.0000	0.0039	1.0161	0.0005	7.97E-02	1503	1000	21
Case 5	58	424.34	4.671	1.0000	0.0039	1.0121	0.0004	8.02E-02	1503	1000	39
Case 6	58	424.34	4.671	1.0000	0.0039	1.0097	0.0004	8.05E-02	1503	1000	75

PU-SOL-THERM-026											
Case 1	57.3	430.26	4.67	1.0000	0.0052	0.9996	0.0005	8.82E-02	1503	1000	56
Case 2	57.7	425.56	4.67	1.0000	0.0052	0.9974	0.0005	8.89E-02	1503	1000	123
Case 3	57.7	425.27	4.67	1.0000	0.0051	0.9968	0.0004	8.90E-02	1503	1000	50

ATTACHMENT NUMBER 1B

AOA(1) CRITICALITY RESULTS ON PC PLATFORM

(PC calculation results)

Experiment	C(Pu) [g/l]	H/Pu	^{240}Pu [wt. %]	Exp. k_{eff}	Exp. uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF [eV]	GEN	NPG	NSK
PU-SOL-THERM-001											
Case 1	73.00	352.91	4.67	1.0000	0.005	1.0091	0.0012	8.80E-02	1503	1000	7
Case 2	96.00	258.05	4.67	1.0000	0.005	1.0097	0.0008	1.11E-01	1503	1000	23
Case 3	119.00	205.14	4.67	1.0000	0.005	1.0115	0.0008	1.35E-01	1503	1000	17
Case 4	132.00	180.97	4.67	1.0000	0.005	1.0059	0.0008	1.51E-01	1503	1000	48
Case 5	140.00	171.21	4.67	1.0000	0.005	1.0092	0.0008	1.60E-01	1503	1000	42
Case 6	268.70	86.66	4.67	1.0000	0.005	1.0087	0.0008	3.47E-01	1503	1000	61
PU-SOL-THERM-002											
Case 1	50.32	507.98	3.12	1.0000	0.0047	1.0077	0.0008	7.12E-02	1503	1000	19
Case 2	51.80	489.18	3.12	1.0000	0.0047	1.0077	0.0008	7.29E-02	1503	1000	26
Case 3	56.48	437.28	3.12	1.0000	0.0047	1.0083	0.0007	7.79E-02	1503	1000	17
Case 4	60.14	407.45	3.12	1.0000	0.0047	1.0100	0.0009	8.14E-02	1503	1000	6
Case 5	63.96	380.57	3.12	1.0000	0.0047	1.0115	0.0008	8.51E-02	1503	1000	39
Case 6	70.22	333.54	3.12	1.0000	0.0047	1.0082	0.0008	9.29E-02	1503	1000	25
Case 7	77.22	299.26	3.12	1.0000	0.0047	1.0103	0.0008	1.00E-01	1503	1000	10
PU-SOL-THERM-003											
Case 1	33.62	774.15	1.76	1.0000	0.0047	1.0062	0.0008	5.84E-02	1503	1000	9
Case 2	34.70	742.71	1.76	1.0000	0.0047	1.0068	0.0008	5.96E-02	1503	1000	13
Case 3	38.05	677.17	3.12	1.0000	0.0047	1.0078	0.0008	6.19E-02	1503	1000	8
Case 4	38.83	660.55	3.12	1.0000	0.0047	1.0092	0.0007	6.27E-02	1503	1000	11
Case 5	40.90	607.17	3.12	1.0000	0.0047	1.0100	0.0008	6.54E-02	1503	1000	14
Case 6	44.38	545.33	3.12	1.0000	0.0047	1.0099	0.0009	6.94E-02	1503	1000	44
Case 7	36.27	714.83	3.12	1.0000	0.0047	1.0106	0.0008	5.92E-02	1503	1000	7
Case 8	37.11	692.12	3.12	1.0000	0.0047	1.0100	0.0007	6.01E-02	1503	1000	20

GEN : = Number of generations
NPG : = Number of neutrons per generation
NSK : = Number of generations skipped prior to collecting data

(PC calculation results)

Experiment	C(Pu) [g/l]	H/Pu	^{240}Pu [wt. %]	Exp. k_{eff}	Exp. uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF [eV]	GEN	NPG	NSK
PU-SOL-THERM-004											
Case 1	26.51	981.67	0.54	1.0000	0.0047	1.0063	0.0008	5.34E-02	1503	1000	209
Case 2	26.50	971.63	0.54	1.0000	0.0047	1.0036	0.0007	5.37E-02	1503	1000	21
Case 3	27.65	929.60	0.54	1.0000	0.0047	1.0061	0.0007	5.47E-02	1503	1000	4
Case 4	28.57	884.12	0.54	1.0000	0.0047	1.0038	0.0007	5.60E-02	1503	1000	25
Case 5	27.94	925.52	1.76	1.0000	0.0047	1.0045	0.0007	5.45E-02	1503	1000	24
Case 6	28.78	898.58	3.12	1.0000	0.0047	1.0065	0.0008	5.49E-02	1503	1000	14
Case 7	29.88	864.01	3.12	1.0000	0.0047	1.0108	0.0008	5.58E-02	1503	1000	47
Case 8	30.33	841.98	3.12	1.0000	0.0047	1.0070	0.0007	5.65E-02	1503	1000	21
Case 9	31.79	780.21	3.12	1.0000	0.0047	1.0046	0.0007	5.86E-02	1503	1000	4
Case 10	35.68	667.98	3.12	1.0000	0.0047	1.0066	0.0008	6.32E-02	1503	1000	8
Case 11	39.62	573.34	3.12	1.0000	0.0047	1.0040	0.0007	6.86E-02	1503	1000	3
Case 12	29.74	865.01	3.12	1.0000	0.0047	1.0077	0.0007	5.59E-02	1503	1000	10
Case 13	29.63	872.21	3.43	1.0000	0.0047	1.0059	0.0007	5.56E-02	1503	1000	3
PU-SOL-THERM-005											
Case 1	29.94	866.36	4.05	1.0000	0.0047	1.0085	0.0007	5.55E-02	1503	1000	4
Case 2	30.77	832.71	4.05	1.0000	0.0047	1.0074	0.0007	5.66E-02	1503	1000	12
Case 3	31.72	800.71	4.05	1.0000	0.0047	1.0078	0.0008	5.76E-02	1503	1000	39
Case 4	33.94	734.37	4.05	1.0000	0.0047	1.0106	0.0008	6.00E-02	1503	1000	8
Case 5	36.38	666.08	4.05	1.0000	0.0047	1.0101	0.0007	6.29E-02	1503	1000	5
Case 6	38.72	607.89	4.05	1.0000	0.0047	1.0104	0.0007	6.60E-02	1503	1000	7
Case 7	41.16	557.17	4.05	1.0000	0.0047	1.0083	0.0009	6.92E-02	1503	1000	16
Case 8	30.92	830.64	4.40	1.0000	0.0047	1.0051	0.0007	5.67E-02	1503	1000	18
Case 9	32.41	788.95	4.40	1.0000	0.0047	1.0070	0.0007	5.79E-02	1503	1000	38
PU-SOL-THERM-006											
Case 1	25.06	1028.16	3.12	1.0000	0.0035	1.0050	0.0008	5.25E-02	1503	1000	10
Case 2	25.83	986.18	3.12	1.0000	0.0035	1.0062	0.0007	5.33E-02	1503	1000	30
Case 3	27.05	910.90	3.12	1.0000	0.0035	1.0063	0.0007	5.52E-02	1503	1000	3

(PC calculation results)

Experiment	C(Pu) [g/l]	H/Pu	^{240}Pu [wt. %]	Exp. k_{eff}	Exp. uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF [eV]	GEN	NPG	NSK
PU-SOL-THERM-008											
Case 1	35.5	683.88	4.67	1.0000	0.0033	1.0137	0.0008	6.49E-02	1503	1000	17
Case 2	45.2	495.93	4.67	1.0000	0.0040	1.0159	0.0008	7.84E-02	1503	1000	14
Case 3	46.4	488.55	4.67	1.0000	0.0040	1.0227	0.0008	7.95E-02	1503	1000	28
Case 4	46.9	486.15	4.67	1.0000	0.0040	1.0274	0.0007	8.01E-02	1503	1000	14
Case 5	32.8	782.40	4.67	1.0000	0.0028	1.0282	0.0007	6.02E-02	1503	1000	58
Case 7	29.6	867.10	4.67	1.0000	0.0028	1.0220	0.0007	5.72E-02	1503	1000	24
Case 8	50.9	454.50	4.67	1.0000	0.0040	1.0014	0.0008	8.73E-02	1503	1000	18
Case 9	232	85.03	4.67	1.0000	0.0061	1.0071	0.0008	5.49E-01	1503	1000	24
Case 10	43.4	521.45	4.67	1.0000	0.0037	1.0317	0.0007	7.52E-02	1503	1000	6
Case 11	36.6	650.83	4.67	1.0000	0.0031	1.0264	0.0007	6.62E-02	1503	1000	18
Case 12	67.9	344.02	4.67	1.0000	0.0041	1.0219	0.0009	9.97E-02	1503	1000	5
Case 13	50.4	499.92	4.67	1.0000	0.0041	1.0275	0.0008	7.67E-02	1503	1000	29
Case 14	75.0	328.02	4.67	1.0000	0.0042	1.0074	0.0008	1.07E-01	1503	1000	4
Case 15	46.4	538.18	4.67	1.0000	0.0041	1.0172	0.0008	7.44E-02	1503	1000	3
Case 16	36.5	673.07	4.67	1.0000	0.0033	1.0207	0.0008	6.53E-02	1503	1000	65
Case 17	46.4	488.55	4.67	1.0000	0.0040	1.0176	0.0008	7.95E-02	1503	1000	3
Case 18	46.9	486.15	4.67	1.0000	0.0040	1.0247	0.0007	8.02E-02	1503	1000	7
Case 19	32.9	776.81	4.67	1.0000	0.0028	1.0200	0.0007	6.05E-02	1503	1000	38
Case 20	30.0	856.60	4.67	1.0000	0.0028	1.0195	0.0008	5.75E-02	1503	1000	31
Case 21	50.9	462.99	4.67	1.0000	0.0040	1.0022	0.0008	8.60E-02	1503	1000	10
Case 22	232	88.43	4.67	1.0000	0.0061	0.9948	0.0008	5.20E-01	1503	1000	10
Case 23	44.8	496.98	4.67	1.0000	0.0037	1.0246	0.0008	7.72E-02	1503	1000	12
Case 24	36.8	639.34	4.67	1.0000	0.0031	1.0187	0.0007	6.68E-02	1503	1000	12
Case 25	67.8	344.02	4.67	1.0000	0.0042	1.0208	0.0008	9.94E-02	1503	1000	3
Case 26	52.1	474.90	4.67	1.0000	0.0041	1.0204	0.0008	7.92E-02	1503	1000	81
Case 27	106	232.01	4.67	1.0000	0.0042	1.0129	0.0009	1.47E-01	1503	1000	16
Case 28	81.7	301.12	4.67	1.0000	0.0042	1.0062	0.0008	1.15E-01	1503	1000	3
Case 29	52.4	475.39	4.67	1.0000	0.0041	1.0208	0.0009	8.03E-02	1503	1000	6
Case 30	47.0	531.21	4.67	1.0000	0.0041	1.0180	0.0008	7.50E-02	1503	1000	3

PU-SOL-THERM-011											
Case 1-16	35.0	733.00	4.17	1.0000	0.0052	1.0155	0.0008	6.34E-02	1503	1000	21
Case 1-18	22.4	1157.29	4.2	1.0000	0.0052	0.9998	0.0007	5.20E-02	1503	1000	12
Case 2-16	36.2	705.45	4.17	1.0000	0.0052	1.0209	0.0008	6.47E-02	1503	1000	49
Case 2-18	23.3	1103.19	4.2	1.0000	0.0052	1.0055	0.0008	5.30E-02	1503	1000	102
Case 3-16	38.1	662.77	4.17	1.0000	0.0052	1.0207	0.0008	6.72E-02	1503	1000	13
Case 3-18	23.1	1109.78	4.2	1.0000	0.0052	1.0023	0.0007	5.29E-02	1503	1000	7
Case 4-16	38.2	653.42	4.17	1.0000	0.0052	1.0132	0.0009	6.79E-02	1503	1000	93
Case 4-18	23.8	1053.74	4.2	1.0000	0.0052	0.9994	0.0008	5.41E-02	1503	1000	5
Case 5-16	43.4	550.66	4.17	1.0000	0.0052	1.0102	0.0008	7.54E-02	1503	1000	11
Case 5-18	25.2	995.41	4.2	1.0000	0.0052	1.0105	0.0008	5.56E-02	1503	1000	36
Case 6-18	27.5	870.37	4.2	1.0000	0.0052	1.0064	0.0008	5.93E-02	1503	1000	3
Case 7-18	23.9	1056.43	4.2	1.0000	0.0052	1.0063	0.0008	5.40E-02	1503	1000	32

(PC calculation results)

Experiment	C(Pu) [g/l]	H/Pu	^{240}Pu [wt. %]	Exp. k_{eff}	Exp. uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF [eV]	GEN	NPG	NSK
PU-SOL-THERM-014											
Case 1	115.10	210.18	4.23	0.9980	0.0032	1.0071	0.0008	1.68E-01	1503	1000	31
Case 2	115.10	210.18	4.23	0.9980	0.0032	1.0059	0.0009	1.67E-01	1503	1000	28
Case 3	115.10	210.18	4.23	0.9980	0.0032	1.0080	0.0009	1.67E-01	1503	1000	11
Case 4	115.10	210.18	4.23	0.9980	0.0032	1.0060	0.0008	1.67E-01	1503	1000	22
Case 5	115.10	210.18	4.23	0.9980	0.0032	1.0074	0.0009	1.67E-01	1503	1000	35
Case 6	115.10	210.18	4.23	0.9980	0.0032	1.0060	0.0009	1.67E-01	1503	1000	4
Case 7	115.10	210.18	4.23	0.9980	0.0032	1.0059	0.0009	1.68E-01	1503	1000	29
Case 8	115.10	210.18	4.23	0.9980	0.0032	1.0055	0.0008	1.68E-01	1503	1000	23
Case 9	115.10	210.18	4.23	0.9980	0.0032	1.0052	0.0008	1.67E-01	1503	1000	9
Case 10	115.10	210.18	4.23	0.9980	0.0032	1.0038	0.0009	1.67E-01	1503	1000	9
Case 11	115.10	210.18	4.23	0.9980	0.0032	1.0053	0.0008	1.67E-01	1503	1000	7
Case 12	115.10	210.18	4.23	0.9980	0.0032	1.0070	0.0009	1.67E-01	1503	1000	58
Case 13	115.10	210.18	4.23	0.9980	0.0043	1.0077	0.0008	1.68E-01	1503	1000	3
Case 14	115.10	210.18	4.23	0.9980	0.0043	1.0043	0.0009	1.68E-01	1503	1000	99
Case 15	115.10	210.18	4.23	0.9980	0.0043	1.0070	0.0008	1.67E-01	1503	1000	10
Case 16	115.10	210.18	4.23	0.9980	0.0043	1.0057	0.0009	1.67E-01	1503	1000	7
Case 17	115.10	210.18	4.23	0.9980	0.0043	1.0055	0.0009	1.67E-01	1503	1000	5
Case 18	115.10	210.18	4.23	0.9980	0.0043	1.0080	0.0009	1.68E-01	1503	1000	7
Case 19	115.10	210.18	4.23	0.9980	0.0043	1.0049	0.0010	1.68E-01	1503	1000	9
Case 20	115.10	210.18	4.23	0.9980	0.0043	1.0068	0.0009	1.67E-01	1503	1000	114
Case 21	115.10	210.18	4.23	0.9980	0.0043	1.0063	0.0008	1.67E-01	1503	1000	22
Case 22	115.10	210.18	4.23	0.9980	0.0043	1.0060	0.0009	1.67E-01	1503	1000	4
Case 23	115.10	210.18	4.23	0.9980	0.0043	1.0053	0.0009	1.67E-01	1503	1000	28
Case 24	115.10	210.18	4.23	0.9980	0.0043	1.0082	0.0008	1.69E-01	1503	1000	36
Case 25	115.10	210.18	4.23	0.9980	0.0043	1.0042	0.0009	1.68E-01	1503	1000	65
Case 26	115.10	210.18	4.23	0.9980	0.0043	1.0068	0.0009	1.67E-01	1503	1000	20
Case 27	115.10	210.18	4.23	0.9980	0.0043	1.0059	0.0009	1.67E-01	1503	1000	70
Case 28	115.10	210.18	4.23	0.9980	0.0043	1.0053	0.0009	1.67E-01	1503	1000	15
Case 29	115.10	210.18	4.23	0.9980	0.0043	1.0057	0.0009	1.67E-01	1503	1000	5
Case 30	115.10	210.18	4.23	0.9980	0.0043	1.0051	0.0008	1.68E-01	1503	1000	32
Case 31	115.10	210.18	4.23	0.9980	0.0043	1.0039	0.0009	1.68E-01	1503	1000	5
Case 32	115.10	210.18	4.23	0.9980	0.0043	1.0045	0.0009	1.68E-01	1503	1000	23
Case 33	115.10	210.18	4.23	0.9980	0.0043	1.0063	0.0008	1.67E-01	1503	1000	10
Case 34	115.10	210.18	4.23	0.9980	0.0043	1.0043	0.0010	1.68E-01	1503	1000	44
Case 35	115.10	210.18	4.23	0.9980	0.0043	1.0050	0.0010	1.67E-01	1503	1000	12

(PC calculation results)

Experiment	C(Pu) [g/l]	H/Pu	^{240}Pu [wt. %]	Exp. k_{eff}	Exp. uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF [eV]	GEN	NPG	NSK
PU-SOL-THERM-015											
Case 1	152.50	155.21	4.23	0.9980	0.0038	1.0073	0.0009	2.38E-01	1503	1000	61
Case 2	152.50	155.27	4.23	0.9980	0.0038	1.0080	0.0008	2.37E-01	1503	1000	5
Case 3	152.50	155.27	4.23	0.9980	0.0038	1.0059	0.0009	2.37E-01	1503	1000	3
Case 4	152.50	155.27	4.23	0.9980	0.0038	1.0063	0.0009	2.37E-01	1503	1000	38
Case 5	152.50	155.27	4.23	0.9980	0.0038	1.0047	0.0009	2.37E-01	1503	1000	231
Case 6	152.50	155.27	4.23	0.9980	0.0038	1.0073	0.0008	2.36E-01	1503	1000	40
Case 7	152.50	155.27	4.23	0.9971	0.0047	1.0075	0.0009	2.38E-01	1503	1000	71
Case 8	152.50	155.27	4.23	0.9971	0.0047	1.0070	0.0009	2.37E-01	1503	1000	19
Case 9	152.50	155.27	4.23	0.9971	0.0047	1.0068	0.0008	2.37E-01	1503	1000	15
Case 10	152.50	155.27	4.23	0.9971	0.0047	1.0055	0.0009	2.36E-01	1503	1000	6
Case 11	152.50	155.27	4.23	0.9971	0.0047	1.0040	0.0009	2.38E-01	1503	1000	150
Case 12	152.50	155.27	4.23	0.9971	0.0047	1.0036	0.0008	2.38E-01	1503	1000	4
Case 13	152.50	155.27	4.23	0.9971	0.0047	1.0060	0.0009	2.37E-01	1503	1000	6
Case 14	152.50	155.27	4.23	0.9971	0.0047	1.0067	0.0009	2.36E-01	1503	1000	19
Case 15	152.50	155.27	4.23	0.9971	0.0047	1.0071	0.0008	2.39E-01	1503	1000	22
Case 16	152.50	155.27	4.23	0.9971	0.0047	1.0053	0.0009	2.38E-01	1503	1000	53
Case 17	152.50	155.27	4.23	0.9971	0.0047	1.0062	0.0009	2.37E-01	1503	1000	4

PU-SOL-THERM-016											
Case 1	152.50	155.27	4.23	0.9980	0.0043	1.0061	0.0009	2.37E-01	1503	1000	3
Case 2	152.50	155.27	4.23	0.9980	0.0043	1.0053	0.0009	2.37E-01	1503	1000	14
Case 3	152.50	155.27	4.23	0.9980	0.0043	1.0071	0.0009	2.37E-01	1503	1000	10
Case 4	152.50	155.27	4.23	0.9980	0.0043	1.0068	0.0009	2.36E-01	1503	1000	16
Case 5	115.10	210.18	4.23	0.9969	0.0038	1.0043	0.0009	1.68E-01	1503	1000	11
Case 6	115.10	210.17	4.23	0.9969	0.0038	1.0044	0.0009	1.67E-01	1503	1000	6
Case 7	115.10	210.17	4.23	0.9969	0.0038	1.0070	0.0009	1.67E-01	1503	1000	13
Case 8	115.10	210.17	4.23	0.9969	0.0038	1.0077	0.0009	1.67E-01	1503	1000	35
Case 9	115.10	210.17	4.23	0.9963	0.0033	1.0059	0.0009	1.66E-01	1503	1000	34
Case 10	115.10	210.17	4.23	0.9963	0.0033	1.0050	0.0010	1.66E-01	1503	1000	6
Case 11	115.10	210.17	4.23	0.9963	0.0033	1.0064	0.0009	1.67E-01	1503	1000	10

(PC calculation results)

Experiment	**C(Pu) [g/l]**	**H/Pu**	**^{240}Pu [wt. %]**	**Exp. k_{eff}**	**Exp. uncertainty**	**CSAS26 238GROUP k_{eff}**	**σ**	**EALF [eV]**	**GEN**	**NPG**	**NSK**
PU-SOL-THERM-017											
Case 1	115.10	210.18	4.23	0.9969	0.0038	1.0042	0.0009	1.67E-01	1503	1000	72
Case 2	115.10	210.18	4.23	0.9969	0.0038	1.0057	0.0009	1.67E-01	1503	1000	12
Case 3	115.10	210.18	4.23	0.9969	0.0038	1.0052	0.0009	1.67E-01	1503	1000	27
Case 4	115.10	210.18	4.23	0.9969	0.0038	1.0049	0.0008	1.67E-01	1503	1000	20
Case 5	115.10	210.18	4.23	0.9969	0.0038	1.0062	0.0009	1.67E-01	1503	1000	15
Case 6	115.10	210.18	4.23	0.9969	0.0038	1.0056	0.0009	1.67E-01	1503	1000	8
Case 7	115.10	210.18	4.23	0.9969	0.0038	1.0038	0.0010	1.67E-01	1503	1000	86
Case 8	115.10	210.18	4.23	0.9969	0.0038	1.0052	0.0010	1.67E-01	1503	1000	25
Case 9	115.10	210.18	4.23	0.9969	0.0038	1.0059	0.0010	1.67E-01	1503	1000	17
Case 10	115.10	210.18	4.23	0.9969	0.0038	1.0047	0.0009	1.68E-01	1503	1000	20
Case 11	115.10	210.18	4.23	0.9969	0.0038	1.0058	0.0009	1.67E-01	1503	1000	36
Case 12	115.10	210.18	4.23	0.9969	0.0038	1.0056	0.0010	1.67E-01	1503	1000	25
Case 13	115.10	210.18	4.23	0.9969	0.0038	1.0060	0.0009	1.67E-01	1503	1000	17
Case 14	115.10	210.18	4.23	0.9969	0.0038	1.0061	0.0009	1.67E-01	1503	1000	71
Case 15	115.10	210.18	4.23	0.9969	0.0038	1.0071	0.0008	1.67E-01	1503	1000	61
Case 16	115.10	210.18	4.23	0.9969	0.0038	1.0070	0.0009	1.67E-01	1503	1000	52
Case 17	115.10	210.18	4.23	0.9969	0.0038	1.0057	0.0009	1.67E-01	1503	1000	39
Case 18	115.10	210.18	4.23	0.9969	0.0038	1.0064	0.0009	1.67E-01	1503	1000	14

PU-SOL-THERM-020											
Case 1	39.20	603.57	4.67	1.0000	0.0059	1.0080	0.0008	6.56E-02	1503	1000	21
Case 2	38.40	621.12	4.67	1.0000	0.0059	1.0104	0.0007	6.47E-02	1503	1000	4
Case 3	33.50	747.18	4.67	1.0000	0.0059	1.0054	0.0008	5.89E-02	1503	1000	15
Case 5	47.90	462.51	4.67	1.0000	0.0059	1.0087	0.0007	7.62E-02	1503	1000	22
Case 6	49.50	451.85	4.67	1.0000	0.0059	1.0073	0.0007	7.92E-02	1503	1000	6
Case 7	34.40	723.85	4.67	1.0000	0.0059	1.0022	0.0008	6.03E-02	1503	1000	32
Case 8	69.40	342.96	4.67	1.0000	0.0059	1.0069	0.0009	1.06E-01	1503	1000	52
Case 9	46.90	540.11	4.67	1.0000	0.0059	0.9989	0.0008	7.60E-02	1503	1000	40
Case 10	38.60	617.24	4.67	1.0000	0.0059	1.0088	0.0008	6.49E-02	1503	1000	3
Case 11	33.20	753.99	4.67	1.0000	0.0059	1.0058	0.0008	5.87E-02	1503	1000	21
Case 12	47.50	465.80	4.67	1.0000	0.0059	1.0072	0.0008	7.60E-02	1503	1000	13
Case 13	49.50	451.85	4.67	1.0000	0.0059	1.0087	0.0008	7.92E-02	1503	1000	18
Case 14	46.90	540.11	4.67	1.0000	0.0059	1.0002	0.0009	7.60E-02	1503	1000	6
Case 15	69.00	341.17	4.67	1.0000	0.0059	1.0017	0.0008	1.06E-01	1503	1000	7

(PC calculation results)

Experiment	C(Pu) [g/l]	H/Pu	^{240}Pu [wt. %]	Exp. k_{eff}	Exp. uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF [eV]	GEN	NPG	NSK
PU-SOL-THERM-025											
Case 1	58	424.34	4.671	1.0000	0.0039	1.0149	0.0004	7.87E-02	1503	1000	87
Case 2	58	424.34	4.671	1.0000	0.0039	1.0159	0.0005	7.88E-02	1503	1000	11
Case 4	58	424.34	4.671	1.0000	0.0039	1.0158	0.0005	7.91E-02	1503	1000	38
Case 5	58	424.34	4.671	1.0000	0.0039	1.015	0.0004	7.97E-02	1503	1000	16
Case 5	58	424.34	4.671	1.0000	0.0039	1.0125	0.0004	8.02E-02	1503	1000	55
Case 6	58	424.34	4.671	1.0000	0.0039	1.0089	0.0004	8.06E-02	1503	1000	16

PU-SOL-THERM-026											
Case 1	57.3	430.26	4.67	1.0000	0.0052	0.9971	0.0005	8.82E-02	1503	1000	52
Case 2	57.7	425.56	4.67	1.0000	0.0052	0.9965	0.0004	8.89E-02	1503	1000	52
Case 3	57.7	425.27	4.67	1.0000	0.0051	0.9971	0.0005	8.90E-02	1503	1000	58

ATTACHMENT NUMBER 2

CRITICAL EXPERIMENTS FOR AOA(2)

ICSBEP MOX Fuel Rod Lattices Benchmarks

The ICSBEP Handbook [6] includes a number of experiments related to the MOX fuel area of applicability. However, some of these experiments were determined to be inapplicable to MFFF design applications within AOA(1). The list below provides the reasoning for inclusion or exclusion of each candidate experiment.

MIX-COMP-THERM-001: This benchmark is not selected because the Pu content is not in range (Pu content = 20%).

MIX-COMP-THERM-002: All the experiments are selected. The k_{eff} and σ used are the experimental k_{eff} and the experimental σ. Hence, the particle effect bias is not accepted as a model simplification, since the design application will itself involve MOX particles.

MIX-COMP-THERM-003: All cases are selected.

MIX-COMP-THERM-004: All cases are selected.

MIX-COMP-THERM-005: All the experiments are selected. The k_{eff} and σ used are the experimental k_{eff} and the experimental σ. Hence, the particle effect bias is not accepted as a model simplification, since the design application will itself involve MOX particles.

MIX-COMP-THERM-007: This benchmark is not selected because the ^{240}Pu ratio is not in range (^{240}Pu ratio = 24%).

MIX-COMP-THERM-008: This benchmark is not selected because the ^{240}Pu ratio is not in range (^{240}Pu ratio = 24%).

MIX-COMP-THERM-009: All the experiments are selected. The k_{eff} and σ used are the experimental k_{eff} and the experimental σ. Hence, the particle effect bias is not accepted as a model simplification, since the design application will itself involve MOX particles.

MIX-COMP-THERM-010: This benchmark is not selected because the presence of gadolinium in the lattice is not a process situation.

ATTACHMENT NUMBER 2A

AOA(2) CRITICALITY RESULTS FOR SUN PLATFORM

(Sun calculation results)

Experiment	v^m/v^f	PuO_2 content [wt. %]	Exp. k_{eff}	Exp. uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF [eV]	GEN	NPG	NSK
MIX-COMP-THERM_002										
PNL-30	1.19	2.04	1.00018	0.0059	0.9933	0.0012	5.76E-01	600	700	12
PNL-31	1.19	2.04	1.00006	0.0045	0.9961	0.0014	7.67E-01	600	700	20
PNL-32	2.52	2.04	1.00019	0.0027	1.0004	0.0012	1.93E-01	600	700	45
PNL-33	2.52	2.04	1.00022	0.0017	1.0059	0.0012	2.82E-01	600	700	14
PNL-34	3.64	2.04	1.00096	0.0018	1.0028	0.0011	1.38E-01	600	700	16
PNL-35	3.64	2.04	1.00013	0.0020	1.0059	0.0011	1.83E-01	600	700	12
MIX-COMP-THERM_003										
Case 1	1.68	6.6	1.0000	0.0071	0.9911	0.0013	9.09E-01	905	600	24
Case 2-a	2.16	6.6	1.0000	0.0057	0.9939	0.0013	5.49E-01	905	600	7
Case 2-b	2.16	6.6	1.0000	0.0057	0.9964	0.0013	5.48E-01	905	600	21
Case 3	2.16	6.6	1.0000	0.0052	0.9971	0.0012	6.54E-01	905	600	86
Case 4	4.71	6.6	1.0000	0.0028	1.0013	0.0013	1.89E-01	905	600	15
Case 5	5.67	6.6	1.0000	0.0024	1.0011	0.0013	1.56E-01	905	600	24
Case 6	10.75	6.6	1.0000	0.0020	1.0022	0.0013	1.02E-01	905	600	8
MIX-COMP-THERM_004										
Case 1	2.42	3.01	1.0000	0.0046	0.9916	0.0012	1.46E-01	600	700	4
Case 2	2.42	3.01	1.0000	0.0046	0.9940	0.0013	1.45E-01	600	700	6
Case 3	2.42	3.01	1.0000	0.0046	0.9944	0.0013	1.44E-01	600	700	4
Case 4	2.98	3.01	1.0000	0.0039	0.9956	0.0013	1.20E-01	600	700	15
Case 5	2.98	3.01	1.0000	0.0039	0.9952	0.0011	1.19E-01	600	700	30
Case 6	2.98	3.01	1.0000	0.0039	0.9966	0.0013	1.18E-01	600	700	4
Case 7	4.24	3.01	1.0000	0.0040	0.9979	0.0012	9.24E-02	600	700	55
Case 8	4.24	3.01	1.0000	0.0040	0.9979	0.0012	9.24E-02	600	700	13
Case 9	4.24	3.01	1.0000	0.0040	0.9995	0.0013	9.23E-02	600	700	7
Case 10	5.55	3.01	1.0000	0.0051	0.9998	0.0014	7.99E-02	600	700	25
Case 11	5.55	3.01	1.0000	0.0051	1.0000	0.0011	7.95E-02	600	700	15
MIX-COMP-THERM_005										
Case 1	1.93	4.0	1.00000	0.0021	0.9963	0.0012	3.92E-01	700	800	18
Case 2	2.56	4.0	1.00000	0.0023	0.9956	0.0015	2.60E-01	700	800	74
Case 3	3.62	4.0	1.00000	0.0024	1.0041	0.0012	1.77E-01	700	800	33
Case 4	4.53	4.0	1.00000	0.0019	1.0033	0.0014	1.46E-01	700	800	10
Case 5	7.27	4.0	1.00000	0.0025	1.0052	0.0016	1.08E-01	700	800	67
Case 6	10.11	4.0	1.00000	0.0027	1.0069	0.0016	9.35E-02	700	800	17
MIX-COMP-THERM_009										
Case 1	1.10	1.5	1.00000	0.0052	0.9964	0.0010	5.48E-01	800	800	50
Case 2	1.56	1.5	1.00000	0.0040	0.9927	0.0010	3.06E-01	800	800	54
Case 3	2.71	1.5	1.00000	0.0026	0.9943	0.0012	1.57E-01	800	800	22
Case 4	3.79	1.5	1.00000	0.0030	0.9971	0.0009	1.17E-01	800	800	18
Case 5	5.14	1.5	1.00000	0.0038	0.9991	0.0008	9.58E-02	800	800	20
Case 6	5.58	1.5	1.00000	0.0043	1.0004	0.0008	9.16E-02	800	800	25

ATTACHMENT NUMBER 2B

AOA(2) CRITICALITY RESULTS FOR PC PLATFORM

(PC calculation results)

Experiment.	v^m/v^f	PuO_2 content [wt. %]	Exp. k_{eff}	Exp. uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF [eV]	GEN	NPG	NSK
MIX-COMP-THERM_002										
PNL-30	1.19	2.04	1.00018	0.0059	0.9949	0.0006	5.77E-01	1503	1000	7
PNL-31	1.19	2.04	1.00006	0.0045	0.9956	0.0006	7.73E-01	1503	1000	7
PNL-32	2.52	2.04	1.00019	0.0027	1.0004	0.0007	1.93E-01	1503	1000	34
PNL-33	2.52	2.04	1.00022	0.0017	1.0049	0.0006	2.83E-01	1503	1000	7
PNL-34	3.64	2.04	1.00096	0.0018	1.0028	0.0007	1.38E-01	1503	1000	16
PNL-35	3.64	2.04	1.00013	0.0020	1.0067	0.0006	1.83E-01	1503	1000	44
MIX-COMP-THERM_003										
Case 1	1.68	6.6	1.0000	0.0071	0.9922	0.0007	9.08E-01	1503	1000	19
Case 2-a	2.16	6.6	1.0000	0.0057	0.9956	0.0008	5.49E-01	1503	1000	5
Case 2-b	2.16	6.6	1.0000	0.0057	0.9957	0.0007	5.46E-01	1503	1000	36
Case 3	2.16	6.6	1.0000	0.0052	0.9942	0.0007	6.51E-01	1503	1000	16
Case 4	4.71	6.6	1.0000	0.0028	0.9980	0.0008	1.89E-01	1503	1000	15
Case 5	5.67	6.6	1.0000	0.0024	1.0004	0.0007	1.56E-01	1503	1000	37
Case 6	10.75	6.6	1.0000	0.0020	1.0036	0.0007	1.01E-01	1503	1000	35
MIX-COMP-THERM_004										
Case 1	2.42	3.01	1.0000	0.0046	0.9933	0.0006	1.46E-01	1503	1000	32
Case 2	2.42	3.01	1.0000	0.0046	0.9958	0.0008	1.45E-01	1503	1000	43
Case 3	2.42	3.01	1.0000	0.0046	0.9953	0.0006	1.44E-01	1503	1000	4
Case 4	2.98	3.01	1.0000	0.0039	0.9950	0.0007	1.19E-01	1503	1000	10
Case 5	2.98	3.01	1.0000	0.0039	0.9965	0.0007	1.19E-01	1503	1000	13
Case 6	2.98	3.01	1.0000	0.0039	0.9967	0.0007	1.18E-01	1503	1000	5
Case 7	4.24	3.01	1.0000	0.0040	0.9981	0.0007	9.28E-02	1503	1000	28
Case 8	4.24	3.01	1.0000	0.0040	0.9986	0.0006	9.25E-02	1503	1000	35
Case 9	4.24	3.01	1.0000	0.0040	0.9987	0.0006	9.16E-02	1503	1000	4
Case 10	5.55	3.01	1.0000	0.0051	0.9997	0.0006	7.96E-02	1503	1000	50
Case 11	5.55	3.01	1.0000	0.0051	1.0000	0.0006	7.94E-02	1503	1000	14
MIX-COMP-THERM_005										
Case 1	1.93	4.0	1.00000	0.0021	0.9956	0.0007	3.94E-01	1503	1000	16
Case 2	2.56	4.0	1.00000	0.0023	0.9939	0.0007	2.59E-01	1503	1000	32
Case 3	3.62	4.0	1.00000	0.0024	1.0032	0.0008	1.77E-01	1503	1000	7
Case 4	4.53	4.0	1.00000	0.0019	1.0020	0.0007	1.47E-01	1503	1000	14
Case 5	7.27	4.0	1.00000	0.0025	1.0053	0.0007	1.08E-01	1503	1000	62
Case 6	10.11	4.0	1.00000	0.0027	1.0065	0.0006	9.29E-02	1503	1000	10
MIX-COMP-THERM_009										
Case 1	1.10	1.5	1.00000	0.0052	0.9963	0.0006	5.46E-01	1503	1000	129
Case 2	1.56	1.5	1.00000	0.0040	0.9941	0.0006	3.07E-01	1503	1000	65
Case 3	2.71	1.5	1.00000	0.0026	0.9969	0.0006	1.56E-01	1503	1000	13
Case 4	3.79	1.5	1.00000	0.0030	0.9978	0.0006	1.17E-01	1503	1000	35
Case 5	5.14	1.5	1.00000	0.0038	0.9992	0.0006	9.62E-02	1503	1000	47
Case 6	5.58	1.5	1.00000	0.0043	0.9996	0.0006	9.16E-02	1503	1000	67

ATTACHMENT NUMBER 3

OUTPUT LISTING OF USLSTATS V1.0 PROGRAM FOR PC PLATFORM

Figure A3–1 AOA(1) – k_{eff} versus EALF as trending parameter – SCALE 4.4a on PC

```
          uslstats: a utility to calculate upper subcritical
                    limits for criticality safety applications

***********************************************************************
                    Version 1.3.7, May 18, 1999
                     Oak Ridge National Laboratory
***********************************************************************


   Input to statistical treatment from file:toto.inp

Title: AOA(1) PC full set EALF

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =  191
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05


   independent     dependent       deviation                 independent     dependent       deviation
   variable - x    variable - y     in y                     variable - x    variable - y     in y

    8.79564E-02     1.00910E+00     5.14198E-03                1.67337E-01     1.00580E+00     3.32415E-03
    1.10854E-01     1.00970E+00     5.06360E-03                1.66955E-01     1.00730E+00     3.29849E-03
    1.34839E-01     1.01150E+00     5.06360E-03                1.66546E-01     1.00900E+00     3.32415E-03
    1.50757E-01     1.00590E+00     5.06360E-03                1.68373E-01     1.00970E+00     4.37379E-03
    1.59544E-01     1.00920E+00     5.06360E-03                1.67903E-01     1.00630E+00     4.39318E-03
    3.46678E-01     1.00870E+00     5.06360E-03                1.67166E-01     1.00900E+00     4.37379E-03
    7.12128E-02     1.00770E+00     4.76760E-03                1.66898E-01     1.00770E+00     4.39318E-03
    7.28617E-02     1.00770E+00     4.76760E-03                1.66630E-01     1.00750E+00     4.39318E-03
    7.78800E-02     1.00830E+00     4.75184E-03                1.68449E-01     1.01000E+00     4.39318E-03
    8.13967E-02     1.01000E+00     4.78539E-03                1.67790E-01     1.00690E+00     4.41475E-03
    8.50698E-02     1.01150E+00     4.76760E-03                1.66997E-01     1.00880E+00     4.39318E-03
    9.29137E-02     1.00820E+00     4.76760E-03                1.66691E-01     1.00830E+00     4.37379E-03
    1.00322E-01     1.01030E+00     4.76760E-03                1.66682E-01     1.00800E+00     4.39318E-03
    5.83795E-02     1.00620E+00     4.76760E-03                1.66969E-01     1.00730E+00     4.39318E-03
    5.95793E-02     1.00680E+00     4.76760E-03                1.68612E-01     1.01020E+00     4.37379E-03
    6.18997E-02     1.00780E+00     4.76760E-03                1.67699E-01     1.00620E+00     4.39318E-03
    6.26929E-02     1.00920E+00     4.75184E-03                1.67331E-01     1.00880E+00     4.39318E-03
    6.54388E-02     1.01000E+00     4.76760E-03                1.66818E-01     1.00790E+00     4.39318E-03
    6.94428E-02     1.00990E+00     4.78539E-03                1.66664E-01     1.00730E+00     4.39318E-03
    5.91641E-02     1.01060E+00     4.76760E-03                1.66641E-01     1.00770E+00     4.39318E-03
    6.01058E-02     1.01000E+00     4.75184E-03                1.68215E-01     1.00710E+00     4.37379E-03
    5.33828E-02     1.00630E+00     4.76760E-03                1.68357E-01     1.00590E+00     4.39318E-03
    5.36833E-02     1.00360E+00     4.75184E-03                1.67772E-01     1.00650E+00     4.39318E-03
    5.47121E-02     1.00610E+00     4.75184E-03                1.67416E-01     1.00830E+00     4.37379E-03
    5.59714E-02     1.00380E+00     4.75184E-03                1.67630E-01     1.00630E+00     4.41475E-03
    5.45435E-02     1.00450E+00     4.75184E-03                1.67462E-01     1.00700E+00     4.41475E-03
    5.48712E-02     1.00650E+00     4.76760E-03                2.37509E-01     1.00930E+00     3.90513E-03
    5.58159E-02     1.01080E+00     4.76760E-03                2.36912E-01     1.01000E+00     3.88330E-03
    5.65395E-02     1.00700E+00     4.75184E-03                2.36543E-01     1.00790E+00     3.90513E-03
    5.85551E-02     1.00460E+00     4.75184E-03                2.36831E-01     1.00830E+00     3.90513E-03
    6.31817E-02     1.00660E+00     4.76760E-03                2.36587E-01     1.00670E+00     3.90513E-03
    6.85846E-02     1.00400E+00     4.75184E-03                2.36202E-01     1.00930E+00     3.88330E-03
    5.58595E-02     1.00770E+00     4.75184E-03                2.38483E-01     1.01040E+00     4.78539E-03
    5.56140E-02     1.00590E+00     4.75184E-03                2.37274E-01     1.00990E+00     4.78539E-03
    5.55403E-02     1.00850E+00     4.75184E-03                2.36695E-01     1.00970E+00     4.76760E-03
    5.65552E-02     1.00740E+00     4.75184E-03                2.36058E-01     1.00840E+00     4.78539E-03
    5.76214E-02     1.00780E+00     4.76760E-03                2.38161E-01     1.00690E+00     4.78539E-03
    6.00338E-02     1.01060E+00     4.76760E-03                2.37891E-01     1.00650E+00     4.76760E-03
    6.29144E-02     1.01010E+00     4.75184E-03                2.36841E-01     1.00890E+00     4.78539E-03
    6.60208E-02     1.01040E+00     4.75184E-03                2.36296E-01     1.00960E+00     4.78539E-03
    6.92278E-02     1.00830E+00     4.78539E-03                2.38548E-01     1.01000E+00     4.76760E-03
    5.66741E-02     1.00510E+00     4.75184E-03                2.38276E-01     1.00820E+00     4.78539E-03
    5.79244E-02     1.00700E+00     4.75184E-03                2.37141E-01     1.00910E+00     4.78539E-03
    5.24565E-02     1.00500E+00     3.59027E-03                2.37431E-01     1.00810E+00     4.39318E-03
    5.33009E-02     1.00620E+00     3.56931E-03                2.36989E-01     1.00730E+00     4.39318E-03
    5.52206E-02     1.00630E+00     3.56931E-03                2.36537E-01     1.00910E+00     4.39318E-03
    6.48964E-02     1.01370E+00     3.39559E-03                2.36458E-01     1.00880E+00     4.39318E-03
    7.83975E-02     1.01590E+00     4.07922E-03                1.67942E-01     1.00740E+00     3.90513E-03
```

```
 7.94782E-02   1.02270E+00   4.07922E-03          1.67467E-01   1.00750E+00   3.90513E-03
 8.00708E-02   1.02740E+00   4.06079E-03          1.67208E-01   1.01010E+00   3.90513E-03
 6.02411E-02   1.02820E+00   2.88617E-03          1.66786E-01   1.01080E+00   3.90513E-03
 5.71888E-02   1.02200E+00   2.88617E-03          1.65519E-01   1.00960E+00   3.42053E-03
 8.72767E-02   1.00140E+00   4.07922E-03          1.66435E-01   1.00870E+00   3.44819E-03
 5.48519E-01   1.00710E+00   6.15224E-03          1.67131E-01   1.01010E+00   3.42053E-03
 7.52280E-02   1.03170E+00   3.76563E-03          1.66869E-01   1.00730E+00   3.90513E-03
 6.61882E-02   1.02640E+00   3.17805E-03          1.66968E-01   1.00880E+00   3.90513E-03
 9.96842E-02   1.02190E+00   4.19762E-03          1.67120E-01   1.00830E+00   3.90513E-03
 7.66779E-02   1.02750E+00   4.17732E-03          1.67064E-01   1.00800E+00   3.88330E-03
 1.07278E-01   1.00740E+00   4.27551E-03          1.67223E-01   1.00930E+00   3.90513E-03
 7.43597E-02   1.01720E+00   4.17732E-03          1.67150E-01   1.00870E+00   3.90513E-03
 6.52939E-02   1.02070E+00   3.39559E-03          1.67269E-01   1.00690E+00   3.92938E-03
 7.95316E-02   1.01760E+00   4.07922E-03          1.67189E-01   1.00830E+00   3.92938E-03
 8.01910E-02   1.02470E+00   4.06079E-03          1.67010E-01   1.00900E+00   3.92938E-03
 6.04976E-02   1.02000E+00   2.88617E-03          1.67538E-01   1.00780E+00   3.90513E-03
 5.74725E-02   1.01950E+00   2.91204E-03          1.66900E-01   1.00890E+00   3.90513E-03
 8.59860E-02   1.00220E+00   4.07922E-03          1.66967E-01   1.00870E+00   3.92938E-03
 5.20183E-01   9.94800E-01   6.15224E-03          1.67078E-01   1.00910E+00   3.90513E-03
 7.71986E-02   1.02460E+00   3.78550E-03          1.67248E-01   1.00920E+00   3.90513E-03
 6.68322E-02   1.01870E+00   3.17805E-03          1.66704E-01   1.01020E+00   3.88330E-03
 9.94312E-02   1.02080E+00   4.27551E-03          1.66824E-01   1.01010E+00   3.90513E-03
 7.91584E-02   1.02040E+00   4.17732E-03          1.66972E-01   1.00880E+00   3.90513E-03
 1.46679E-01   1.01290E+00   4.29535E-03          1.66697E-01   1.00950E+00   3.90513E-03
 1.15325E-01   1.00620E+00   4.27551E-03          6.56132E-02   1.00800E+00   5.95399E-03
 8.03191E-02   1.02080E+00   4.19762E-03          6.46606E-02   1.01040E+00   5.94138E-03
 7.49507E-02   1.01800E+00   4.17732E-03          5.88638E-02   1.00540E+00   5.95399E-03
 6.33838E-02   1.01550E+00   5.26118E-03          7.62407E-02   1.00870E+00   5.94138E-03
 5.20005E-02   9.99800E-01   5.24690E-03          7.91837E-02   1.00730E+00   5.94138E-03
 6.46684E-02   1.02090E+00   5.26118E-03          6.03194E-02   1.00220E+00   5.95399E-03
 5.29627E-02   1.00550E+00   5.26118E-03          1.05952E-01   1.00690E+00   5.96825E-03
 6.71864E-02   1.02070E+00   5.26118E-03          7.60457E-02   9.98900E-01   5.95399E-03
 5.28973E-02   1.00230E+00   5.24690E-03          6.49151E-02   1.00880E+00   5.95399E-03
 6.78595E-02   1.01320E+00   5.27731E-03          5.86666E-02   1.00580E+00   5.95399E-03
 5.41435E-02   9.99400E-01   5.26118E-03          7.60094E-02   1.00720E+00   5.95399E-03
 7.53575E-02   1.01020E+00   5.26118E-03          7.91953E-02   1.00870E+00   5.95399E-03
 5.55823E-02   1.01050E+00   5.26118E-03          7.60421E-02   1.00020E+00   5.96825E-03
 5.93469E-02   1.00640E+00   5.26118E-03          1.06379E-01   1.00170E+00   5.95399E-03
 5.39823E-02   1.00630E+00   5.26118E-03          7.87037E-02   1.01490E+00   3.92046E-03
 1.67812E-01   1.00910E+00   3.29849E-03          7.88171E-02   1.01590E+00   3.93192E-03
 1.67457E-01   1.00790E+00   3.32415E-03          7.90645E-02   1.01580E+00   3.93192E-03
 1.66807E-01   1.01000E+00   3.32415E-03          7.96660E-02   1.01500E+00   3.92046E-03
 1.67233E-01   1.00800E+00   3.29849E-03          8.02144E-02   1.01250E+00   3.92046E-03
 1.66668E-01   1.00940E+00   3.32415E-03          8.05826E-02   1.00890E+00   3.92046E-03
 1.66668E-01   1.00800E+00   3.32415E-03          8.82228E-02   9.97100E-01   5.22398E-03
 1.68142E-01   1.00790E+00   3.32415E-03          8.89412E-02   9.96500E-01   5.21536E-03
 1.67636E-01   1.00750E+00   3.29849E-03          8.89815E-02   9.97100E-01   5.12445E-03
 1.67279E-01   1.00720E+00   3.29849E-03
chi = 92.4817 (upper bound = 9.49). The data tests NOT normal


      Output from statistical treatment

AOA(1) PC full set EALF

 Number of data points (n)                      191
 Linear regression, k(X)                        1.0114 + (-1.5297E-02)*X
 Confidence on fit (1-gamma) [input]             95.0%
 Confidence on proportion (alpha) [input]        95.0%
 Proportion of population falling above
 lower tolerance interval (rho) [input]          99.9%
 Minimum value of X                                0.0520
 Maximum value of X                                0.5485
 Average value of X                                0.12713
 Average value of k                              1.00950
 Minimum value of k                              0.99480
 Variance of fit, s(k,X)^2                       3.1856E-05
 Within variance, s(w)^2                         2.0287E-05
 Pooled variance, s(p)^2                         5.2143E-05
 Pooled std. deviation, s(p)                     7.2210E-03
 C(alpha,rho)*s(p)                               4.1459E-02
 student-t @ (n-2,1-gamma)                       1.64500E+00
 Confidence band width, W                        1.2842E-02
 Minimum margin of subcriticality, C*s(p)-W      2.8617E-02

 Upper subcritical limits: ( 5.20005E-02 <= X <=  0.54852    )
 ***** *********** *******
```

```
    USL Method 1 (Confidence Band with
    Administrative Margin)            USL1 = 0.9372 ( 5.20005E-2< X < 0.54852    )

    USL Method 2 (Single-Sided Uniform
    Width Closed Interval Approach)   USL2 = 0.9585 ( 5.20005E-2< X < 0.54852    )


    USLs Evaluated Over Range of Parameter X:
    **** ********* **** ***** ** ********* **

    X:  5.20E-2  1.23E-1  1.94E-1  2.65E-1  3.36E-1  4.07E-1  4.78E-1  5.49E-1
       ------------------------------------------------------------------------
USL-1:    0.9372   0.9372   0.9372   0.9372   0.9372   0.9372   0.9372   0.9372
USL-2:    0.9585   0.9585   0.9585   0.9585   0.9585   0.9585   0.9585   0.9585
       ------------------------------------------------------------------------

  ****************************************************************************
                             Thus spake USLSTATS
                                   Finis.
```

Figure A3–2 AOA(1) – k_{eff} versus H/Pu as trending parameter – SCALE 4.4a on PC

```
uslstats: a utility to calculate upper subcritical
                        limits for criticality safety applications

  ***************************************************************************
                        Version 1.3.7, May 18, 1999
                         Oak Ridge National Laboratory
  ***************************************************************************


   Input to statistical treatment from file:toto.inp

Title: AOA(1) full set H/Pu

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =  191
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05

   independent     dependent       deviation               independent     dependent       deviation
   variable - x    variable - y     in y                   variable - x    variable - y     in y

    3.52910E+02     1.00910E+00     5.14198E-03             2.10180E+02     1.00580E+00     3.32415E-03
    2.58050E+02     1.00970E+00     5.06360E-03             2.10180E+02     1.00730E+00     3.29849E-03
    2.05140E+02     1.01150E+00     5.06360E-03             2.10180E+02     1.00900E+00     3.32415E-03
    1.80970E+02     1.00590E+00     5.06360E-03             2.10180E+02     1.00970E+00     4.37379E-03
    1.71210E+02     1.00920E+00     5.06360E-03             2.10180E+02     1.00630E+00     4.39318E-03
    8.66600E+01     1.00870E+00     5.06360E-03             2.10180E+02     1.00900E+00     4.37379E-03
    5.07980E+02     1.00770E+00     4.76760E-03             2.10180E+02     1.00770E+00     4.39318E-03
    4.89180E+02     1.00770E+00     4.76760E-03             2.10180E+02     1.00750E+00     4.39318E-03
    4.37280E+02     1.00830E+00     4.75184E-03             2.10180E+02     1.01000E+00     4.39318E-03
    4.07450E+02     1.01000E+00     4.78539E-03             2.10180E+02     1.00690E+00     4.41475E-03
    3.80570E+02     1.01150E+00     4.76760E-03             2.10180E+02     1.00880E+00     4.39318E-03
    3.33540E+02     1.00820E+00     4.76760E-03             2.10180E+02     1.00830E+00     4.37379E-03
    2.99260E+02     1.01030E+00     4.76760E-03             2.10180E+02     1.00800E+00     4.39318E-03
    7.74150E+02     1.00620E+00     4.76760E-03             2.10180E+02     1.00730E+00     4.39318E-03
    7.42710E+02     1.00680E+00     4.76760E-03             2.10180E+02     1.01020E+00     4.37379E-03
    6.77170E+02     1.00780E+00     4.76760E-03             2.10180E+02     1.00620E+00     4.39318E-03
    6.60550E+02     1.00920E+00     4.75184E-03             2.10180E+02     1.00880E+00     4.39318E-03
    6.07170E+02     1.01000E+00     4.76760E-03             2.10180E+02     1.00790E+00     4.39318E-03
    5.45330E+02     1.00990E+00     4.78539E-03             2.10180E+02     1.00730E+00     4.39318E-03
    7.14830E+02     1.01060E+00     4.76760E-03             2.10180E+02     1.00770E+00     4.39318E-03
    6.92120E+02     1.01000E+00     4.75184E-03             2.10180E+02     1.00710E+00     4.37379E-03
    9.81670E+02     1.00630E+00     4.76760E-03             2.10180E+02     1.00590E+00     4.39318E-03
    9.71630E+02     1.00360E+00     4.75184E-03             2.10180E+02     1.00650E+00     4.39318E-03
    9.29600E+02     1.00610E+00     4.75184E-03             2.10180E+02     1.00830E+00     4.37379E-03
    8.84120E+02     1.00380E+00     4.75184E-03             2.10180E+02     1.00630E+00     4.41475E-03
    9.25520E+02     1.00450E+00     4.75184E-03             2.10180E+02     1.00700E+00     4.41475E-03
    8.98580E+02     1.00650E+00     4.76760E-03             1.55210E+02     1.00930E+00     3.90513E-03
    8.64010E+02     1.01080E+00     4.76760E-03             1.55270E+02     1.01000E+00     3.88330E-03
    8.41980E+02     1.00700E+00     4.75184E-03             1.55270E+02     1.00790E+00     3.90513E-03
    7.80210E+02     1.00460E+00     4.75184E-03             1.55270E+02     1.00830E+00     3.90513E-03
    6.67980E+02     1.00660E+00     4.76760E-03             1.55270E+02     1.00670E+00     3.90513E-03
    5.73340E+02     1.00400E+00     4.75184E-03             1.55270E+02     1.00930E+00     3.88330E-03
    8.65010E+02     1.00770E+00     4.75184E-03             1.55270E+02     1.01040E+00     4.78539E-03
    8.72210E+02     1.00590E+00     4.75184E-03             1.55270E+02     1.00990E+00     4.78539E-03
    8.66360E+02     1.00850E+00     4.75184E-03             1.55270E+02     1.00970E+00     4.76760E-03
    8.32710E+02     1.00740E+00     4.75184E-03             1.55270E+02     1.00840E+00     4.78539E-03
    8.00710E+02     1.00780E+00     4.76760E-03             1.55270E+02     1.00690E+00     4.78539E-03
    7.34370E+02     1.01060E+00     4.76760E-03             1.55270E+02     1.00650E+00     4.76760E-03
    6.66080E+02     1.01010E+00     4.75184E-03             1.55270E+02     1.00890E+00     4.78539E-03
    6.07890E+02     1.01040E+00     4.75184E-03             1.55270E+02     1.00960E+00     4.78539E-03
    5.57170E+02     1.00830E+00     4.78539E-03             1.55270E+02     1.01000E+00     4.76760E-03
    8.30640E+02     1.00510E+00     4.75184E-03             1.55270E+02     1.00820E+00     4.78539E-03
    7.88950E+02     1.00700E+00     4.75184E-03             1.55270E+02     1.00910E+00     4.78539E-03
    1.02816E+03     1.00500E+00     3.59027E-03             1.55270E+02     1.00810E+00     4.39318E-03
    9.86180E+02     1.00620E+00     3.56931E-03             1.55270E+02     1.00730E+00     4.39318E-03
    9.10900E+02     1.00630E+00     3.56931E-03             1.55270E+02     1.00910E+00     4.39318E-03
    6.83880E+02     1.01370E+00     3.39559E-03             1.55270E+02     1.00880E+00     4.39318E-03
    4.95930E+02     1.01590E+00     4.07922E-03             2.10180E+02     1.00740E+00     3.90513E-03
    4.88550E+02     1.02270E+00     4.07922E-03             2.10170E+02     1.00750E+00     3.90513E-03
```

```
  4.86150E+02    1.02740E+00    4.06079E-03         2.10170E+02    1.01010E+00    3.90513E-03
  7.82400E+02    1.02820E+00    2.88617E-03         2.10170E+02    1.01080E+00    3.90513E-03
  8.67100E+02    1.02200E+00    2.88617E-03         2.10170E+02    1.00960E+00    3.42053E-03
  4.54500E+02    1.00140E+00    4.07922E-03         2.10170E+02    1.00870E+00    3.44819E-03
  8.50300E+01    1.00710E+00    6.15224E-03         2.10170E+02    1.01010E+00    3.42053E-03
  5.21450E+02    1.03170E+00    3.76563E-03         2.10180E+02    1.00730E+00    3.90513E-03
  6.50830E+02    1.02640E+00    3.17805E-03         2.10180E+02    1.00880E+00    3.90513E-03
  3.44020E+02    1.02190E+00    4.19762E-03         2.10180E+02    1.00830E+00    3.90513E-03
  4.99920E+02    1.02750E+00    4.17732E-03         2.10180E+02    1.00800E+00    3.88330E-03
  3.28020E+02    1.00740E+00    4.27551E-03         2.10180E+02    1.00930E+00    3.90513E-03
  5.38180E+02    1.01720E+00    4.17732E-03         2.10180E+02    1.00870E+00    3.90513E-03
  6.73070E+02    1.02070E+00    3.39559E-03         2.10180E+02    1.00690E+00    3.92938E-03
  4.88550E+02    1.01760E+00    4.07922E-03         2.10180E+02    1.00830E+00    3.92938E-03
  4.86150E+02    1.02470E+00    4.06079E-03         2.10180E+02    1.00900E+00    3.92938E-03
  7.76810E+02    1.02000E+00    2.88617E-03         2.10180E+02    1.00780E+00    3.90513E-03
  8.56600E+02    1.01950E+00    2.91204E-03         2.10180E+02    1.00890E+00    3.90513E-03
  4.62990E+02    1.00220E+00    4.07922E-03         2.10180E+02    1.00870E+00    3.92938E-03
  8.84300E+01    9.94800E-01    6.15224E-03         2.10180E+02    1.00910E+00    3.90513E-03
  4.96980E+02    1.02460E+00    3.78550E-03         2.10180E+02    1.00920E+00    3.90513E-03
  6.39340E+02    1.01870E+00    3.17805E-03         2.10180E+02    1.01020E+00    3.88330E-03
  3.44020E+02    1.02080E+00    4.27551E-03         2.10180E+02    1.01010E+00    3.90513E-03
  4.74900E+02    1.02040E+00    4.17732E-03         2.10180E+02    1.00880E+00    3.90513E-03
  2.32010E+02    1.01290E+00    4.29535E-03         2.10180E+02    1.00950E+00    3.90513E-03
  3.01120E+02    1.00620E+00    4.27551E-03         6.03570E+02    1.00800E+00    5.95399E-03
  4.75390E+02    1.02080E+00    4.19762E-03         6.21120E+02    1.01040E+00    5.94138E-03
  5.31210E+02    1.01800E+00    4.17732E-03         7.47180E+02    1.00540E+00    5.95399E-03
  7.33000E+02    1.01550E+00    5.26118E-03         4.62510E+02    1.00870E+00    5.94138E-03
  1.15729E+03    9.99800E-01    5.24690E-03         4.51850E+02    1.00730E+00    5.94138E-03
  7.05450E+02    1.02090E+00    5.26118E-03         7.23850E+02    1.00220E+00    5.95399E-03
  1.10319E+03    1.00550E+00    5.26118E-03         3.42960E+02    1.00690E+00    5.96825E-03
  6.62770E+02    1.02070E+00    5.26118E-03         5.40110E+02    9.98900E-01    5.95399E-03
  1.10978E+03    1.00230E+00    5.24690E-03         6.17240E+02    1.00880E+00    5.95399E-03
  6.53420E+02    1.01320E+00    5.27731E-03         7.53990E+02    1.00580E+00    5.95399E-03
  1.05374E+03    9.99400E-01    5.26118E-03         4.65800E+02    1.00720E+00    5.95399E-03
  5.50660E+02    1.01020E+00    5.26118E-03         4.51850E+02    1.00870E+00    5.95399E-03
  9.95410E+02    1.01050E+00    5.26118E-03         5.40110E+02    1.00020E+00    5.96825E-03
  8.70370E+02    1.00640E+00    5.26118E-03         3.41170E+02    1.00170E+00    5.95399E-03
  1.05643E+03    1.00630E+00    5.26118E-03         4.24340E+02    1.01490E+00    3.92046E-03
  2.10180E+02    1.00910E+00    3.29849E-03         4.24340E+02    1.01590E+00    3.93192E-03
  2.10180E+02    1.00790E+00    3.32415E-03         4.24340E+02    1.01580E+00    3.93192E-03
  2.10180E+02    1.01000E+00    3.32415E-03         4.24340E+02    1.01500E+00    3.92046E-03
  2.10180E+02    1.00800E+00    3.29849E-03         4.24340E+02    1.01250E+00    3.92046E-03
  2.10180E+02    1.00940E+00    3.32415E-03         4.24340E+02    1.00890E+00    3.92046E-03
  2.10180E+02    1.00800E+00    3.32415E-03         4.30260E+02    9.97100E-01    5.22398E-03
  2.10180E+02    1.00790E+00    3.32415E-03         4.25560E+02    9.96500E-01    5.21536E-03
  2.10180E+02    1.00750E+00    3.29849E-03         4.25270E+02    9.97100E-01    5.12445E-03
  2.10180E+02    1.00720E+00    3.29849E-03
 chi = 92.4817 (upper bound = 9.49). The data tests NOT normal


       Output from statistical treatment

 AOA(1) full set H/Pu

  Number of data points (n)                     191
  Linear regression, k(X)                       1.0091 + ( 8.1036E-07)*X
  Confidence on fit (1-gamma) [input]            95.0%
  Confidence on proportion (alpha) [input]       95.0%
  Proportion of population falling above
  lower tolerance interval (rho) [input]         99.9%
  Minimum value of X                              85.0300
  Maximum value of X                            1157.2900
  Average value of X                             433.28293
  Average value of k                             1.00950
  Minimum value of k                             0.99480
  Variance of fit, s(k,X)^2                     3.3151E-05
  Within variance, s(w)^2                       2.0287E-05
  Pooled variance, s(p)^2                       5.3438E-05
  Pooled std. deviation, s(p)                   7.3101E-03
  C(alpha,rho)*s(p)                             3.8993E-02
  student-t @ (n-2,1-gamma)                     1.64500E+00
  Confidence band width, W                      1.2273E-02
  Minimum margin of subcriticality, C*s(p)-W    2.6720E-02

  Upper subcritical limits: (  85.030     <= X <=    1157.3     )
  ***** *********** *******

  USL Method 1 (Confidence Band with
```

```
Administrative Margin)          USL1 = 0.9377 (  85.030    < X <  1157.3   )

USL Method 2 (Single-Sided Uniform
Width Closed Interval Approach)  USL2 = 0.9610 (  85.030    < X <  1157.3   )


USLs Evaluated Over Range of Parameter X:
**** ********* **** ***** ** ********* **

X:  8.50E+1  2.38E+2  3.91E+2  5.45E+2  6.98E+2  8.51E+2  1.00E+3  1.16E+3
   ------------------------------------------------------------------------
USL-1:   0.9377   0.9377   0.9377   0.9377   0.9377   0.9377   0.9377   0.9377
USL-2:   0.9610   0.9610   0.9610   0.9610   0.9610   0.9610   0.9610   0.9610
   ------------------------------------------------------------------------

 ****************************************************************************
                             Thus spake USLSTATS
                                   Finis.
```

Figure A3–3 AOA(1) – k_{eff} versus ^{240}Pu content as trending parameter – SCALE 4.4a on PC

```
              uslstats: a utility to calculate upper subcritical
                        limits for criticality safety applications

  ***************************************************************************
                        Version 1.3.7, May 18, 1999
                         Oak Ridge National Laboratory
  ***************************************************************************


   Input to statistical treatment from file:toto.inp

Title: AOA(1) Pu content Pu240

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =   46
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05

   independent     dependent       deviation               independent     dependent       deviation
   variable - x    variable - y     in y                   variable - x    variable - y     in y

    4.67000E+00     1.00910E+00     5.14198E-03             5.40000E-01     1.00610E+00     4.75184E-03
    4.67000E+00     1.00970E+00     5.06360E-03             5.40000E-01     1.00380E+00     4.75184E-03
    4.67000E+00     1.01150E+00     5.06360E-03             1.76000E+00     1.00450E+00     4.75184E-03
    4.67000E+00     1.00590E+00     5.06360E-03             3.12000E+00     1.00650E+00     4.76760E-03
    4.67000E+00     1.00920E+00     5.06360E-03             3.12000E+00     1.01080E+00     4.76760E-03
    4.67000E+00     1.00870E+00     5.06360E-03             3.12000E+00     1.00700E+00     4.75184E-03
    3.12000E+00     1.00770E+00     4.76760E-03             3.12000E+00     1.00460E+00     4.75184E-03
    3.12000E+00     1.00770E+00     4.76760E-03             3.12000E+00     1.00660E+00     4.76760E-03
    3.12000E+00     1.00830E+00     4.75184E-03             3.12000E+00     1.00400E+00     4.75184E-03
    3.12000E+00     1.01000E+00     4.78539E-03             3.12000E+00     1.00770E+00     4.75184E-03
    3.12000E+00     1.01150E+00     4.76760E-03             3.43000E+00     1.00590E+00     4.75184E-03
    3.12000E+00     1.00820E+00     4.76760E-03             4.05000E+00     1.00850E+00     4.75184E-03
    3.12000E+00     1.01030E+00     4.76760E-03             4.05000E+00     1.00740E+00     4.75184E-03
    1.76000E+00     1.00620E+00     4.76760E-03             4.05000E+00     1.00780E+00     4.76760E-03
    1.76000E+00     1.00680E+00     4.76760E-03             4.05000E+00     1.01060E+00     4.76760E-03
    3.12000E+00     1.00780E+00     4.76760E-03             4.05000E+00     1.01010E+00     4.75184E-03
    3.12000E+00     1.00920E+00     4.75184E-03             4.05000E+00     1.01040E+00     4.75184E-03
    3.12000E+00     1.01000E+00     4.76760E-03             4.05000E+00     1.00830E+00     4.78539E-03
    3.12000E+00     1.00990E+00     4.78539E-03             4.40000E+00     1.00510E+00     4.75184E-03
    3.12000E+00     1.01060E+00     4.76760E-03             4.40000E+00     1.00700E+00     4.75184E-03
    3.12000E+00     1.01000E+00     4.75184E-03             3.12000E+00     1.00500E+00     3.59027E-03
    5.40000E-01     1.00630E+00     4.76760E-03             3.12000E+00     1.00620E+00     3.56931E-03
    5.40000E-01     1.00360E+00     4.75184E-03             3.12000E+00     1.00630E+00     3.56931E-03

   chi =  3.5652 (upper bound = 9.49). The data tests normal.


         Output from statistical treatment

   AOA(1) Pu content Pu240

    Number of data points (n)                           46
    Linear regression, k(X)                            1.0048 + ( 9.2819E-04)*X
    Confidence on fit (1-gamma) [input]                 95.0%
    Confidence on proportion (alpha) [input]            95.0%
    Proportion of population falling above
    lower tolerance interval (rho) [input]              99.9%
    Minimum value of X                                     0.5400
    Maximum value of X                                     4.6700
    Average value of X                                     3.21304
    Average value of k                                   1.00779
    Minimum value of k                                   1.00360
    Variance of fit, s(k,X)^2                           3.6868E-06
    Within variance, s(w)^2                             2.2431E-05
    Pooled variance, s(p)^2                             2.6118E-05
    Pooled std. deviation, s(p)                         5.1106E-03
    C(alpha,rho)*s(p)                                   2.3960E-02
```

```
    student-t @ (n-2,1-gamma)                     1.68140E+00
    Confidence band width, W                      9.2157E-03
    Minimum margin of subcriticality, C*s(p)-W    1.4744E-02

    Upper subcritical limits: ( 0.54000     <= X <=    4.6700     )
    ***** *********** *******

    USL Method 1 (Confidence Band with
    Administrative Margin)           USL1 = 0.9408 ( 0.54000    < X <  4.6700    )

    USL Method 2 (Single-Sided Uniform
    Width Closed Interval Approach)  USL2 = 0.9760 ( 0.54000    < X <  4.6700    )


    USLs Evaluated Over Range of Parameter X:
    **** ********* **** ***** ** ********* **

    X:  5.40E-1  1.13E+0  1.72E+0  2.31E+0  2.90E+0  3.49E+0  4.08E+0  4.67E+0
       -------------------------------------------------------------------------
USL-1:    0.9408   0.9408   0.9408   0.9408   0.9408   0.9408   0.9408   0.9408
USL-2:    0.9760   0.9760   0.9760   0.9760   0.9760   0.9760   0.9760   0.9760
       -------------------------------------------------------------------------

  ******************************************************************************
                            Thus spake USLSTATS
                                   Finis.
```

Figure A3–4 AOA(2) – k_{eff} versus EALF as trending parameter – SCALE 4.4a on PC

```
          uslstats: a utility to calculate upper subcritical
                    limits for criticality safety applications

 **************************************************************************
                    Version 1.3.7, May 18, 1999
                     Oak Ridge National Laboratory
 **************************************************************************


  Input to statistical treatment from file:toto.inp

Title: AOA(2) MIX full set EALF

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =  36
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05

  independent     dependent       deviation                   independent     dependent       deviation
  variable - x    variable - y     in y                       variable - x    variable - y     in y

   5.76975E-01     9.94700E-01     5.93043E-03                 1.17852E-01     9.96700E-01     3.96232E-03
   7.72991E-01     9.95500E-01     4.53982E-03                 9.27500E-02     9.98100E-01     4.06079E-03
   1.92667E-01     1.00020E+00     2.78927E-03                 9.25340E-02     9.98600E-01     4.04475E-03
   2.83406E-01     1.00470E+00     1.80278E-03                 9.16020E-02     9.98700E-01     4.04475E-03
   1.37835E-01     1.00180E+00     1.93132E-03                 7.95960E-02     9.99700E-01     5.13517E-03
   1.82640E-01     1.00660E+00     2.08806E-03                 7.94010E-02     1.00000E+00     5.13517E-03
   9.08459E-01     9.92200E-01     7.15433E-03                 3.93591E-01     9.95600E-01     2.21359E-03
   5.48741E-01     9.95600E-01     5.78558E-03                 2.58965E-01     9.93900E-01     2.40416E-03
   5.46028E-01     9.95700E-01     5.77260E-03                 1.76572E-01     1.00320E+00     2.52982E-03
   6.51324E-01     9.94200E-01     5.26673E-03                 1.46536E-01     1.00200E+00     2.02485E-03
   1.88606E-01     9.98000E-01     2.94090E-03                 1.07841E-01     1.00530E+00     2.59615E-03
   1.56232E-01     1.00040E+00     2.45204E-03                 9.29310E-02     1.00650E+00     2.76586E-03
   1.01290E-01     1.00360E+00     2.09067E-03                 5.45635E-01     9.97600E-01     5.23450E-03
   1.45559E-01     9.93300E-01     4.63897E-03                 3.06613E-01     9.94800E-01     4.04475E-03
   1.44786E-01     9.95800E-01     4.66905E-03                 1.56238E-01     9.97700E-01     2.66833E-03
   1.44219E-01     9.95300E-01     4.63897E-03                 1.17437E-01     9.98600E-01     3.05941E-03
   1.19304E-01     9.95000E-01     3.96232E-03                 9.61990E-02     9.99700E-01     3.84708E-03
   1.19169E-01     9.96500E-01     3.96232E-03                 9.16430E-02     9.99600E-01     4.34166E-03

  chi =  0.3889 (upper bound = 9.49). The data tests normal.


        Output from statistical treatment

  AOA(2) MIX full set EALF

   Number of data points (n)                           36
   Linear regression, k(X)                            1.0007 + (-8.7123E-03)*X
   Confidence on fit (1-gamma) [input]                 95.0%
   Confidence on proportion (alpha) [input]            95.0%
   Proportion of population falling above
   lower tolerance interval (rho) [input]              99.9%
   Minimum value of X                                     0.0794
   Maximum value of X                                     0.9085
   Average value of X                                     0.24900
   Average value of k                                   0.99848
   Minimum value of k                                   0.99220
   Variance of fit, s(k,X)^2                           1.1132E-05
   Within variance, s(w)^2                             1.6194E-05
   Pooled variance, s(p)^2                             2.7326E-05
   Pooled std. deviation, s(p)                         5.2274E-03
   C(alpha,rho)*s(p)                                   2.6833E-02
   student-t @ (n-2,1-gamma)                           1.69180E+00
   Confidence band width, W                            1.0036E-02
   Minimum margin of subcriticality, C*s(p)-W          1.6797E-02

   Upper subcritical limits: ( 7.94010E-02 <= X <=  0.90846     )
```

```
     ***** *********** *******

     USL Method 1 (Confidence Band with
     Administrative Margin)            USL1 = 0.9406 + (-8.7123E-03)*X

     USL Method 2 (Single-Sided Uniform
     Width Closed Interval Approach)   USL2 = 0.9738 + (-8.7123E-03)*X


     USLs Evaluated Over Range of Parameter X:
     **** ********* **** ***** ** ********* **

     X:  7.94E-2  1.98E-1  3.16E-1  4.35E-1  5.53E-1  6.72E-1  7.90E-1  9.08E-1
         ----------------------------------------------------------------------
 USL-1:    0.9399   0.9389   0.9379   0.9368   0.9358   0.9348   0.9337   0.9327
 USL-2:    0.9731   0.9721   0.9711   0.9700   0.9690   0.9680   0.9669   0.9659
         ----------------------------------------------------------------------

  ***************************************************************************
                           Thus spake USLSTATS
                                 Finis.
```

Figure A3–5 AOA(2) – k_{eff} versus v^m/v^f as trending parameter – SCALE 4.4a on PC

```
              uslstats: a utility to calculate upper subcritical
                        limits for criticality safety applications

  ***************************************************************************
                     Version 1.3.7, May 18, 1999
                      Oak Ridge National Laboratory
  ***************************************************************************


   Input to statistical treatment from file:toto.inp

Title: AOA(2) MIX full set Vm/Vf

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =   36
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05


   independent     dependent       deviation                  independent     dependent       deviation
   variable - x    variable - y     in y                      variable - x    variable - y     in y

    1.19000E+00     9.94700E-01     5.93043E-03                2.98000E+00     9.96700E-01     3.96232E-03
    1.19000E+00     9.95500E-01     4.53982E-03                4.24000E+00     9.98100E-01     4.06079E-03
    2.52000E+00     1.00020E+00     2.78927E-03                4.24000E+00     9.98600E-01     4.04475E-03
    2.52000E+00     1.00470E+00     1.80278E-03                4.24000E+00     9.98700E-01     4.04475E-03
    3.64000E+00     1.00180E+00     1.93132E-03                5.55000E+00     9.99700E-01     5.13517E-03
    3.64000E+00     1.00660E+00     2.08806E-03                5.55000E+00     1.00000E+00     5.13517E-03
    1.68000E+00     9.92200E-01     7.15433E-03                1.93000E+00     9.95600E-01     2.21359E-03
    2.16000E+00     9.95600E-01     5.78558E-03                2.56000E+00     9.93900E-01     2.40416E-03
    2.16000E+00     9.95700E-01     5.77260E-03                3.62000E+00     1.00320E+00     2.52982E-03
    2.16000E+00     9.94200E-01     5.26673E-03                4.53000E+00     1.00200E+00     2.02485E-03
    4.71000E+00     9.98000E-01     2.94090E-03                7.27000E+00     1.00530E+00     2.59615E-03
    5.67000E+00     1.00040E+00     2.45204E-03                1.01100E+01     1.00650E+00     2.76586E-03
    1.07500E+01     1.00360E+00     2.09067E-03                1.10000E+00     9.97600E-01     5.23450E-03
    2.42000E+00     9.93300E-01     4.63897E-03                1.56000E+00     9.94800E-01     4.04475E-03
    2.42000E+00     9.95800E-01     4.66905E-03                2.71000E+00     9.97700E-01     2.66833E-03
    2.42000E+00     9.95300E-01     4.63897E-03                3.79000E+00     9.98600E-01     3.05941E-03
    2.98000E+00     9.95000E-01     3.96232E-03                5.14000E+00     9.99700E-01     3.84708E-03
    2.98000E+00     9.96500E-01     3.96232E-03                5.58000E+00     9.99600E-01     4.34166E-03

   chi =  0.3889 (upper bound = 9.49). The data tests normal.


         Output from statistical treatment

   AOA(2) MIX full set Vm/Vf

    Number of data points (n)                          36
    Linear regression, k(X)                           0.9941 + ( 1.1733E-03)*X
    Confidence on fit (1-gamma) [input]                95.0%
    Confidence on proportion (alpha) [input]           95.0%
    Proportion of population falling above
    lower tolerance interval (rho) [input]             99.9%
    Minimum value of X                                    1.1000
    Maximum value of X                                   10.7500
    Average value of X                                    3.71972
    Average value of k                                  0.99848
    Minimum value of k                                  0.99220
    Variance of fit, s(k,X)^2                          7.8921E-06
    Within variance, s(w)^2                            1.6194E-05
    Pooled variance, s(p)^2                            2.4087E-05
    Pooled std. deviation, s(p)                        4.9078E-03
    C(alpha,rho)*s(p)                                  2.5437E-02
    student-t @ (n-2,1-gamma)                          1.69180E+00
    Confidence band width, W                           9.5203E-03
    Minimum margin of subcriticality, C*s(p)-W         1.5916E-02

    Upper subcritical limits: (  1.1000      <= X <=    10.750     )
```

```
     ***** *********** *******

     USL Method 1 (Confidence Band with
     Administrative Margin)        USL1 = 0.9346 + ( 1.1733E-03)*X (X <     5.0124    )
                                        = 0.9405                    (X >=    5.012)

     USL Method 2 (Single-Sided Uniform
     Width Closed Interval Approach)    USL2 = 0.9687 + ( 1.1733E-03)*X (X <     5.0124    )
                                        = 0.9746                    (X >=    5.012)


     USLs Evaluated Over Range of Parameter X:
     **** ********* **** ***** ** ********* **

     X:  1.10E+0  2.48E+0  3.86E+0  5.24E+0  6.61E+0  7.99E+0  9.37E+0  1.08E+1
        -----------------------------------------------------------------------
USL-1:     0.9359   0.9375   0.9391   0.9405   0.9405   0.9405   0.9405   0.9405
USL-2:     0.9700   0.9716   0.9732   0.9746   0.9746   0.9746   0.9746   0.9746
        -----------------------------------------------------------------------

  ****************************************************************************
                              Thus spake USLSTATS
                                     Finis.
```

Figure A3–6 AOA(2) – k_{eff} versus Pu content as trending parameter – SCALE 4.4a on PC

```
          uslstats: a utility to calculate upper subcritical
                    limits for criticality safety applications

***************************************************************************
                    Version 1.3.7, May 18, 1999
                     Oak Ridge National Laboratory
***************************************************************************


   Input to statistical treatment from file:toto.inp

Title: AOA(2) MIX full set PuO2

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =  36
   Minimum value of closed band =   0.00
   Maximum value of closed band =   0.00
   Administrative margin        =   0.05

   independent     dependent       deviation              independent     dependent       deviation
   variable - x    variable - y     in y                  variable - x    variable - y     in y

    2.04000E+00     9.94700E-01     5.93043E-03            3.01000E+00     9.96700E-01     3.96232E-03
    2.04000E+00     9.95500E-01     4.53982E-03            3.01000E+00     9.98100E-01     4.06079E-03
    2.04000E+00     1.00020E+00     2.78927E-03            3.01000E+00     9.98600E-01     4.04475E-03
    2.04000E+00     1.00470E+00     1.80278E-03            3.01000E+00     9.98700E-01     4.04475E-03
    2.04000E+00     1.00180E+00     1.93132E-03            3.01000E+00     9.99700E-01     5.13517E-03
    2.04000E+00     1.00660E+00     2.08806E-03            3.01000E+00     1.00000E+00     5.13517E-03
    6.60000E+00     9.92200E-01     7.15433E-03            4.00000E+00     9.95600E-01     2.21359E-03
    6.60000E+00     9.95600E-01     5.78558E-03            4.00000E+00     9.93900E-01     2.40416E-03
    6.60000E+00     9.95700E-01     5.77260E-03            4.00000E+00     1.00320E+00     2.52982E-03
    6.60000E+00     9.94200E-01     5.26673E-03            4.00000E+00     1.00200E+00     2.02485E-03
    6.60000E+00     9.98000E-01     2.94090E-03            4.00000E+00     1.00530E+00     2.59615E-03
    6.60000E+00     1.00040E+00     2.45204E-03            4.00000E+00     1.00650E+00     2.76586E-03
    6.60000E+00     1.00360E+00     2.09067E-03            1.50000E+00     9.97600E-01     5.23450E-03
    3.01000E+00     9.93300E-01     4.63897E-03            1.50000E+00     9.94800E-01     4.04475E-03
    3.01000E+00     9.95800E-01     4.66905E-03            1.50000E+00     9.97700E-01     2.66833E-03
    3.01000E+00     9.95300E-01     4.63897E-03            1.50000E+00     9.98600E-01     3.05941E-03
    3.01000E+00     9.95000E-01     3.96232E-03            1.50000E+00     9.99700E-01     3.84708E-03
    3.01000E+00     9.96500E-01     3.96232E-03            1.50000E+00     9.99600E-01     4.34166E-03

   chi =  0.3889 (upper bound = 9.49). The data tests normal.


         Output from statistical treatment

   AOA(2) MIX full set PuO2

    Number of data points (n)                      36
    Linear regression, k(X)                       0.9994 + (-2.5117E-04)*X
    Confidence on fit (1-gamma) [input]            95.0%
    Confidence on proportion (alpha) [input]       95.0%
    Proportion of population falling above
    lower tolerance interval (rho) [input]         99.9%
    Minimum value of X                               1.5000
    Maximum value of X                               6.6000
    Average value of X                               3.45972
    Average value of k                              0.99848
    Minimum value of k                              0.99220
    Variance of fit, s(k,X)^2                      1.4666E-05
    Within variance, s(w)^2                        1.6194E-05
    Pooled variance, s(p)^2                        3.0861E-05
    Pooled std. deviation, s(p)                    5.5552E-03
    C(alpha,rho)*s(p)                              2.6473E-02
    student-t @ (n-2,1-gamma)                      1.69180E+00
    Confidence band width, W                       9.9417E-03
    Minimum margin of subcriticality, C*s(p)-W     1.6531E-02

    Upper subcritical limits: (  1.5000     <= X <=   6.6000     )
    ***** *********** *******
```

```
    USL Method 1 (Confidence Band with
    Administrative Margin)              USL1 = 0.9394 + (-2.5117E-04)*X

    USL Method 2 (Single-Sided Uniform
    Width Closed Interval Approach)     USL2 = 0.9729 + (-2.5117E-04)*X


    USLs Evaluated Over Range of Parameter X:
    **** ********* **** ***** ** ********* **

    X:  1.50E+0  2.23E+0  2.96E+0  3.69E+0  4.41E+0  5.14E+0  5.87E+0  6.60E+0
       -----------------------------------------------------------------------
USL-1:    0.9390   0.9389   0.9387   0.9385   0.9383   0.9381   0.9379   0.9378
USL-2:    0.9725   0.9723   0.9721   0.9720   0.9718   0.9716   0.9714   0.9712
       -----------------------------------------------------------------------

  ****************************************************************************
                               Thus spake USLSTATS
                                     Finis.
```

ATTACHMENT NUMBER 4

OUTPUT LISTING OF USLSTATS V1.0 PROGRAM FOR SUN PLATFORM

Figure A4–1 AOA(1) – k_{eff} versus EALF as trending parameter – SCALE 4.4 on Sun

```
              uslstats: a utility to calculate upper subcritical
                        limits for criticality safety applications

  ****************************************************************************
                        Version 1.3.7, May 18, 1999
                         Oak Ridge National Laboratory
  ****************************************************************************


   Input to statistical treatment from file:toto.inp

Title: Test2 case data (no data supplied by user)

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =  191
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05

   independent     dependent       deviation               independent     dependent       deviation
   variable - x    variable - y      in y                  variable - x    variable - y      in y

    8.79000E-02     1.00910E+00     5.11957E-03             1.67000E-01     1.00910E+00     3.38379E-03
    1.11000E-01     1.00980E+00     5.09902E-03             1.67000E-01     1.00820E+00     3.38379E-03
    1.35000E-01     1.01090E+00     5.11957E-03             1.66000E-01     1.01030E+00     3.32415E-03
    1.51000E-01     1.00490E+00     5.11957E-03             1.69000E-01     1.00980E+00     4.41475E-03
    1.59000E-01     1.00860E+00     5.09902E-03             1.68000E-01     1.00880E+00     4.41475E-03
    3.48000E-01     1.00860E+00     5.11957E-03             1.67000E-01     1.00810E+00     4.41475E-03
    7.12000E-02     1.00820E+00     4.82701E-03             1.66000E-01     1.00820E+00     4.41475E-03
    7.29000E-02     1.00780E+00     4.82701E-03             1.67000E-01     1.00870E+00     4.46430E-03
    7.78000E-02     1.00730E+00     4.82701E-03             1.68000E-01     1.01020E+00     4.39318E-03
    8.15000E-02     1.00970E+00     4.82701E-03             1.68000E-01     1.00870E+00     4.41475E-03
    8.51000E-02     1.01270E+00     4.80521E-03             1.67000E-01     1.00780E+00     4.41475E-03
    9.29000E-02     1.00860E+00     4.82701E-03             1.67000E-01     1.00730E+00     4.41475E-03
    1.00000E-01     1.01090E+00     4.82701E-03             1.67000E-01     1.00690E+00     4.43847E-03
    5.84000E-02     1.00730E+00     4.78539E-03             1.67000E-01     1.00760E+00     4.43847E-03
    5.96000E-02     1.00700E+00     4.80521E-03             1.68000E-01     1.01020E+00     4.46430E-03
    6.18000E-02     1.00950E+00     4.78539E-03             1.68000E-01     1.00620E+00     4.43847E-03
    6.27000E-02     1.00920E+00     4.80521E-03             1.67000E-01     1.00530E+00     4.43847E-03
    6.54000E-02     1.01100E+00     4.80521E-03             1.67000E-01     1.00770E+00     4.41475E-03
    6.94000E-02     1.01030E+00     4.85077E-03             1.67000E-01     1.00760E+00     4.41475E-03
    5.91000E-02     1.01130E+00     4.82701E-03             1.67000E-01     1.00820E+00     4.46430E-03
    6.01000E-02     1.00860E+00     4.80521E-03             1.69000E-01     1.00770E+00     4.41475E-03
    5.34000E-02     1.00900E+00     4.93356E-03             1.68000E-01     1.00470E+00     4.41475E-03
    5.37000E-02     1.00190E+00     4.87647E-03             1.68000E-01     1.00680E+00     4.41475E-03
    5.48000E-02     1.00730E+00     4.93356E-03             1.68000E-01     1.00560E+00     4.43847E-03
    5.60000E-02     1.00430E+00     4.87647E-03             1.67000E-01     1.00630E+00     4.39318E-03
    5.46000E-02     1.00250E+00     4.87647E-03             1.67000E-01     1.00620E+00     4.41475E-03
    5.49000E-02     1.00440E+00     4.93356E-03             2.37000E-01     1.01190E+00     3.92938E-03
    5.59000E-02     1.01030E+00     4.93356E-03             2.37000E-01     1.01070E+00     3.92938E-03
    5.65000E-02     1.00690E+00     4.87647E-03             2.36000E-01     1.00960E+00     3.92938E-03
    5.87000E-02     1.00380E+00     4.90408E-03             2.36000E-01     1.00900E+00     3.98497E-03
    6.32000E-02     1.00490E+00     4.96488E-03             2.36000E-01     1.00970E+00     3.92938E-03
    6.85000E-02     1.00590E+00     4.87647E-03             2.36000E-01     1.00820E+00     3.95601E-03
    5.59000E-02     1.00700E+00     4.90408E-03             2.38000E-01     1.01260E+00     4.80521E-03
    5.56000E-02     1.00560E+00     4.85077E-03             2.38000E-01     1.00730E+00     4.82701E-03
    5.56000E-02     1.00620E+00     4.93356E-03             2.36000E-01     1.01070E+00     4.80521E-03
    5.66000E-02     1.00700E+00     4.90408E-03             2.36000E-01     1.00980E+00     4.82701E-03
    5.77000E-02     1.00920E+00     4.85077E-03             2.38000E-01     1.00630E+00     4.85077E-03
    6.01000E-02     1.00970E+00     4.90408E-03             2.38000E-01     1.00470E+00     4.82701E-03
    6.30000E-02     1.01140E+00     4.87647E-03             2.37000E-01     1.00910E+00     4.80521E-03
    6.61000E-02     1.00990E+00     4.93356E-03             2.35000E-01     1.01080E+00     4.82701E-03
    6.93000E-02     1.00660E+00     4.85077E-03             2.38000E-01     1.01070E+00     4.80521E-03
    5.66000E-02     1.00370E+00     4.87647E-03             2.38000E-01     1.00850E+00     4.82701E-03
    5.80000E-02     1.00440E+00     4.87647E-03             2.37000E-01     1.00910E+00     4.87647E-03
    5.24000E-02     1.00650E+00     3.59027E-03             2.38000E-01     1.00740E+00     4.43847E-03
    5.34000E-02     1.00770E+00     3.59027E-03             2.37000E-01     1.00970E+00     4.41475E-03
    5.52000E-02     1.00810E+00     3.59027E-03             2.36000E-01     1.00930E+00     4.46430E-03
    6.48000E-02     1.01400E+00     3.44819E-03             2.37000E-01     1.00970E+00     4.43847E-03
    7.85000E-02     1.01510E+00     4.17612E-03             1.68000E-01     1.00870E+00     3.98497E-03
```

```
 7.94000E-02    1.02330E+00    4.12311E-03        1.67000E-01    1.00870E+00    3.98497E-03
 8.02000E-02    1.02480E+00    4.14849E-03        1.67000E-01    1.01090E+00    3.95601E-03
 6.03000E-02    1.02680E+00    3.04631E-03        1.67000E-01    1.01030E+00    3.92938E-03
 5.71000E-02    1.02320E+00    3.04631E-03        1.65000E-01    1.00920E+00    3.51141E-03
 8.73000E-02    1.00070E+00    4.17612E-03        1.66000E-01    1.00930E+00    3.51141E-03
 5.51000E-01    1.00600E+00    6.21691E-03        1.67000E-01    1.01010E+00    3.51141E-03
 7.52000E-02    1.03200E+00    3.86005E-03        1.67000E-01    1.00830E+00    3.95601E-03
 6.62000E-02    1.02680E+00    3.28938E-03        1.67000E-01    1.00940E+00    3.98497E-03
 9.94000E-02    1.02260E+00    4.30116E-03        1.67000E-01    1.00760E+00    3.98497E-03
 7.68000E-02    1.02810E+00    4.30116E-03        1.67000E-01    1.00890E+00    3.95601E-03
 1.08000E-01    1.00670E+00    4.39659E-03        1.67000E-01    1.00890E+00    3.92938E-03
 7.46000E-02    1.01670E+00    4.27200E-03        1.67000E-01    1.00820E+00    3.95601E-03
 6.53000E-02    1.01980E+00    3.54683E-03        1.67000E-01    1.00880E+00    3.98497E-03
 7.95000E-02    1.01770E+00    4.14849E-03        1.67000E-01    1.01030E+00    3.95601E-03
 8.01000E-02    1.02480E+00    4.17612E-03        1.67000E-01    1.00960E+00    3.95601E-03
 6.05000E-02    1.02280E+00    3.04631E-03        1.67000E-01    1.01080E+00    4.01622E-03
 5.74000E-02    1.02040E+00    3.00832E-03        1.67000E-01    1.00760E+00    3.92938E-03
 8.60000E-02    1.00260E+00    4.20595E-03        1.67000E-01    1.00950E+00    3.95601E-03
 5.20000E-01    9.97600E-01    6.28172E-03        1.67000E-01    1.00830E+00    3.95601E-03
 7.73000E-02    1.02410E+00    3.86005E-03        1.67000E-01    1.01180E+00    3.98497E-03
 6.68000E-02    1.01830E+00    3.32415E-03        1.67000E-01    1.00850E+00    3.98497E-03
 9.96000E-02    1.02100E+00    4.34166E-03        1.67000E-01    1.01120E+00    3.95601E-03
 7.93000E-02    1.01940E+00    4.33244E-03        1.67000E-01    1.00680E+00    3.95601E-03
 1.47000E-01    1.01280E+00    4.42719E-03        1.67000E-01    1.00840E+00    3.95601E-03
 1.16000E-01    1.00710E+00    4.42719E-03        6.57000E-02    1.00880E+00    6.02080E-03
 8.03000E-02    1.02130E+00    4.30116E-03        6.47000E-02    1.01130E+00    6.08769E-03
 7.50000E-02    1.01720E+00    4.33244E-03        5.89000E-02    1.00590E+00    6.02080E-03
 6.36000E-02    1.01380E+00    5.36004E-03        7.63000E-02    1.00600E+00    6.06383E-03
 5.20000E-02    9.99300E-01    5.29528E-03        7.93000E-02    1.00630E+00    6.04152E-03
 6.47000E-02    1.02010E+00    5.29528E-03        6.04000E-02    1.00210E+00    6.04152E-03
 5.29000E-02    1.00510E+00    5.27731E-03        1.06000E-01    1.00960E+00    6.06383E-03
 6.70000E-02    1.02150E+00    5.29528E-03        7.58000E-02    1.00240E+00    6.04152E-03
 5.29000E-02    1.00070E+00    5.29528E-03        6.48000E-02    1.01000E+00    6.08769E-03
 6.78000E-02    1.01570E+00    5.27731E-03        5.85000E-02    1.00780E+00    6.02080E-03
 5.41000E-02    9.99000E-01    5.27731E-03        7.59000E-02    1.00650E+00    6.06383E-03
 7.55000E-02    1.00980E+00    5.29528E-03        7.92000E-02    1.00550E+00    6.04152E-03
 5.56000E-02    1.00890E+00    5.29528E-03        7.60000E-02    1.00050E+00    6.06383E-03
 5.93000E-02    1.00560E+00    5.27731E-03        1.07000E-01    1.00040E+00    6.08769E-03
 5.40000E-02    1.00450E+00    5.27731E-03        7.87000E-02    1.01500E+00    3.92046E-03
 1.68000E-01    1.00900E+00    3.35261E-03        7.88000E-02    1.01550E+00    3.92046E-03
 1.67000E-01    1.00790E+00    3.38379E-03        7.91000E-02    1.01600E+00    3.92046E-03
 1.67000E-01    1.00910E+00    3.38379E-03        7.97000E-02    1.01610E+00    3.92046E-03
 1.67000E-01    1.00860E+00    3.35261E-03        8.02000E-02    1.01210E+00    3.92046E-03
 1.67000E-01    1.00900E+00    3.38379E-03        8.05000E-02    1.00970E+00    3.92046E-03
 1.67000E-01    1.00770E+00    3.38379E-03        8.82000E-02    9.99600E-01    5.22398E-03
 1.68000E-01    1.00990E+00    3.41760E-03        8.89000E-02    9.97400E-01    5.22398E-03
 1.67000E-01    1.00810E+00    3.38379E-03        8.90000E-02    9.96800E-01    5.11566E-03
 1.68000E-01    1.00800E+00    3.32415E-03
chi = 69.1309 (upper bound = 9.49). The data tests NOT normal


      Output from statistical treatment

Test2 case data (no data supplied by user)

 Number of data points (n)                      191
 Linear regression, k(X)                        1.0113 + (-1.2867E-02)*X
 Confidence on fit (1-gamma) [input]             95.0%
 Confidence on proportion (alpha) [input]        95.0%
 Proportion of population falling above
 lower tolerance interval (rho) [input]          99.9%
 Minimum value of X                                0.0520
 Maximum value of X                                0.5510
 Average value of X                                0.12713
 Average value of k                              1.00963
 Minimum value of k                              0.99680
 Variance of fit, s(k,X)^2                      3.2416E-05
 Within variance, s(w)^2                        2.0902E-05
 Pooled variance, s(p)^2                        5.3318E-05
 Pooled std. deviation, s(p)                    7.3019E-03
 C(alpha,rho)*s(p)                              4.1941E-02
 student-t @ (n-2,1-gamma)                      1.64500E+00
 Confidence band width, W                       1.2996E-02
 Minimum margin of subcriticality, C*s(p)-W     2.8945E-02

 Upper subcritical limits: ( 5.20000E-02 <= X <=  0.55100    )
 ***** *********** *******
```

```
    USL Method 1 (Confidence Band with
    Administrative Margin)           USL1 = 0.9370 ( 5.20000E-2< X < 0.55100    )

    USL Method 2 (Single-Sided Uniform
    Width Closed Interval Approach)  USL2 = 0.9581 ( 5.20000E-2< X < 0.55100    )


    USLs Evaluated Over Range of Parameter X:
    **** ********* **** ***** ** ********* **

    X:  5.20E-2  1.23E-1  1.95E-1  2.66E-1  3.37E-1  4.08E-1  4.80E-1  5.51E-1
       -------------------------------------------------------------------------
USL-1:    0.9370   0.9370   0.9370   0.9370   0.9370   0.9370   0.9370   0.9370
USL-2:    0.9581   0.9581   0.9581   0.9581   0.9581   0.9581   0.9581   0.9581
       -------------------------------------------------------------------------

  *****************************************************************************
                                 Thus spake USLSTATS
                                        Finis.
```

Figure A4–2 AOA(1) – k_{eff} versus H/Pu as trending parameter – SCALE 4.4 on Sun

```
              uslstats: a utility to calculate upper subcritical
                        limits for criticality safety applications

  ****************************************************************************
                        Version 1.3.7, May 18, 1999
                         Oak Ridge National Laboratory
  ****************************************************************************


   Input to statistical treatment from file:toto.inp

Title: Test2 case data (no data supplied by user)

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =  191
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05

   independent     dependent       deviation               independent     dependent       deviation
   variable - x    variable - y      in y                  variable - x    variable - y      in y

    3.52910E+02     1.00910E+00     5.11957E-03             2.10180E+02     1.00910E+00     3.38379E-03
    2.58050E+02     1.00980E+00     5.09902E-03             2.10180E+02     1.00820E+00     3.38379E-03
    2.05140E+02     1.01090E+00     5.11957E-03             2.10180E+02     1.01030E+00     3.32415E-03
    1.80970E+02     1.00490E+00     5.11957E-03             2.10180E+02     1.00980E+00     4.41475E-03
    1.71210E+02     1.00860E+00     5.09902E-03             2.10180E+02     1.00880E+00     4.41475E-03
    8.66600E+01     1.00860E+00     5.11957E-03             2.10180E+02     1.00810E+00     4.41475E-03
    5.07980E+02     1.00820E+00     4.82701E-03             2.10180E+02     1.00820E+00     4.41475E-03
    4.89180E+02     1.00780E+00     4.82701E-03             2.10180E+02     1.00870E+00     4.46430E-03
    4.37280E+02     1.00730E+00     4.82701E-03             2.10180E+02     1.01020E+00     4.39318E-03
    4.07450E+02     1.00970E+00     4.82701E-03             2.10180E+02     1.00870E+00     4.41475E-03
    3.80570E+02     1.01270E+00     4.80521E-03             2.10180E+02     1.00780E+00     4.41475E-03
    3.33540E+02     1.00860E+00     4.82701E-03             2.10180E+02     1.00730E+00     4.41475E-03
    2.99260E+02     1.01090E+00     4.82701E-03             2.10180E+02     1.00690E+00     4.43847E-03
    7.74150E+02     1.00730E+00     4.78539E-03             2.10180E+02     1.00760E+00     4.43847E-03
    7.42710E+02     1.00700E+00     4.80521E-03             2.10180E+02     1.01020E+00     4.46430E-03
    6.77170E+02     1.00950E+00     4.78539E-03             2.10180E+02     1.00620E+00     4.43847E-03
    6.60550E+02     1.00920E+00     4.80521E-03             2.10180E+02     1.00530E+00     4.43847E-03
    6.07170E+02     1.01100E+00     4.80521E-03             2.10180E+02     1.00770E+00     4.41475E-03
    5.45330E+02     1.01030E+00     4.85077E-03             2.10180E+02     1.00760E+00     4.41475E-03
    7.14830E+02     1.01130E+00     4.82701E-03             2.10180E+02     1.00820E+00     4.46430E-03
    6.92120E+02     1.00860E+00     4.80521E-03             2.10180E+02     1.00770E+00     4.41475E-03
    9.81670E+02     1.00900E+00     4.93356E-03             2.10180E+02     1.00470E+00     4.41475E-03
    9.71630E+02     1.00190E+00     4.87647E-03             2.10180E+02     1.00680E+00     4.41475E-03
    9.29600E+02     1.00730E+00     4.93356E-03             2.10180E+02     1.00560E+00     4.43847E-03
    8.84120E+02     1.00430E+00     4.87647E-03             2.10180E+02     1.00630E+00     4.39318E-03
    9.25520E+02     1.00250E+00     4.87647E-03             2.10180E+02     1.00620E+00     4.41475E-03
    8.98580E+02     1.00440E+00     4.93356E-03             1.55210E+02     1.01190E+00     3.92938E-03
    8.64010E+02     1.01030E+00     4.93356E-03             1.55270E+02     1.01070E+00     3.92938E-03
    8.41980E+02     1.00690E+00     4.87647E-03             1.55270E+02     1.00960E+00     3.92938E-03
    7.80210E+02     1.00380E+00     4.90408E-03             1.55270E+02     1.00900E+00     3.98497E-03
    6.67980E+02     1.00490E+00     4.96488E-03             1.55270E+02     1.00970E+00     3.92938E-03
    5.73340E+02     1.00590E+00     4.87647E-03             1.55270E+02     1.00820E+00     3.95601E-03
    8.65010E+02     1.00700E+00     4.90408E-03             1.55270E+02     1.01260E+00     4.80521E-03
    8.72210E+02     1.00560E+00     4.85077E-03             1.55270E+02     1.00730E+00     4.82701E-03
    8.66360E+02     1.00620E+00     4.93356E-03             1.55270E+02     1.01070E+00     4.80521E-03
    8.32710E+02     1.00700E+00     4.90408E-03             1.55270E+02     1.00980E+00     4.82701E-03
    8.00710E+02     1.00920E+00     4.85077E-03             1.55270E+02     1.00630E+00     4.85077E-03
    7.34370E+02     1.00970E+00     4.90408E-03             1.55270E+02     1.00470E+00     4.82701E-03
    6.66080E+02     1.01140E+00     4.87647E-03             1.55270E+02     1.00910E+00     4.80521E-03
    6.07890E+02     1.00990E+00     4.93356E-03             1.55270E+02     1.01080E+00     4.82701E-03
    5.57170E+02     1.00660E+00     4.85077E-03             1.55270E+02     1.01070E+00     4.80521E-03
    8.30640E+02     1.00370E+00     4.87647E-03             1.55270E+02     1.00850E+00     4.82701E-03
    7.88950E+02     1.00440E+00     4.87647E-03             1.55270E+02     1.00910E+00     4.87647E-03
    1.02816E+03     1.00650E+00     3.59027E-03             1.55270E+02     1.00740E+00     4.43847E-03
    9.86180E+02     1.00770E+00     3.59027E-03             1.55270E+02     1.00970E+00     4.41475E-03
    9.10900E+02     1.00810E+00     3.59027E-03             1.55270E+02     1.00930E+00     4.46430E-03
    6.83880E+02     1.01400E+00     3.44819E-03             1.55270E+02     1.00970E+00     4.43847E-03
    4.95930E+02     1.01510E+00     4.17612E-03             2.10180E+02     1.00870E+00     3.98497E-03
    4.88550E+02     1.02330E+00     4.12311E-03             2.10170E+02     1.00870E+00     3.98497E-03
```

```
 4.86150E+02   1.02480E+00   4.14849E-03          2.10170E+02   1.01090E+00   3.95601E-03
 7.82400E+02   1.02680E+00   3.04631E-03          2.10170E+02   1.01030E+00   3.92938E-03
 8.67100E+02   1.02320E+00   3.04631E-03          2.10170E+02   1.00920E+00   3.51141E-03
 4.54500E+02   1.00070E+00   4.17612E-03          2.10170E+02   1.00930E+00   3.51141E-03
 8.50300E+01   1.00600E+00   6.21691E-03          2.10170E+02   1.01010E+00   3.51141E-03
 5.21450E+02   1.03200E+00   3.86005E-03          2.10180E+02   1.00830E+00   3.95601E-03
 6.50830E+02   1.02680E+00   3.28938E-03          2.10180E+02   1.00940E+00   3.98497E-03
 3.44020E+02   1.02260E+00   4.30116E-03          2.10180E+02   1.00760E+00   3.98497E-03
 4.99920E+02   1.02810E+00   4.30116E-03          2.10180E+02   1.00890E+00   3.95601E-03
 3.28020E+02   1.00670E+00   4.39659E-03          2.10180E+02   1.00890E+00   3.92938E-03
 5.38180E+02   1.01670E+00   4.27200E-03          2.10180E+02   1.00820E+00   3.95601E-03
 6.73070E+02   1.01980E+00   3.54683E-03          2.10180E+02   1.00880E+00   3.98497E-03
 4.88550E+02   1.01770E+00   4.14849E-03          2.10180E+02   1.01030E+00   3.95601E-03
 4.86150E+02   1.02480E+00   4.17612E-03          2.10180E+02   1.00960E+00   3.95601E-03
 7.76810E+02   1.02280E+00   3.04631E-03          2.10180E+02   1.01080E+00   4.01622E-03
 8.56600E+02   1.02040E+00   3.00832E-03          2.10180E+02   1.00760E+00   3.92938E-03
 4.62990E+02   1.00260E+00   4.20595E-03          2.10180E+02   1.00950E+00   3.95601E-03
 8.84300E+01   9.97600E-01   6.28172E-03          2.10180E+02   1.00830E+00   3.95601E-03
 4.96980E+02   1.02410E+00   3.86005E-03          2.10180E+02   1.01180E+00   3.98497E-03
 6.39340E+02   1.01830E+00   3.32415E-03          2.10180E+02   1.00850E+00   3.98497E-03
 3.44020E+02   1.02100E+00   4.34166E-03          2.10180E+02   1.01120E+00   3.95601E-03
 4.74900E+02   1.01940E+00   4.33244E-03          2.10180E+02   1.00680E+00   3.95601E-03
 2.32010E+02   1.01280E+00   4.42719E-03          2.10180E+02   1.00840E+00   3.95601E-03
 3.01120E+02   1.00710E+00   4.42719E-03          6.03570E+02   1.00880E+00   6.02080E-03
 4.75390E+02   1.02130E+00   4.30116E-03          6.21120E+02   1.01130E+00   6.08769E-03
 5.31210E+02   1.01720E+00   4.33244E-03          7.47180E+02   1.00590E+00   6.02080E-03
 7.33000E+02   1.01380E+00   5.36004E-03          4.62510E+02   1.00600E+00   6.06383E-03
 1.15729E+03   9.99300E-01   5.29528E-03          4.51850E+02   1.00630E+00   6.04152E-03
 7.05450E+02   1.02010E+00   5.29528E-03          7.23850E+02   1.00210E+00   6.04152E-03
 1.10319E+03   1.00510E+00   5.27731E-03          3.42960E+02   1.00960E+00   6.06383E-03
 6.62770E+02   1.02150E+00   5.29528E-03          5.40110E+02   1.00240E+00   6.04152E-03
 1.10978E+03   1.00070E+00   5.29528E-03          6.17240E+02   1.01000E+00   6.08769E-03
 6.53420E+02   1.01570E+00   5.27731E-03          7.53990E+02   1.00780E+00   6.02080E-03
 1.05374E+03   9.99000E-01   5.27731E-03          4.65800E+02   1.00650E+00   6.06383E-03
 5.50660E+02   1.00980E+00   5.29528E-03          4.51850E+02   1.00550E+00   6.04152E-03
 9.95410E+02   1.00890E+00   5.29528E-03          5.40110E+02   1.00050E+00   6.06383E-03
 8.70370E+02   1.00560E+00   5.27731E-03          3.41170E+02   1.00040E+00   6.08769E-03
 1.05643E+03   1.00450E+00   5.27731E-03          4.24340E+02   1.01500E+00   3.92046E-03
 2.10180E+02   1.00900E+00   3.35261E-03          4.24340E+02   1.01550E+00   3.92046E-03
 2.10180E+02   1.00790E+00   3.38379E-03          4.24340E+02   1.01600E+00   3.92046E-03
 2.10180E+02   1.00910E+00   3.38379E-03          4.24340E+02   1.01610E+00   3.92046E-03
 2.10180E+02   1.00860E+00   3.35261E-03          4.24340E+02   1.01210E+00   3.92046E-03
 2.10180E+02   1.00900E+00   3.38379E-03          4.24340E+02   1.00970E+00   3.92046E-03
 2.10180E+02   1.00770E+00   3.38379E-03          4.30260E+02   9.99600E-01   5.22398E-03
 2.10180E+02   1.00990E+00   3.41760E-03          4.25560E+02   9.97400E-01   5.22398E-03
 2.10180E+02   1.00810E+00   3.38379E-03          4.25270E+02   9.96800E-01   5.11566E-03
 2.10180E+02   1.00800E+00   3.32415E-03
chi = 69.1309 (upper bound = 9.49). The data tests NOT normal


      Output from statistical treatment

Test2 case data (no data supplied by user)

 Number of data points (n)                      191
 Linear regression, k(X)                        1.0096 + ( 1.7495E-07)*X
 Confidence on fit (1-gamma) [input]             95.0%
 Confidence on proportion (alpha) [input]        95.0%
 Proportion of population falling above
 lower tolerance interval (rho) [input]          99.9%
 Minimum value of X                               85.0300
 Maximum value of X                             1157.2900
 Average value of X                              433.28293
 Average value of k                               1.00963
 Minimum value of k                               0.99680
 Variance of fit, s(k,X)^2                       3.3366E-05
 Within variance, s(w)^2                         2.0902E-05
 Pooled variance, s(p)^2                         5.4268E-05
 Pooled std. deviation, s(p)                     7.3667E-03
 C(alpha,rho)*s(p)                               3.9294E-02
 student-t @ (n-2,1-gamma)                       1.64500E+00
 Confidence band width, W                        1.2368E-02
 Minimum margin of subcriticality, C*s(p)-W      2.6926E-02

 Upper subcritical limits: (  85.030     <= X <=   1157.3     )
 ***** *********** *******

 USL Method 1 (Confidence Band with
```

```
    Administrative Margin)            USL1 = 0.9376 (  85.030    < X <  1157.3    )

    USL Method 2 (Single-Sided Uniform
    Width Closed Interval Approach)   USL2 = 0.9607 (  85.030    < X <  1157.3    )


    USLs Evaluated Over Range of Parameter X:
    **** ********* **** ***** ** ********* **

    X:  8.50E+1  2.38E+2  3.91E+2  5.45E+2  6.98E+2  8.51E+2  1.00E+3  1.16E+3
       ------------------------------------------------------------------------
USL-1:     0.9376   0.9376   0.9376   0.9376   0.9376   0.9376   0.9376   0.9376
USL-2:     0.9607   0.9607   0.9607   0.9607   0.9607   0.9607   0.9607   0.9607
       ------------------------------------------------------------------------

  ****************************************************************************
                              Thus spake USLSTATS
                                     Finis.
```

Figure A4–3 AOA(1) – k_{eff} versus ^{240}Pu content as trending parameter – SCALE 4.4 on Sun

```
          uslstats: a utility to calculate upper subcritical
                    limits for criticality safety applications

 **************************************************************************
                    Version 1.3.7, May 18, 1999
                     Oak Ridge National Laboratory
 **************************************************************************


  Input to statistical treatment from file:toto.inp

Title: AOA(1) SUN Pu240

  Proportion of the population = .999
  Confidence of fit            = .950
  Confidence on proportion     = .950
  Number of observations       =  46
  Minimum value of closed band =    0.00
  Maximum value of closed band =    0.00
  Administrative margin        =    0.05

  independent     dependent       deviation              independent     dependent       deviation
  variable - x    variable - y     in y                  variable - x    variable - y     in y

   4.67000E+00     1.00910E+00     5.11957E-03            5.40000E-01     1.00730E+00     4.93356E-03
   4.67000E+00     1.00980E+00     5.09902E-03            5.40000E-01     1.00430E+00     4.87647E-03
   4.67000E+00     1.01090E+00     5.11957E-03            1.76000E+00     1.00250E+00     4.87647E-03
   4.67000E+00     1.00490E+00     5.11957E-03            3.12000E+00     1.00440E+00     4.93356E-03
   4.67000E+00     1.00860E+00     5.09902E-03            3.12000E+00     1.01030E+00     4.93356E-03
   4.67000E+00     1.00860E+00     5.11957E-03            3.12000E+00     1.00690E+00     4.87647E-03
   3.12000E+00     1.00820E+00     4.82701E-03            3.12000E+00     1.00380E+00     4.90408E-03
   3.12000E+00     1.00780E+00     4.82701E-03            3.12000E+00     1.00490E+00     4.96488E-03
   3.12000E+00     1.00730E+00     4.82701E-03            3.12000E+00     1.00590E+00     4.87647E-03
   3.12000E+00     1.00970E+00     4.82701E-03            3.12000E+00     1.00700E+00     4.90408E-03
   3.12000E+00     1.01270E+00     4.80521E-03            3.43000E+00     1.00560E+00     4.85077E-03
   3.12000E+00     1.00860E+00     4.82701E-03            4.05000E+00     1.00620E+00     4.93356E-03
   3.12000E+00     1.01090E+00     4.82701E-03            4.05000E+00     1.00700E+00     4.90408E-03
   1.76000E+00     1.00730E+00     4.78539E-03            4.05000E+00     1.00920E+00     4.85077E-03
   1.76000E+00     1.00700E+00     4.80521E-03            4.05000E+00     1.00970E+00     4.90408E-03
   3.12000E+00     1.00950E+00     4.78539E-03            4.05000E+00     1.01140E+00     4.87647E-03
   3.12000E+00     1.00920E+00     4.80521E-03            4.05000E+00     1.00990E+00     4.93356E-03
   3.12000E+00     1.01100E+00     4.80521E-03            4.05000E+00     1.00660E+00     4.85077E-03
   3.12000E+00     1.01030E+00     4.85077E-03            4.40000E+00     1.00370E+00     4.87647E-03
   3.12000E+00     1.01130E+00     4.82701E-03            4.40000E+00     1.00440E+00     4.87647E-03
   3.12000E+00     1.00860E+00     4.80521E-03            3.12000E+00     1.00650E+00     3.59027E-03
   5.40000E-01     1.00900E+00     4.93356E-03            3.12000E+00     1.00770E+00     3.59027E-03
   5.40000E-01     1.00190E+00     4.87647E-03            3.12000E+00     1.00810E+00     3.59027E-03

  chi =  1.6087 (upper bound = 9.49). The data tests normal.


        Output from statistical treatment

  AOA(1) SUN Pu240

   Number of data points (n)                          46
   Linear regression, k(X)                           1.0057 + ( 6.1803E-04)*X
   Confidence on fit (1-gamma) [input]                95.0%
   Confidence on proportion (alpha) [input]           95.0%
   Proportion of population falling above
   lower tolerance interval (rho) [input]             99.9%
   Minimum value of X                                   0.5400
   Maximum value of X                                   4.6700
   Average value of X                                   3.21304
   Average value of k                                 1.00773
   Minimum value of k                                 1.00190
   Variance of fit, s(k,X)^2                          5.9911E-06
   Within variance, s(w)^2                            2.3285E-05
   Pooled variance, s(p)^2                            2.9276E-05
   Pooled std. deviation, s(p)                        5.4107E-03
   C(alpha,rho)*s(p)                                  2.5367E-02
```

```
      student-t @ (n-2,1-gamma)                        1.68140E+00
      Confidence band width, W                         9.7570E-03
      Minimum margin of subcriticality, C*s(p)-W       1.5610E-02

      Upper subcritical limits: ( 0.54000     <= X <=    4.6700     )
      ***** *********** *******

      USL Method 1 (Confidence Band with
      Administrative Margin)            USL1 = 0.9402 ( 0.54000     < X <   4.6700     )

      USL Method 2 (Single-Sided Uniform
      Width Closed Interval Approach)   USL2 = 0.9746 ( 0.54000     < X <   4.6700     )


      USLs Evaluated Over Range of Parameter X:
      **** ********* **** ***** ** ********* **

      X:   5.40E-1  1.13E+0  1.72E+0  2.31E+0  2.90E+0  3.49E+0  4.08E+0  4.67E+0
          ------------------------------------------------------------------------
  USL-1:     0.9402   0.9402   0.9402   0.9402   0.9402   0.9402   0.9402   0.9402
  USL-2:     0.9746   0.9746   0.9746   0.9746   0.9746   0.9746   0.9746   0.9746
          ------------------------------------------------------------------------

   ****************************************************************************
                              Thus spake USLSTATS
                                     Finis.
```

Figure A4–4 AOA(2) – k_{eff} versus EALF as trending parameter – SCALE 4.4 on Sun

```
              uslstats: a utility to calculate upper subcritical
                        limits for criticality safety applications

  ****************************************************************************
                        Version 1.3.7, May 18, 1999
                         Oak Ridge National Laboratory
  ****************************************************************************


   Input to statistical treatment from file:toto.inp

Title: AOA(2) Mix full set EALF

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =  36
   Minimum value of closed band =   0.00
   Maximum value of closed band =   0.00
   Administrative margin        =   0.05

   independent     dependent       deviation               independent     dependent       deviation
   variable - x    variable - y     in y                   variable - x    variable - y     in y

    5.76000E-01     9.93100E-01     6.02080E-03             1.18000E-01     9.96600E-01     4.11096E-03
    7.67000E-01     9.96000E-01     4.71275E-03             9.24000E-02     9.97900E-01     4.17612E-03
    1.93000E-01     1.00020E+00     2.95466E-03             9.24000E-02     9.97900E-01     4.17612E-03
    2.82000E-01     1.00570E+00     2.08087E-03             9.23000E-02     9.99500E-01     4.20595E-03
    1.38000E-01     1.00180E+00     2.10950E-03             7.99000E-02     9.99800E-01     5.28867E-03
    1.83000E-01     1.00580E+00     2.28254E-03             7.95000E-02     1.00000E+00     5.21728E-03
    9.09000E-01     9.91100E-01     7.23771E-03             3.92000E-01     9.96300E-01     2.41868E-03
    5.49000E-01     9.93900E-01     5.87562E-03             2.60000E-01     9.95600E-01     2.74591E-03
    5.48000E-01     9.96400E-01     5.87562E-03             1.77000E-01     1.00410E+00     2.68328E-03
    6.54000E-01     9.97100E-01     5.35616E-03             1.46000E-01     1.00330E+00     2.36009E-03
    1.89000E-01     1.00130E+00     3.11431E-03             1.08000E-01     1.00520E+00     2.96816E-03
    1.56000E-01     1.00110E+00     2.68561E-03             9.35000E-02     1.00690E+00     3.13847E-03
    1.02000E-01     1.00220E+00     2.36027E-03             5.48000E-01     9.97700E-01     5.29528E-03
    1.46000E-01     9.91600E-01     4.75395E-03             3.06000E-01     9.93400E-01     4.12311E-03
    1.45000E-01     9.94000E-01     4.78017E-03             1.57000E-01     9.95100E-01     2.86356E-03
    1.44000E-01     9.94400E-01     4.78017E-03             1.17000E-01     9.97900E-01     3.13209E-03
    1.20000E-01     9.95600E-01     4.11096E-03             9.58000E-02     9.99600E-01     3.88330E-03
    1.19000E-01     9.95200E-01     4.05216E-03             9.16000E-02     1.00040E+00     4.37379E-03

   WARNING *** the test for normal may be unreliable due to insufficient data.

   chi =  2.3333 (upper bound = 9.49). The data tests normal.


         Output from statistical treatment

   AOA(2) Mix full set EALF

    Number of data points (n)                          36
    Linear regression, k(X)                           1.0005 + (-8.4182E-03)*X
    Confidence on fit (1-gamma) [input]                95.0%
    Confidence on proportion (alpha) [input]           95.0%
    Proportion of population falling above
    lower tolerance interval (rho) [input]             99.9%
    Minimum value of X                                    0.0795
    Maximum value of X                                    0.9090
    Average value of X                                    0.24907
    Average value of k                                  0.99844
    Minimum value of k                                  0.99110
    Variance of fit, s(k,X)^2                          1.4297E-05
    Within variance, s(w)^2                            1.7282E-05
    Pooled variance, s(p)^2                            3.1579E-05
    Pooled std. deviation, s(p)                        5.6195E-03
    C(alpha,rho)*s(p)                                  2.8854E-02
    student-t @ (n-2,1-gamma)                          1.69180E+00
    Confidence band width, W                           1.0792E-02
```

```
    Minimum margin of subcriticality, C*s(p)-W        1.8062E-02

    Upper subcritical limits: ( 7.95000E-02 <= X <=  0.90900    )
    ***** *********** *******

    USL Method 1 (Confidence Band with
    Administrative Margin)            USL1 = 0.9397 + (-8.4182E-03)*X

    USL Method 2 (Single-Sided Uniform
    Width Closed Interval Approach)   USL2 = 0.9717 + (-8.4182E-03)*X


    USLs Evaluated Over Range of Parameter X:
    **** ********* **** ***** ** ********* **

    X:  7.95E-2  1.98E-1  3.17E-1  4.35E-1  5.54E-1  6.72E-1  7.91E-1  9.09E-1
       ------------------------------------------------------------------------
USL-1:    0.9391   0.9381   0.9371   0.9361   0.9351   0.9341   0.9331   0.9321
USL-2:    0.9710   0.9700   0.9690   0.9680   0.9670   0.9660   0.9650   0.9640
       ------------------------------------------------------------------------

  ****************************************************************************
                              Thus spake USLSTATS
                                    Finis.
```

Figure A4–5 AOA(2) – k_{eff} versus v^m/v^f as trending parameter – SCALE 4.4 on Sun

```
              uslstats: a utility to calculate upper subcritical
                        limits for criticality safety applications

  ***************************************************************************
                        Version 1.3.7, May 18, 1999
                         Oak Ridge National Laboratory
  ***************************************************************************


   Input to statistical treatment from file:toto.inp

Title: AOA(2) Mix full set Vm/Vf

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =   36
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05

   independent     dependent       deviation              independent     dependent       deviation
   variable - x    variable - y     in y                  variable - x    variable - y     in y

    1.19000E+00     9.93100E-01     6.02080E-03            2.98000E+00     9.96600E-01     4.11096E-03
    1.19000E+00     9.96000E-01     4.71275E-03            4.24000E+00     9.97900E-01     4.17612E-03
    2.52000E+00     1.00020E+00     2.95466E-03            4.24000E+00     9.97900E-01     4.17612E-03
    2.52000E+00     1.00570E+00     2.08087E-03            4.24000E+00     9.99500E-01     4.20595E-03
    3.64000E+00     1.00180E+00     2.10950E-03            5.55000E+00     9.99800E-01     5.28867E-03
    3.64000E+00     1.00580E+00     2.28254E-03            5.55000E+00     1.00000E+00     5.21728E-03
    1.68000E+00     9.91100E-01     7.23771E-03            1.93000E+00     9.96300E-01     2.41868E-03
    2.16000E+00     9.93900E-01     5.87562E-03            2.56000E+00     9.95600E-01     2.74591E-03
    2.16000E+00     9.96400E-01     5.87562E-03            3.62000E+00     1.00410E+00     2.68328E-03
    2.16000E+00     9.97100E-01     5.35616E-03            4.53000E+00     1.00330E+00     2.36009E-03
    4.71000E+00     1.00130E+00     3.11431E-03            7.27000E+00     1.00520E+00     2.96816E-03
    5.67000E+00     1.00110E+00     2.68561E-03            1.01100E+01     1.00690E+00     3.13847E-03
    1.07500E+01     1.00220E+00     2.36027E-03            1.10000E+00     9.97700E-01     5.29528E-03
    2.42000E+00     9.91600E-01     4.75395E-03            1.56000E+00     9.93400E-01     4.12311E-03
    2.42000E+00     9.94000E-01     4.78017E-03            2.71000E+00     9.95100E-01     2.86356E-03
    2.42000E+00     9.94400E-01     4.78017E-03            3.79000E+00     9.97900E-01     3.13209E-03
    2.98000E+00     9.95600E-01     4.11096E-03            5.14000E+00     9.99600E-01     3.88330E-03
    2.98000E+00     9.95200E-01     4.05216E-03            5.58000E+00     1.00040E+00     4.37379E-03

   WARNING *** the test for normal may be unreliable due to insufficient data.

   chi =  2.3333 (upper bound = 9.49). The data tests normal.


         Output from statistical treatment

   AOA(2) Mix full set Vm/Vf

    Number of data points (n)                         36
    Linear regression, k(X)                          0.9939 + ( 1.2243E-03)*X
    Confidence on fit (1-gamma) [input]               95.0%
    Confidence on proportion (alpha) [input]          95.0%
    Proportion of population falling above
    lower tolerance interval (rho) [input]            99.9%
    Minimum value of X                                   1.1000
    Maximum value of X                                  10.7500
    Average value of X                                   3.71972
    Average value of k                                 0.99844
    Minimum value of k                                 0.99110
    Variance of fit, s(k,X)^2                         1.0185E-05
    Within variance, s(w)^2                           1.7282E-05
    Pooled variance, s(p)^2                           2.7467E-05
    Pooled std. deviation, s(p)                       5.2409E-03
    C(alpha,rho)*s(p)                                 2.7163E-02
    student-t @ (n-2,1-gamma)                         1.69180E+00
    Confidence band width, W                          1.0166E-02
```

```
Minimum margin of subcriticality, C*s(p)-W          1.6997E-02

Upper subcritical limits: ( 1.1000      <= X <=    10.750     )
***** *********** *******

USL Method 1 (Confidence Band with
Administrative Margin)             USL1 = 0.9337 + ( 1.2243E-03)*X (X <     4.9971    )
                                        = 0.9398                   (X >=    4.997)

USL Method 2 (Single-Sided Uniform
Width Closed Interval Approach)    USL2 = 0.9667 + ( 1.2243E-03)*X (X <     4.9971    )
                                        = 0.9728                   (X >=    4.997)


USLs Evaluated Over Range of Parameter X:
**** ********* **** ***** ** ********* **

    X:  1.10E+0  2.48E+0  3.86E+0  5.24E+0  6.61E+0  7.99E+0  9.37E+0  1.08E+1
        ------------------------------------------------------------------------
USL-1:    0.9351   0.9368   0.9384   0.9398   0.9398   0.9398   0.9398   0.9398
USL-2:    0.9681   0.9698   0.9714   0.9728   0.9728   0.9728   0.9728   0.9728
        ------------------------------------------------------------------------

  ****************************************************************************
                              Thus spake USLSTATS
                                     Finis.
```

Figure A4–6 AOA(2) – k_{eff} versus Pu content as trending parameter – SCALE 4.4 on Sun

```
              uslstats: a utility to calculate upper subcritical
                        limits for criticality safety applications

  ***************************************************************************
                        Version 1.3.7, May 18, 1999
                         Oak Ridge National Laboratory
  ***************************************************************************


   Input to statistical treatment from file:toto.inp

Title: AOA(2) Mix full set Pu content

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =   36
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05

   independent     dependent       deviation              independent    dependent      deviation
   variable - x    variable - y     in y                  variable - x   variable - y    in y

    2.04000E+00     9.93100E-01     6.02080E-03             3.01000E+00    9.96600E-01     4.11096E-03
    2.04000E+00     9.96000E-01     4.71275E-03             3.01000E+00    9.97900E-01     4.17612E-03
    2.04000E+00     1.00020E+00     2.95466E-03             3.01000E+00    9.97900E-01     4.17612E-03
    2.04000E+00     1.00570E+00     2.08087E-03             3.01000E+00    9.99500E-01     4.20595E-03
    2.04000E+00     1.00180E+00     2.10950E-03             3.01000E+00    9.99800E-01     5.28867E-03
    2.04000E+00     1.00580E+00     2.28254E-03             3.01000E+00    1.00000E+00     5.21728E-03
    6.60000E+00     9.91100E-01     7.23771E-03             4.00000E+00    9.96300E-01     2.41868E-03
    6.60000E+00     9.93900E-01     5.87562E-03             4.00000E+00    9.95600E-01     2.74591E-03
    6.60000E+00     9.96400E-01     5.87562E-03             4.00000E+00    1.00410E+00     2.68328E-03
    6.60000E+00     9.97100E-01     5.35616E-03             4.00000E+00    1.00330E+00     2.36009E-03
    6.60000E+00     1.00130E+00     3.11431E-03             4.00000E+00    1.00520E+00     2.96816E-03
    6.60000E+00     1.00110E+00     2.68561E-03             4.00000E+00    1.00690E+00     3.13847E-03
    6.60000E+00     1.00220E+00     2.36027E-03             1.50000E+00    9.97700E-01     5.29528E-03
    3.01000E+00     9.91600E-01     4.75395E-03             1.50000E+00    9.93400E-01     4.12311E-03
    3.01000E+00     9.94000E-01     4.78017E-03             1.50000E+00    9.95100E-01     2.86356E-03
    3.01000E+00     9.94400E-01     4.78017E-03             1.50000E+00    9.97900E-01     3.13209E-03
    3.01000E+00     9.95600E-01     4.11096E-03             1.50000E+00    9.99600E-01     3.88330E-03
    3.01000E+00     9.95200E-01     4.05216E-03             1.50000E+00    1.00040E+00     4.37379E-03

   WARNING *** the test for normal may be unreliable due to insufficient data.

   chi =  2.3333 (upper bound = 9.49). The data tests normal.


         Output from statistical treatment

   AOA(2) Mix full set Pu content

    Number of data points (n)                         36
    Linear regression, k(X)                          0.9985 + (-2.3845E-05)*X
    Confidence on fit (1-gamma) [input]               95.0%
    Confidence on proportion (alpha) [input]          95.0%
    Proportion of population falling above
    lower tolerance interval (rho) [input]            99.9%
    Minimum value of X                                   1.5000
    Maximum value of X                                   6.6000
    Average value of X                                   3.45972
    Average value of k                                 0.99844
    Minimum value of k                                 0.99110
    Variance of fit, s(k,X)^2                         1.7777E-05
    Within variance, s(w)^2                           1.7282E-05
    Pooled variance, s(p)^2                           3.5059E-05
    Pooled std. deviation, s(p)                       5.9210E-03
    C(alpha,rho)*s(p)                                 2.8216E-02
    student-t @ (n-2,1-gamma)                         1.69180E+00
    Confidence band width, W                          1.0596E-02
```

```
    Minimum margin of subcriticality, C*s(p)-W        1.7620E-02

    Upper subcritical limits: ( 1.5000     <= X <=    6.6000    )
    ***** *********** *******

    USL Method 1 (Confidence Band with
    Administrative Margin)           USL1 = 0.9379 + (-2.3845E-05)*X

    USL Method 2 (Single-Sided Uniform
    Width Closed Interval Approach)   USL2 = 0.9703 + (-2.3845E-05)*X


    USLs Evaluated Over Range of Parameter X:
    **** ********* **** ***** ** ********* **

    X:  1.50E+0  2.23E+0  2.96E+0  3.69E+0  4.41E+0  5.14E+0  5.87E+0  6.60E+0
        ------------------------------------------------------------------------
USL-1:    0.9379   0.9379   0.9379   0.9378   0.9378   0.9378   0.9378   0.9378
USL-2:    0.9703   0.9702   0.9702   0.9702   0.9702   0.9702   0.9702   0.9701
        ------------------------------------------------------------------------

  ****************************************************************************
                              Thus spake USLSTATS
                                     Finis.
```

ATTACHMENT 5

BORATED CONCRETE REFLECTORS

ABSTRACT

This attachment presents validation results for the SCALE 4.4 CSAS26 (KENO VI) criticality analysis sequence and the 238 energy group cross-section library (238GROUPNDF5) applicable to borated concrete fixed neutron absorber materials. As noted in Section 3.2, borated concrete is used in reflector regions of several MFFF plutonium nitrate aqueous solution design applications. However, the validation presented in the body of the report includes no benchmark experiment data or results for plutonium nitrate solution systems that include borated concrete neutron absorber materials. This attachment presents benchmark experiment data and validation results for high enrichment uranium nitrate aqueous solution systems that includes borated concrete supplemental absorber materials. The validation results presented for high enrichment uranium nitrate solution systems indicate that the CSAS26 criticality analysis sequence and the 238GROUPNDF5 cross-section library produce comparable results for systems with and without borated concrete neutron absorber materials present. This conclusion supports the use of the USL-1 for AOA-1 presented in Section 6.1 of this validation report as an acceptance criterion for plutonium nitrate aqueous solution systems that include borated concrete supplemental neutron absorber materials.

INTRODUCTION

Some design applications in the MFFF involving plutonium nitrate (Pu-nitrate) aqueous solutions include consideration of a full range of possible pure water reflection conditions. For those applications, the benchmarks selected in Section 4.1 are directly applicable. Other MFFF Pu-nitrate solution design applications incorporate borated concrete as a neutron absorber for criticality control purposes. A review of technical literature, including the International Handbook of Evaluated Criticality Safety Benchmark Experiments (Nuclear Energy Agency 1999), did not identify any Pu-nitrate solution benchmark experiments that included borated concrete or other boron containing neutron absorber materials. However, a number of uranium nitrate (U-nitrate) solution fissile medium experiments that include borated concrete, borated plaster, and borated water neutron absorber materials were identified. These experiments are evaluated using the SCALE 4.4 CSAS26 (KENO VI) criticality analysis sequence and the 238 energy group cross-section library (238GROUPNDF5). The results of this evaluation are used to demonstrate the applicability of the USL-1 acceptance criterion for AOA-1 presented in Section 6.1 of this validation report to Pu-nitrate systems incorporating borated concrete neutron absorber materials.

The appendix begins by providing a brief description of the high enrichment U-nitrate solution benchmark experiments and CSAS26/238GROUPNDF5 analyzed results. The results are then evaluated to accomplish the following:

1. Determine the bias, if any, between k_{eff} results obtained for experiments with borated concrete or borated plaster neutron absorbers and other similar experiments without these materials present,

2. Confirm the applicability of the U-nitrate experiment results to Pu-nitrate solution design applications, and

3. Determine the area(s) of applicability (AOA) encompassed by the borated concrete and borated plaster neutron absorber experiments evaluated and determine if any trends can be identified.

The approach taken to validate the CSAS26/238GROUPNDF5 criticality analysis methodology for application to Pu-nitrate systems incorporating borated concrete neutron absorber materials does not involve direct inclusion of the U-nitrate solution experiment data in the USL-1 determination. The approach involves a separate evaluation of the uranium-based data to demonstrate no significant method bias or uncertainty variations are observed when comparing results for systems that include borated concrete neutron absorber materials with results for systems that do not. The approach also demonstrates that the neutron absorption spectrum within the absorbing material is relatively insensitive to the source of the neutrons (e.g., U or Pu). This indirect approach is selected to avoid combining plutonium and uranium fissile medium benchmark experiment k_{eff} results in the USL-1 determination. Significant differences in method bias as a function of neutron energy spectra have been previously observed when comparing results for plutonium and uranium fissile systems (DeHart and Bowman 1994).

U-NITRATE SOLUTION EXPERIMENT DESCRIPTIONS AND ANALYZED RESULTS

The critical experiments designated as HEU-SOL-THERM-033 in the International Handbook of Evaluated Criticality Safety Benchmark Experiments are used in order to validate the CSAS26/238GROUPNDF5 code system for use in Pu-nitrate solution design applications involving borated concrete supplemental neutron absorber materials. The HEU-SOL-THERM-033 experiments were performed at the Rocky Flats Critical Mass Laboratory and involved nested annular steel tanks containing fissile material solution with various materials inserted as a "plug" in the central annulus region formed by the innermost annular tank. The tank system was situated inside a concrete enclosure. Materials inserted in the central region included air, boron-free water, borated water, boron-free concrete, borated concrete, and borated plaster. Critical heights of the highly enriched solutions were measured. Thirty-seven critical configurations were attempted during 12 experiment sets. Nine of the configurations were subcritical. Of the 28 critical configurations, 26 were judged acceptable for benchmark applications by the experiment evaluator and reviewers (Nuclear Energy Agency 1999).

All 26 HEU-SOL-THERM-033 critical experiments judged acceptable by the benchmark handbook evaluator and reviewers were analyzed using CSAS25 (238-Group ENDF/B-IV cross section library) for verification purposes. Verification results are reported in the handbook. CSAS26 input files were prepared and calculations performed using the 238GROUPNDF5 cross section set as well. The calculated k_{eff} results for the complete set of all 26 of the benchmark experiments are presented in Table 1. Also presented in Table 1 are estimated values for measured k_{eff} and experiment uncertainties reported in the handbook and results of statistical analysis performed on the calculated data. Calculated k_{eff} results and similar grouped statistical analysis results are presented in Tables 2 through 5 for the following subsets of experiments: (a) 15 experiments with no borated concrete or borated plaster, (b) 18 experiments with no boron-free concrete, (c) 19 experiments with boron-free concrete, borated concrete, or borated plaster, and (d) 11 experiments with borated concrete or borated plaster. A summary of the statistical results for the five sets of experiment results evaluated is provided in Table 6.

A review of the Table 6 results summary indicates that no significant difference in bias results for systems that include borated concrete neutron absorbers as compared to systems that do not when using CSAS26 and the 238GROUPNDF5 cross section library. For example, the evaluated variation in CSAS26 method bias indicated for benchmark experiment sets with and without borated concrete (i.e., Table 2 and 5 method bias values) is 0.0015. This variation is small compared to the level of uncertainty in the method bias accounted for in the determination of USL-1 in Section 6.1 of the report (i.e., 0.01). The results also indicate that the criticality analysis methodology tends to predict higher k_{eff} results for systems containing borated concrete than for systems without any concrete, though slightly less than for systems containing boron-free concrete. It is noted that the number of experiments in the HEU-SOL-THERM-033 set is small (26 total) with only 11 experiments with borated concrete. As noted above and shown in Table 6, the data indicates that there is no significant difference in bias results for systems that include borated concrete as compared to systems that do no. However, with this small number of experiments, it is recognized that one can not say conclusively on a statistical basis that boron has no effect. However, the fact that the results, as shown in Table 6, do not show contrary results supports the conclusion that the effect of borated concrete (as modeled in these benchmarks and is representative of borated concrete in the MFFF) is small and provides additional rationale supporting the acceptability of extrapolating Section 6.1 Pu-nitrate solution validation results to MFFF design applications containing borated concrete.

EXPERIMENT SET APPLICABILITY TO PU-NITRATE SYSTEMS

The applicability of the HEU-SOL-THERM-033 critical experiment set to design applications containing Pu-nitrate solutions is addressed through an evaluation of the neutron energy spectra in the absorbing medium. The absorbed neutron energy spectrum for the borated concrete region of benchmark experiment configuration 8a is compared to the absorption spectrum for the same region of identical configurations with Pu-nitrate substituted for the U-nitrate in the fissile medium regions. This approach is selected to demonstrate that the neutron absorption spectrum within the absorbing material is insensitive to the source of the neutrons (i.e., Pu-nitrate versus U-nitrate solution systems).

Experiment configuration 8a is selected for the purposes of this applicability demonstration since it is the most heavily borated concrete experiment in the HEU-SOL-THERM-033 set. Experiment 8a incorporates 2.5 weight percent boron in the concrete plug placed in the central region of the annular tank system.

Calculations with Pu-nitrate substituted for U-nitrate fissile medium are created with all other attributes of the HEU-SOL-THERM-033 experiment 8a remaining unaltered. Two Pu-nitrate composition cases are evaluated. In the first case, the concentration of the Pu-nitrate was specified at a value comparable to the high enrichment uranium concentration used in the HEU-SOL-THERM-033 case (i.e., H/X=70). In the second case, a value which represents optimum moderation for the Pu-nitrate isotopic composition is specified (i.e., H/X=125). In both cases, the plutonium isotopic distribution assumed is 96 weight percent Pu-239, and 4 weight percent Pu-240.

Figure 1 presents the neutron absorption energy spectra results for the three fissile medium cases evaluated. The results indicate that the borated concrete absorption spectra are similar for the three fissile medium cases evaluated and that the absorption spectra are relatively insensitive to the fissile medium composition (i.e., high enrichment uranium versus plutonium). This favorable comparison of absorption spectra supports the use of U-nitrate based benchmark experiment data in the validation of the CSAS26/238GROUPNDF5 criticality analysis method for the limited purpose of extrapolating the AOA(1) USL result to Pu-nitrate solution systems containing borated concrete as a supplemental neutron absorber.

AREA(S) OF APPLICABILITY DETERMINATION

The general arrangement of the HEU-SOL-THERM-033 critical experiments supports a conclusion that the experiments evaluated encompass the entire AOA of any MFFF Pu-nitrate design application that incorporates borated concrete as a neutron absorber material. This conclusion is based on the experiment arrangement that places borated concrete plugs in the central cavity formed by annular steel tanks containing fissile aqueous solutions. In addition to being physically similar to MFFF design applications where annular tanks are utilized with borated concrete incorporated in the central cavity, the experiment arrangements place borated concrete in a position where the absorber acts to limit interaction between opposite sides of an annular tank. Thus, the experimental arrangements incorporate the neutron absorber in a high reactivity worth region of a fissile system relative to other typical design application arrangements. Other design application arrangements involving borated concrete supplemental neutron absorber materials include reflectors external to cylindrical tank outer radial surfaces, or interaction control shields placed between physically separated fissile solution containing tanks or components.

Although the physical arrangement of the HEU-SOL-THERM-033 critical experiments supports a favorable AOA conclusion, additional analysis is necessary to fully establish the area of applicability encompassed by the borated concrete benchmark experiments included in the experiment set. Borated concrete supplemental neutron absorber materials are typically placed in a close proximity reflector region to reduce neutron reflection back into the source fissile unit, or at more remote locations between fissile units/regions to limit interaction. In any case, the borated concrete absorber will have only limited impact on the neutron spectrum characteristics of the fissile medium in aqueous solution fissile systems where the absorber is situated outside and separate from the fissile solution. Any impact on the neutron spectrum characteristics of the fissile medium is expected to be well within the fission spectrum encompassed by the AOA(1) bias basis benchmark experiment set (i.e., see Figure 6.2 of main report). Therefore, the most relevant trending parameter(s) would measure the effectiveness of the material as an absorber rather than its potential effect on a characteristic of the fissile medium, such as Energy of Average Lethargy Causing Fission (EALF). Both boron-10 (B-10) and hydrogen content are important characteristics of borated concrete absorber materials and are thus selected as additional AOA trending parameters.

Trending analysis on the B-10 and hydrogen content of materials placed in the central cavity of the annular tank experiments is performed to provide additional insights into the AOA encompassed by the HEU-SOL-THERM-033 critical experiment set. The calculated bias results presented in Table 1 and the HEU-SOL-THERM-033 critical experiment material atom density information provided in the International Handbook of Evaluated Criticality Safety Benchmark Experiments (Nuclear Energy Agency 1999) are used to produce a trending analysis. Trending analysis results are presented in Figures 2 and 3 for B-10 and hydrogen content, respectively.

The trending analysis results do not indicate any strong trends exist within the AOA covered by the experiment set (i.e., 0 to 5.4E-4 atoms/barn-cm B-10, and 0 to 6.6E-2 atoms/barn-cm for hydrogen). Although the benchmark experiment AOA for B-10 content is limited to a maximum of 5.4E-4 atoms/barn-cm B-10, the trending analysis presented in Figure 2 supports the conclusion that extrapolation of benchmark evaluation results beyond the evaluated AOA is acceptable. The data presented for hydrogen content spans a wide range of conditions from dry air to full density pure water. Thus, the hydrogen content AOA encompasses the borated concrete absorber material used in design applications.

SUMMARY

Results calculated by the CSAS26/238GROUPNDF5 criticality analysis methodology for U-nitrate aqueous solution benchmark experiments containing borated concrete, borated plaster, borated water, boron-free concrete, boron-free water, and void within the central cavity of an annular tank fissile configuration are presented. Comparisons of results for experiments containing borated materials against results for non-borated materials were performed. The comparisons did not indicate any significant bias exists between CSAS26/238GROUPNDF5 criticality analysis methodology calculated results for systems that contain borated neutron absorber materials relative to systems that are boron-free.

A comparison is also presented to demonstrate the applicability of the U-nitrate solution benchmark experiment conclusions to systems that contain Pu-nitrate aqueous solutions as a fissile medium (i.e., with respect to potential biases introduced by the presence of external borated neutron absorber materials). The absorbed neutron energy spectrum within the borated concrete medium is obtained from CSAS26 output for benchmark experiment configuration 8a (i.e., 2.5 weight percent boron case). Similar spectrum data are obtained for experiment 8a where the U-nitrate solution was replaced with Pu-nitrate with H/X ratios of 70 and 125. The absorbed neutron energy spectrum data for borated concrete was not significantly affected by substituting Pu-nitrate for the U-nitrate solution used in the actual experiment. This favorable comparison demonstrates that the neutron absorption characteristics of borated concrete incorporated separate and external to the fissile medium is not significantly affected by the fissile medium composition, and that the U-nitrate experiment derived borated concrete method bias conclusions are also applicable to Pu-nitrate aqueous solution systems.

Trending analyses are presented for borated concrete B-10 and hydrogen content for the purposes of establishing the AOA covered by the experiment set. Based on the results of this AOA trending analysis, it is concluded that the USL-1=0.9370 acceptance criterion can be assumed applicable to Pu-nitrate aqueous solution systems incorporating borated concrete external to the fissile medium over a wide range of borated concrete hydrogen or B-10 content.

It should be noted that the purpose of these three tests (impact of boron on U-nitrate, comparison of absorpotion spectra between U-nitrate and Pu-nitrate, and trending of the boron content with calculated bias) is to show that, from this data, there is no reason to suspect that the addition of boron concrete to the MFFF fissile systems causes not significant effect to cast a question on the bias determination of the 191 boron-free benchmarks evaluated. The point is, external borated concrete has little impact on the bias of the U-nitrate systems. The absorptive effects, as evidenced by the absorption spectra for both U-nitrate and Pu-nitrate systems appears to be the same, and there is no significant trend in the bias as the boron content is varied.

Table 1. CSAS Results for All Experiments in HEU-SOL-THERM-033

Experiment	Experiment/Case Description	OECD Result [1]		CSAS26; 238		Benchmark Model Bias & Uncertainty [2]			CSAS26; 238 Bias [5]
		k_{eff}	1-Sigma	k_{eff}	1-Sigma	k_{eff}	Bias	Uncertainty	
1	2a; None	1.0019	0.0011	0.9996	0.0012	0.9979	-0.0021	0.0112	0.0017
2	2b; None	0.9982	0.0012	0.9984	0.0012	1.0000	0.0000	0.0109	-0.0016
3	2c; None	0.9996	0.0010	0.9981	0.0010	0.9979	-0.0021	0.0067	0.0002
4	3a; Conc.	1.0015	0.0011	1.0014	0.0013	0.9942	-0.0058	0.0115	0.0072
5	3b; Conc.	1.0032	0.0010	1.0019	0.0013	0.9979	-0.0021	0.0112	0.0040
6	3c; Conc.	1.0110	0.0012	1.0125	0.0012	0.9979	-0.0021	0.0072	0.0146
7	4a; Conc. & Cd	0.9994	0.0011	1.0004	0.0013	0.9942	-0.0058	0.0115	0.0062
8	4b; Conc. & Cd	1.0078	0.0011	1.0060	0.0013	0.9979	-0.0021	0.0112	0.0081
9	5a; 1.2 w/o B-Conc.	1.0087	0.0011	1.0077	0.0012	0.9942	-0.0058	0.0112	0.0135
10	5b; 1.2 w/o B-Conc.	1.0077	0.0012	1.0085	0.0014	1.0000	0.0000	0.0109	0.0085
11	6a; 1.2 w/o B-Conc.	1.0031	0.0011	1.0022	0.0013	0.9942	-0.0058	0.0112	0.0080
12	6b; 1.2 w/o B-Conc.	1.0079	0.0011	1.0108	0.0012	1.0000	0.0000	0.0109	0.0108
13	7a; 1.1 w/o B-Plast.	0.9987	0.0011	0.9993	0.0012	0.9942	-0.0058	0.0112	0.0051
14	7b; 1.1 w/o B-Plast.	1.0053	0.0010	1.0058	0.0013	1.0000	0.0000	0.0109	0.0058
15	8a; 2.5 w/o B-Conc.	1.0026	0.0010	1.0034	0.0011	0.9942	-0.0058	0.0112	0.0092
16	8b; 2.5 w/o B-Conc.	1.0055	0.0011	1.0072	0.0013	1.0000	0.0000	0.0109	0.0072
17	9a; 1.1 w/o B-Plast.	0.9984	0.0011	0.9954	0.0012	0.9942	-0.0058	0.0112	0.0012
18	9b; 1.1 w/o B-Plast.	0.9961	0.0012	0.9971	0.0012	1.0000	0.0000	0.0109	-0.0029
19	9c; 1.1 w/o B-Plast.	0.9967	0.0012	0.9931	0.0012	0.9979	-0.0021	0.0105	-0.0048
20	10a; Conc.	1.0025	0.0011	1.0021	0.0011	0.9942	-0.0058	0.0115	0.0079
21	10c; Conc.	1.0027	0.0011	1.0016	0.0011	0.9979	-0.0021	0.0072	0.0036
22	10d; Conc.	0.9929	0.0011	0.9947	0.0013	0.9979	-0.0021	0.0106	-0.0032
23	11a; Water	1.0012	0.0012	1.0000	0.0012	0.9942	-0.0058	0.0112	0.0058
24	11b; Water	1.0013	0.0012	0.9982	0.0012	0.9979	-0.0021	0.0109	0.0003
25	12a; B-Water	0.9997	0.0011	0.9986	0.0011	0.9942	-0.0058	0.0112	0.0044
26	12b; B-Water	0.9996	0.0011	1.0019	0.0011	1.0000	0.0000	0.0109	0.0019
	Mean	1.0020		1.0018		0.9970	-0.0030	0.0106	
	Standard Deviation +/-	0.0043		0.0049					
	Method Bias [3]	0.0050		0.0047					
	Uncertainty in Bias [4] +/-	0.0115		0.0117					

NOTES:

[1] Table 49, International Handbook of Evaluated Criticality Safety Benchmark Experiments (Nuclear Energy Agency 1999).

[2] Table 47, International Handbook of Evaluated Criticality Safety Benchmark Experiments (Nuclear Energy Agency 1999).

[3] Method Bias = Mean - Mean Benchmark Model

[4] Uncertainty in Bias = $(\text{Standard Deviation}^2 + \text{Mean Benchmark Model Uncertainty}^2)^{0.5}$

[5] CSAS26 Bias = CSAS26; 238 k_{eff} - Benchmark Model k_{eff}.

Table 2. CSAS Results for Experiments in HEU-SOL-THERM-033; No Borated Concrete or Plaster

		OECD Result [1]		CSAS26; 238		Benchmark Model Bias & Uncertainty [2]			CSAS26; 238
Experiment	Experiment/Case Description	k_{eff}	1-Sigma	k_{eff}	1-Sigma	k_{eff}	Bias	Uncertainty	Bias [5]
1	2a; None	1.0019	0.0011	0.9996	0.0012	0.9979	-0.0021	0.0112	0.0017
2	2b; None	0.9982	0.0012	0.9984	0.0012	1.0000	0.0000	0.0109	-0.0016
3	2c; None	0.9996	0.0010	0.9981	0.0010	0.9979	-0.0021	0.0067	0.0002
4	3a; Conc.	1.0015	0.0011	1.0014	0.0013	0.9942	-0.0058	0.0115	0.0072
5	3b; Conc.	1.0032	0.0010	1.0019	0.0013	0.9979	-0.0021	0.0112	0.0040
6	3c; Conc.	1.0110	0.0012	1.0125	0.0012	0.9979	-0.0021	0.0072	0.0146
7	4a; Conc. & Cd	0.9994	0.0011	1.0004	0.0013	0.9942	-0.0058	0.0115	0.0062
8	4b; Conc. & Cd	1.0078	0.0011	1.0060	0.0013	0.9979	-0.0021	0.0112	0.0081
9	10a; Conc.	1.0025	0.0011	1.0021	0.0011	0.9942	-0.0058	0.0115	0.0079
10	10c; Conc.	1.0027	0.0011	1.0016	0.0011	0.9979	-0.0021	0.0072	0.0036
11	10d; Conc.	0.9929	0.0011	0.9947	0.0013	0.9979	-0.0021	0.0106	-0.0032
12	11a; Water	1.0012	0.0012	1.0000	0.0012	0.9942	-0.0058	0.0112	0.0058
13	11b; Water	1.0013	0.0012	0.9982	0.0012	0.9979	-0.0021	0.0109	0.0003
14	12a; B-Water	0.9997	0.0011	0.9986	0.0011	0.9942	-0.0058	0.0112	0.0044
15	12b; B-Water	0.9996	0.0011	1.0019	0.0011	1.0000	0.0000	0.0109	0.0019
	Mean	1.0015		1.0010		0.9969	-0.0031	0.0103	
	Standard Deviation +/-	0.0041		0.0041					
	Method Bias [3]	0.0046		0.0041					
	Uncertainty in Bias [4] +/-	0.0111		0.0111					

NOTES:

[1] Table 49, International Handbook of Evaluated Criticality Safety Benchmark Experiments (Nuclear Energy Agency 1999).

[2] Table 47, International Handbook of Evaluated Criticality Safety Benchmark Experiments (Nuclear Energy Agency 1999).

[3] Method Bias = Mean - Mean Benchmark Model

[4] Uncertainty in Bias = (Standard Deviation^2 + Mean Benchmark Model Uncertainty^2)$^{0.5}$

[5] CSAS26 Bias = CSAS26; 238 k_{eff} - Benchmark Model k_{eff}.

Table 3. CSAS Results for Experiments in HEU-SOL-THERM-033; No Boron-free Concrete

Experiment	Experiment/Case Description	OECD Result [1]		CSAS26; 238		Benchmark Model Bias & Uncertainty [2]			CSAS26; 238 Bias [5]
		k_{eff}	1-Sigma	k_{eff}	1-Sigma	k_{eff}	Bias	Uncertainty	
1	2a; None	1.0019	0.0011	0.9996	0.0012	0.9979	-0.0021	0.0112	0.0017
2	2b; None	0.9982	0.0012	0.9984	0.0012	1.0000	0.0000	0.0109	-0.0016
3	2c; None	0.9996	0.0010	0.9981	0.0010	0.9979	-0.0021	0.0067	0.0002
4	5a; 1.2 w/o B-Conc.	1.0087	0.0011	1.0077	0.0012	0.9942	-0.0058	0.0112	0.0135
5	5b; 1.2 w/o B-Conc.	1.0077	0.0012	1.0085	0.0014	1.0000	0.0000	0.0109	0.0085
6	6a; 1.2 w/o B-Conc.	1.0031	0.0011	1.0022	0.0013	0.9942	-0.0058	0.0112	0.0080
7	6b; 1.2 w/o B-Conc.	1.0079	0.0011	1.0108	0.0012	1.0000	0.0000	0.0109	0.0108
8	7a; 1.1 w/o B-Plast.	0.9987	0.0011	0.9993	0.0012	0.9942	-0.0058	0.0112	0.0051
9	7b; 1.1 w/o B-Plast.	1.0053	0.0010	1.0058	0.0013	1.0000	0.0000	0.0109	0.0058
10	8a; 2.5 w/o B-Conc.	1.0026	0.0010	1.0034	0.0011	0.9942	-0.0058	0.0112	0.0092
11	8b; 2.5 w/o B-Conc.	1.0055	0.0011	1.0072	0.0013	1.0000	0.0000	0.0109	0.0072
12	9a; 1.1 w/o B-Plast.	0.9984	0.0011	0.9954	0.0012	0.9942	-0.0058	0.0112	0.0012
13	9b; 1.1 w/o B-Plast.	0.9961	0.0012	0.9971	0.0012	1.0000	0.0000	0.0109	-0.0029
14	9c; 1.1 w/o B-Plast.	0.9967	0.0012	0.9931	0.0012	0.9979	-0.0021	0.0105	-0.0048
15	11a; Water	1.0012	0.0012	1.0000	0.0012	0.9942	-0.0058	0.0112	0.0058
16	11b; Water	1.0013	0.0012	0.9982	0.0012	0.9979	-0.0021	0.0109	0.0003
17	12a; B-Water	0.9997	0.0011	0.9986	0.0011	0.9942	-0.0058	0.0112	0.0044
18	12b; B-Water	0.9996	0.0011	1.0019	0.0011	1.0000	0.0000	0.0109	0.0019
	Mean	1.0018		1.0014		0.9973	-0.0027	0.0108	
	Standard Deviation +/-	0.0039		0.0049					
	Method Bias [3]	0.0045		0.0041					
	Uncertainty in Bias [4] +/-	0.0115		0.0118					

NOTES:

[1] Table 49, International Handbook of Evaluated Criticality Safety Benchmark Experiments (Nuclear Energy Agency 1999).

[2] Table 47, International Handbook of Evaluated Criticality Safety Benchmark Experiments (Nuclear Energy Agency 1999).

[3] Method Bias = Mean - Mean Benchmark Model

[4] Uncertainty in Bias = (Standard Deviation^2 + Mean Benchmark Model Uncertainty^2)$^{0.5}$

[5] CSAS26 Bias = CSAS26; 238 k_{eff} - Benchmark Model k_{eff}.

Table 4. CSAS Results for Experiments in HEU-SOL-THERM-033; All Concrete and Plaster Only

Experiment	Experiment/Case Description	OECD Result [1]		CSAS26; 238		Benchmark Model Bias & Uncertainty [2]			CSAS26; 238 Bias [5]
		k_{eff}	1-Sigma	k_{eff}	1-Sigma	k_{eff}	Bias	Uncertainty	
1	3a; Conc.	1.0015	0.0011	1.0014	0.0013	0.9942	-0.0058	0.0115	0.0072
2	3b; Conc.	1.0032	0.0010	1.0019	0.0013	0.9979	-0.0021	0.0112	0.0040
3	3c; Conc.	1.0110	0.0012	1.0125	0.0012	0.9979	-0.0021	0.0072	0.0146
4	4a; Conc. & Cd	0.9994	0.0011	1.0004	0.0013	0.9942	-0.0058	0.0115	0.0062
5	4b; Conc. & Cd	1.0078	0.0011	1.0060	0.0013	0.9979	-0.0021	0.0112	0.0081
6	5a; 1.2 w/o B-Conc.	1.0087	0.0011	1.0077	0.0012	0.9942	-0.0058	0.0112	0.0135
7	5b; 1.2 w/o B-Conc.	1.0077	0.0012	1.0085	0.0014	1.0000	0.0000	0.0109	0.0085
8	6a; 1.2 w/o B-Conc.	1.0031	0.0011	1.0022	0.0013	0.9942	-0.0058	0.0112	0.0080
9	6b; 1.2 w/o B-Conc.	1.0079	0.0011	1.0108	0.0012	1.0000	0.0000	0.0109	0.0108
10	7a; 1.1 w/o B-Plast.	0.9987	0.0011	0.9993	0.0012	0.9942	-0.0058	0.0112	0.0051
11	7b; 1.1 w/o B-Plast.	1.0053	0.0010	1.0058	0.0013	1.0000	0.0000	0.0109	0.0058
12	8a; 2.5 w/o B-Conc.	1.0026	0.0010	1.0034	0.0011	0.9942	-0.0058	0.0112	0.0092
13	8b; 2.5 w/o B-Conc.	1.0055	0.0011	1.0072	0.0013	1.0000	0.0000	0.0109	0.0072
14	9a; 1.1 w/o B-Plast.	0.9984	0.0011	0.9954	0.0012	0.9942	-0.0058	0.0112	0.0012
15	9b; 1.1 w/o B-Plast.	0.9961	0.0012	0.9971	0.0012	1.0000	0.0000	0.0109	-0.0029
16	9c; 1.1 w/o B-Plast.	0.9967	0.0012	0.9931	0.0012	0.9979	-0.0021	0.0105	-0.0048
17	10a; Conc.	1.0025	0.0011	1.0021	0.0011	0.9942	-0.0058	0.0115	0.0079
18	10c; Conc.	1.0027	0.0011	1.0016	0.0011	0.9979	-0.0021	0.0072	0.0036
19	10d; Conc.	0.9929	0.0011	0.9947	0.0013	0.9979	-0.0021	0.0106	-0.0032
	Mean	1.0027		1.0027		0.9969	-0.0031	0.0107	
	Standard Deviation +/-	0.0048		0.0054					
	Method Bias [3]	0.0058		0.0058					
	Uncertainty in Bias [4] +/-	0.0117		0.0120					

NOTES:

[1] Table 49, International Handbook of Evaluated Criticality Safety Benchmark Experiments (Nuclear Energy Agency 1999).

[2] Table 47, International Handbook of Evaluated Criticality Safety Benchmark Experiments (Nuclear Energy Agency 1999).

[3] Method Bias = Mean - Mean Benchmark Model

[4] Uncertainty in Bias = (Standard Deviation^2 + Mean Benchmark Model Uncertainty^2)$^{0.5}$

[5] CSAS26 Bias = CSAS26; 238 k_{eff} - Benchmark Model k_{eff}.

Table 5. CSAS Results for Experiments in HEU-SOL-THERM-033; Borated Concrete and Plaster Only

		OECD Result [1]		CSAS26; 238		Benchmark Model Bias & Uncertainty [2]			CSAS26; 238
Experiment	Experiment/Case Description	k_{eff}	1-Sigma	k_{eff}	1-Sigma	k_{eff}	Bias	Uncertainty	Bias [5]
1	5a; 1.2 w/o B-Conc.	1.0087	0.0011	1.0077	0.0012	0.9942	-0.0058	0.0112	0.0135
2	5b; 1.2 w/o B-Conc.	1.0077	0.0012	1.0085	0.0014	1.0000	0.0000	0.0109	0.0085
3	6a; 1.2 w/o B-Conc.	1.0031	0.0011	1.0022	0.0013	0.9942	-0.0058	0.0112	0.0080
4	6b; 1.2 w/o B-Conc.	1.0079	0.0011	1.0108	0.0012	1.0000	0.0000	0.0109	0.0108
5	7a; 1.1 w/o B-Plast.	0.9987	0.0011	0.9993	0.0012	0.9942	-0.0058	0.0112	0.0051
6	7b; 1.1 w/o B-Plast.	1.0053	0.0010	1.0058	0.0013	1.0000	0.0000	0.0109	0.0058
7	8a; 2.5 w/o B-Conc.	1.0026	0.0010	1.0034	0.0011	0.9942	-0.0058	0.0112	0.0092
8	8b; 2.5 w/o B-Conc.	1.0055	0.0011	1.0072	0.0013	1.0000	0.0000	0.0109	0.0072
9	9a; 1.1 w/o B-Plast.	0.9984	0.0011	0.9954	0.0012	0.9942	-0.0058	0.0112	0.0012
10	9b; 1.1 w/o B-Plast.	0.9961	0.0012	0.9971	0.0012	1.0000	0.0000	0.0109	-0.0029
11	9c; 1.1 w/o B-Plast.	0.9967	0.0012	0.9931	0.0012	0.9979	-0.0021	0.0105	-0.0048
	Mean	1.0028		1.0028		0.9972	-0.0028	0.0110	
	Standard Deviation +/-	0.0047		0.0059					
	Method Bias [3]	0.0056		0.0056					
	Uncertainty in Bias [4] +/-	0.0119		0.0125					

NOTES:

[1] Table 49, International Handbook of Evaluated Criticality Safety Benchmark Experiments (Nuclear Energy Agency 1999).

[2] Table 47, International Handbook of Evaluated Criticality Safety Benchmark Experiments (Nuclear Energy Agency 1999).

[3] Method Bias = Mean - Mean Benchmark Model

[4] Uncertainty in Bias = $(\text{Standard Deviation}^2 + \text{Mean Benchmark Model Uncertainty}^2)^{0.5}$

[5] CSAS26 Bias = CSAS26; 238 k_{eff} - Benchmark Model k_{eff}.

Table 6. Summary of Grouped Statistics Results

Experiment Group	CSAS26/238GROUPNDF5			
	Mean	Standard Deviation (+/-)	Method Bias	Uncertainty in Bias (+/-)
All Experiments (Table 1)	1.0018	0.0049	0.0047	0.0117
No Borated Concrete or Plaster (Table 2)	1.0010	0.0041	0.0041 [1]	0.0111
No Boron-free Concrete (Table 3)	1.0014	0.0049	0.0041	0.0118
All Concrete and Plaster Only (Table 4)	1.0027	0.0054	0.0058	0.0120
Borated Concrete and Plaster Only (Table 5)	1.0028	0.0059	0.0056 [1]	0.0125

NOTE:

[1] Evaluated variation in CSAS26/238GROUPNDF method bias for systems "with" vs. "without" borated supplemental neutron absorber materials = 0.0015 = 0.0056 - 0.0041.

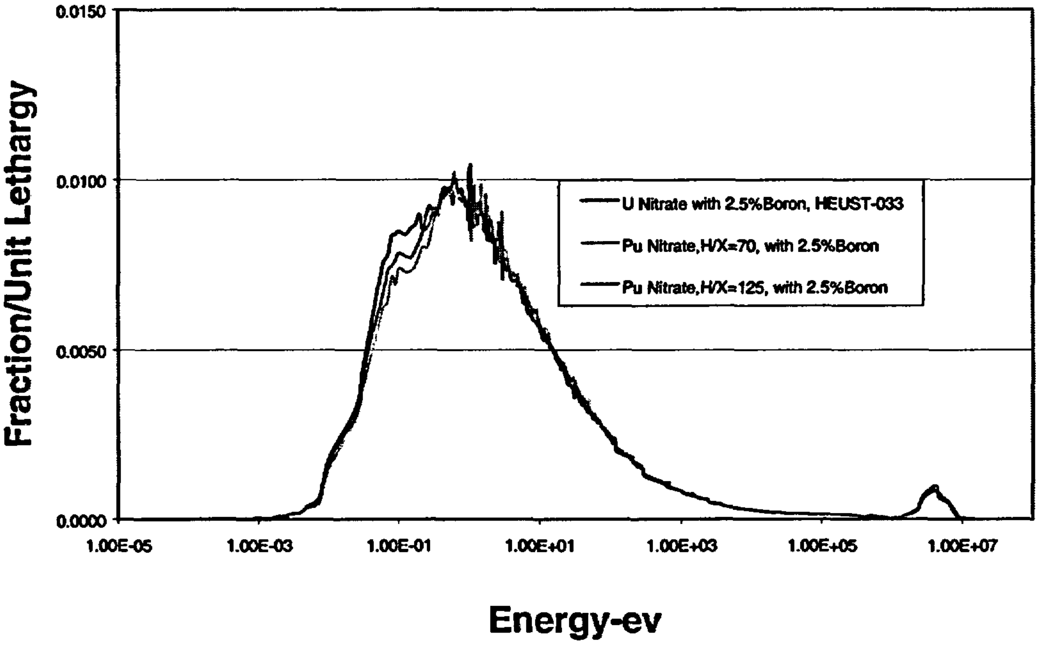


Figure 1. Borated Concrete Absorption Spectra

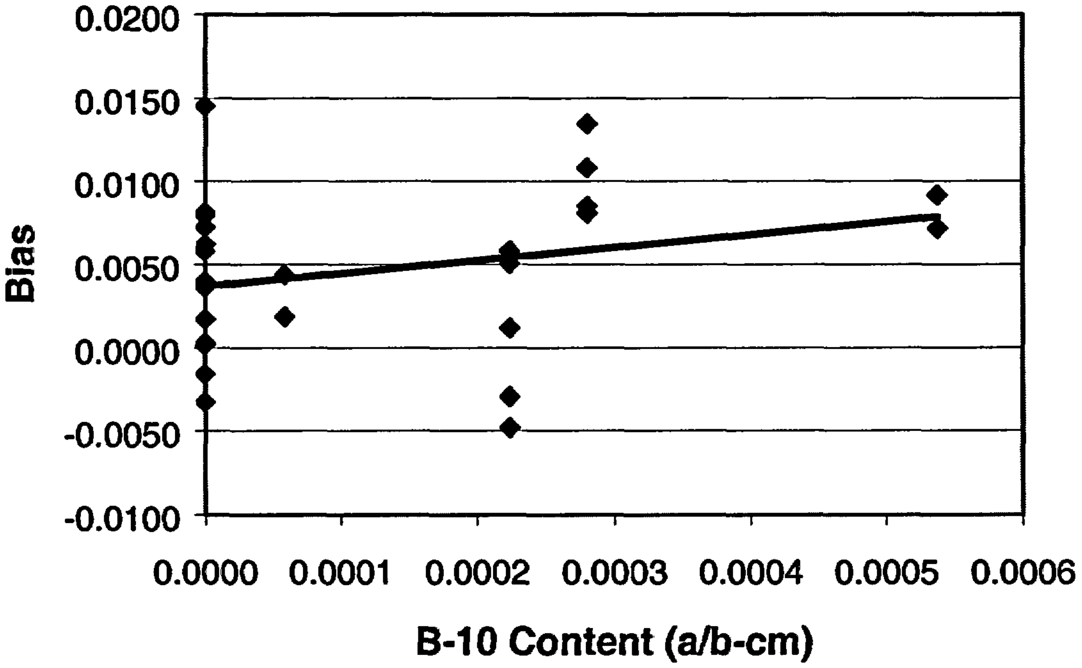


Figure 2. Bias versus B-10 Content

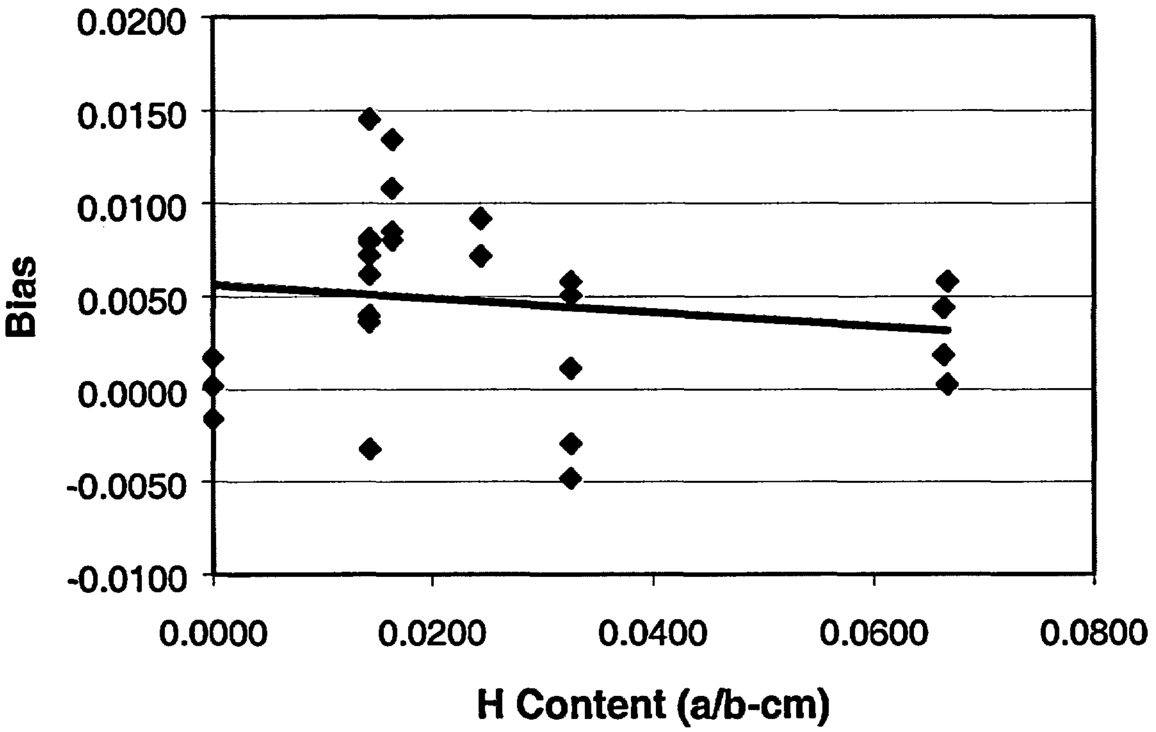


Figure 3. Bias versus H Content

ATTACHMENT 6

CONCRETE AND CD/WATER REFLECTORS

INTRODUCTION

The 191 critical experiments modeled for AOA(1) (see Section 6.1) include bare spheres, water reflected spheres, concrete reflected spheres, cadmium/concrete reflected spheres, and cadmium/water reflected spheres. This attachment divides the set into three subgroups (i.e., concrete reflector, Cd/water reflector, and water reflector experiments) to evaluate whether the full group of 191 experiments adequately encompasses the subgroups.

A further evaluation of an addition experiment set involving 17 experiments (9 with cadmium) is also presented.

USL FOR EXPERIMENTS WITH CONCRETE REFLECTORS

Twenty-nine experiments were selected using the PU-SOL-THERM-008 benchmark evaluations to evaluate the effect of concrete reflectors on the reactivity of the system. These experiments have similar characteristics:

- Pu-nitrate solution (30 g/l < C(Pu) < 100 g/l , 4.1% < % ^{240}Pu < 4.6%)
- Spherical geometry
- Concrete reflector or cadmium/concrete reflector.

The evaluations include 24 experiments with a concrete reflector and five experiments with cadmium and concrete reflectors.

EXPERIMENTS WITH CADMIUM/WATER REFLECTOR

Fourteen experiments were selected from the benchmark experiment PU-SOL-THERM-020 to evaluate the effect of water and cadmium/water reflectors on the reactivity of the system. These experiments were further divided to those experiments with and without Cd. The experiments have the following characteristics:

- Pu-nitrate solution (30 g/l < C(Pu) < 70 g/l , 4.67 % ^{240}Pu)
- Spherical geometry.

Ten experiments are reflected by water and four are reflected by cadmium/water.

SUMMARY OF EVALUATIONS OF CONCRETE/CADMIUM EXPERIMENTS INCLUDED IN THE AOA(1) EXPERIMENT SET

Table 1 provides a comparison of the mean k_{eff} of each subset with the mean k_{eff} from the full set. The table indicates that the bias is positive for all cases and that there is no significant difference in the bias results. Furthermore, the variation is small compared to the level of uncertainty in the computational bias accounted for in the determination of USL-1 in Section 6.1 of the report. Therefore, since the subsets are included in the calculation of the USL and computational bias established for AOA(1), the USL and range established for the AOA(1) is applicable to the subsets of concrete reflectors, Cd/water reflectors, and water reflectors.

FURTHER EVALUATION OF CADMIUM REFLECTORS

As noted previously, some design applications in the MFFF involving plutonium nitrate (Pu-nitrate) aqueous solutions include consideration of a full range of possible pure water reflection conditions. For those applications, the benchmarks selected in Section 4.1 are directly applicable. Other MFFF Pu-nitrate solution design applications incorporate cadmium as a neutron absorber for criticality control purposes. This has been discussed above. While only four of the 191 selected benchmark experiments for AOA(1) involved cadmium a review of the International Handbook of Evaluated Criticality Safety Benchmark Experiments (Nuclear Energy Agency 1999), identifies another set of experiments in PU-SOL-THERM-022 which, although it has an elevated concentration of ^{240}Pu compared to that used in criticality calculations for the MFFF, is otherwise suitable and provides good information on the impact of cadmium. Therefore, these experiments were analyzed as reported in this attachment. These experiments are evaluated using the SCALE 4.4 CSAS26 (KENO VI) criticality analysis sequence and the 238 energy group cross-section library (238GROUPNDF5). The results of this evaluation are used to demonstrate the applicability of the USL-1 acceptance criterion for AOA-1 presented in Section 6.1 of this validation report to Pu-nitrate systems incorporating cadmium neutron absorber materials.

The evaluation begins by providing a brief description of the high enrichment U-nitrate solution benchmark experiments and CSAS26/238GROUPNDF5 analyzed results. The results are then evaluated to determine the bias, if any, between k_{eff} results obtained for experiments with cadmium neutron absorbers and other similar experiments without these materials present.

PU-NITRATE SOLUTION EXPERIMENT DESCRIPTIONS AND ANALYZED RESULTS

The critical experiments designated as PU-SOL-THERM-022 in the International Handbook of Evaluated Criticality Safety Benchmark Experiments are used in order to validate the CSAS26/238GROUPNDF5 code system for use in Pu-nitrate solution design applications involving cadmium supplemental neutron absorber materials. The PU-SOL-THERM-022 experiments were performed at the VALDUC facility in France and involved an annular steel tanks containing fissile material solution with various materials inserted as a "plug" in the central annulus region formed by the innermost annular tank. Materials inserted in the central region included air and a paraffin cylinder surrounded by a sheet of Cadmium similar to the thickness used in the slab tanks in the MFFF. Critical heights of the highly enriched solutions and reflector were measured. A total of 17 experiments were performed. Nine were performed without cadmium and eight were performed with cadmium sheets similar to that used on the slab tanks in the MFFF. Of the 17 critical configurations, all 17 were judged acceptable for benchmark applications by the experiment evaluator and reviewers (Nuclear Energy Agency 2002).

All 17 PU-SOL-THERM-022 critical experiments were analyzed by the handbook reviewers using MCNP-4B (ENDF/B-VI cross section library) for verification purposes. Verification results are reported in the handbook. For comparison, DCS prepared CSAS26 input files for each of the 17 experiments and calculations were performed using the SCALE 4.4a with the 238GROUPNDF5 cross section set. The calculated k_{eff} results for the complete set of all 17 of the benchmark experiments are presented in Table 2. Also presented in Table 2 are estimated values for measured k_{eff} and experiment uncertainties reported in the handbook and results of statistical analysis performed on the calculated data. Calculated k_{eff} results and similar grouped statistical analysis results are presented in Tables 3 and 4 for the following subsets of experiments: (a) 9 experiments without cadmium and (b) 8 experiments with cadmium. A summary of the statistical results for the three sets of experiment results evaluated is provided in Table 5.

A review of the Table 5 results summary indicates that no significant non-conservative difference in bias results for systems that include cadmium neutron absorbers as compared to systems that do not when using CSAS26 and the 238GROUPNDF5 cross section library. In fact, the criticality calculations for the experiments with cadmium perform more better than those that do not have cadmium. (This behavior is also reflected in the original MCNP results presented in the handbook.) For example, the evaluated variation in CSAS26 method bias indicated for benchmark experiment sets with and without cadmium (i.e., Table 3 and 4 method bias values) is 0.0071 lower. Yet the mean for the experiments with cadmium is 1.0004 matching the critical value of experiments (i.e., k_{eff}=1.0000) closely. This variation is small compared to the level of uncertainty in the method bias accounted for in the determination of USL-1 in Section 6.1 of the report (i.e., 0.01). While the number of experiments in the PU-SOL-THERM-022 set is small (17 total) and thus can not conclusively establish that cadmium has no effect, the lack of results to the contrary from this analysis supports the observation and provides additional rationale supporting the acceptability of extrapolating Section 6.1 Pu-nitrate solution validation results to MFFF design applications containing cadmium.

AREA(S) OF APPLICABILITY DETERMINATION

The general arrangement of the PU-SOL-THERM-022 critical experiments supports a conclusion that the experiments evaluated encompass the entire AOA of any MFFF Pu-nitrate design application that incorporates cadmium as a neutron absorber material. This conclusion is based on the experiment arrangement that places cadmium sheets in the vicinity of steel tanks containing fissile aqueous solutions.

SUMMARY

Table 1 shows that comparing the mean k_{eff} of each subset of experiments involving cadmium and concrete reflectors contained in the 191 benchmarks with the mean k_{eff} from the full set shows that the bias is positive for all cases and that there is no significant difference in the bias results.

Results with additional experiments from the PU-SOL-THERM-022 benchmark experiment set and calculated by the CSAS26/238GROUPNDF5 criticality analysis methodology for Pu-nitrate aqueous solution benchmark experiments containing cadmium and air within the central cavity of an annular tank fissile configuration are also presented. Comparisons of results for these experiments containing cadmium materials against results for no cadmium materials were performed. The comparisons did not indicate any significant bias exists between

CSAS26/238GROUPNDF5 criticality analysis methodology calculated results for systems that contain cadmium neutron absorber materials relative to systems that are cadmium-free.

Table 1. Mean calculated k_{eff} for full set and subsets of AOA(1) benchmarks

	Sun Results (SCALE 4.4)					**PC Results (SCALE 4.4a)**				
Metric	**All**	**Concrete**	**Cd/Conc**	**Water**	**Cd/H2O**	**All**	**Concrete**	**Cd/Conc**	**Water**	**Cd/H2O**
Num Exp	191	29	5	10	4	191	29	5	10	4
Avg k	1.0096	1.0177	1.0017	1.0070	1.0032	1.0095	1.0177	1.0014	1.0073	1.0019
σ of Avg	0.0046	0.0042	0.0053	0.0060	0.0061	0.0045	0.0040	0.0052	0.0060	0.0060
Min k	0.9968	0.9976	0.9976	1.0021	1.0004	0.9948	0.9948	0.9948	1.0022	0.9989
Max k	1.0320	1.0320	1.0060	1.0113	1.0096	1.0317	1.0317	1.0071	1.0104	1.0069

Table 2. CSAS Results for All Experiments in PU-SOL-THERM-022

		OECD Result [1]		CSAS26; 238		Benchmark Model Bias & Uncertainty [2]			CSAS26; 238
Experiment	Experiment/Case Description	k_{eff}	1-Sigma	k_{eff}	1-Sigma	k_{eff}	Bias	Uncertainty	Bias [5]
1	1, no Cadmium	0.9969	0.0009	1.0026	0.0015	1.0000	0.0000	0.0024	0.0026
2	2, no Cadmium	0.9992	0.0010	1.0050	0.0015	1.0000	0.0000	0.0022	0.0050
3	3, no Cadmium	1.0007	0.0008	1.0043	0.0014	1.0000	0.0000	0.0024	0.0043
4	4, no Cadmium	1.0012	0.0008	1.0072	0.0014	1.0000	0.0000	0.0024	0.0072
5	5, no Cadmium	1.0030	0.0008	1.0073	0.0014	1.0000	0.0000	0.0024	0.0073
6	6, no Cadmium	1.0023	0.0007	1.0090	0.0012	1.0000	0.0000	0.0032	0.0090
7	7, no Cadmium	1.0055	0.0007	1.0098	0.0013	1.0000	0.0000	0.0032	0.0098
8	8, no Cadmium	1.0048	0.0007	1.0097	0.0012	1.0000	0.0000	0.0032	0.0097
9	9, no Cadmium	1.0030	0.0007	1.0124	0.0011	1.0000	0.0000	0.0032	0.0124
10	10, With Cadmium	0.9966	0.0009	1.0013	0.0014	1.0000	0.0000	0.0016	0.0013
11	11, With Cadmium	0.9947	0.0009	0.9986	0.0014	1.0000	0.0000	0.0016	-0.0014
12	12, With Cadmium	0.9966	0.0009	1.0020	0.0013	1.0000	0.0000	0.0015	0.0020
13	13, With Cadmium	0.9948	0.0009	1.0005	0.0014	1.0000	0.0000	0.0015	0.0005
14	14, With Cadmium	0.9970	0.0009	1.0001	0.0013	1.0000	0.0000	0.0015	0.0001
15	15, With Cadmium	0.9933	0.0008	0.9986	0.0013	1.0000	0.0000	0.0015	-0.0014
16	16, With Cadmium	0.9942	0.0008	1.0024	0.0012	1.0000	0.0000	0.0015	0.0024
17	17, With Cadmium	0.9951	0.0008	0.9993	0.0013	1.0000	0.0000	0.0015	-0.0007
	Mean	0.9988		1.0041		1.0000	0.0000	0.0022	
	Standard Deviation +/-	0.0040		0.0044					
	Method Bias [3]	-0.0012		0.0041					
	Uncertainty in Bias [4] +/-	0.0040		0.0044					

NOTES:

[1] Table 10.b, International Handbook of Evaluated Criticality Safety Benchmark Experiments (Nuclear Energy Agency 2002).

[2] Table 9, International Handbook of Evaluated Criticality Safety Benchmark Experiments (Nuclear Energy Agency 2002).

[3] Method Bias = Mean - Mean Benchmark Model

[4] Uncertainty in Bias = (Standard Deviation^2 + Mean Benchmark Model Uncertainty^2)$^{0.5}$

[5] CSAS26 Bias = CSAS26; 238 k_{eff} - Benchmark Model k_{eff}.

Table 3. CSAS Results for All Experiments in PU-SOL-THERM-022, No Cadmium

		OECD Result [1]		CSAS26; 238		Benchmark Model Bias & Uncertainty [2]			CSAS26; 238
Experiment	Experiment/Case Description	k_{eff}	1-Sigma	k_{eff}	1-Sigma	k_{eff}	Bias	Uncertainty	Bias [5]
1	1, no Cadmium	0.9969	0.0009	1.0026	0.0015	1.0000	0.0000	0.0024	0.0026
2	2, no Cadmium	0.9992	0.0010	1.0050	0.0015	1.0000	0.0000	0.0022	0.0050
3	3, no Cadmium	1.0007	0.0008	1.0043	0.0014	1.0000	0.0000	0.0024	0.0043
4	4, no Cadmium	1.0012	0.0008	1.0072	0.0014	1.0000	0.0000	0.0024	0.0072
5	5, no Cadmium	1.0030	0.0008	1.0073	0.0014	1.0000	0.0000	0.0024	0.0073
6	6, no Cadmium	1.0023	0.0007	1.0090	0.0012	1.0000	0.0000	0.0032	0.0090
7	7, no Cadmium	1.0055	0.0007	1.0098	0.0013	1.0000	0.0000	0.0032	0.0098
8	8, no Cadmium	1.0048	0.0007	1.0097	0.0012	1.0000	0.0000	0.0032	0.0097
9	9, no Cadmium	1.0030	0.0007	1.0124	0.0011	1.0000	0.0000	0.0032	0.0124
	Mean	1.0018		1.0075		1.0000	0.0000	0.0027	
	Standard Deviation +/-	0.0027		0.0031					
	Method Bias [3]	0.0018		0.0075					
	Uncertainty in Bias [4] +/-	0.0027		0.0031					

NOTES:

[1] Table 10.b, International Handbook of Evaluated Criticality Safety Benchmark Experiments (Nuclear Energy Agency 2002).

[2] Table 9, International Handbook of Evaluated Criticality Safety Benchmark Experiments (Nuclear Energy Agency 2002).

[3] Method Bias = Mean - Mean Benchmark Model

[4] Uncertainty in Bias = (Standard Deviation^2 + Mean Benchmark Model Uncertainty^2)$^{0.5}$

[5] CSAS26 Bias = CSAS26; 238 k_{eff} - Benchmark Model k_{eff}.

Table 4. CSAS Results for All Experiments in PU-SOL-THERM-022, With Cadmium

		OECD Result [1]		CSAS26; 238		Benchmark Model Bias & Uncertainty [2]			CSAS26; 238
Experiment	Experiment/Case Description	k_{eff}	1-Sigma	k_{eff}	1-Sigma	k_{eff}	Bias	Uncertainty	Bias [5]
1	10, With Cadmium	0.9966	0.0009	1.0013	0.0014	1.0000	0.0000	0.0016	0.0013
2	11, With Cadmium	0.9947	0.0009	0.9986	0.0014	1.0000	0.0000	0.0016	-0.0014
3	12, With Cadmium	0.9966	0.0009	1.0020	0.0013	1.0000	0.0000	0.0015	0.0020
4	13, With Cadmium	0.9948	0.0009	1.0005	0.0014	1.0000	0.0000	0.0015	0.0005
5	14, With Cadmium	0.9970	0.0009	1.0001	0.0013	1.0000	0.0000	0.0015	0.0001
6	15, With Cadmium	0.9933	0.0008	0.9986	0.0013	1.0000	0.0000	0.0015	-0.0014
7	16, With Cadmium	0.9942	0.0008	1.0024	0.0012	1.0000	0.0000	0.0015	0.0024
8	17, With Cadmium	0.9951	0.0008	0.9993	0.0013	1.0000	0.0000	0.0015	-0.0007
	Mean	0.9953		1.0004		1.0000	0.0000	0.0015	
	Standard Deviation +/-	0.0013		0.0014					
	Method Bias [3]	-0.0047		0.0004					
	Uncertainty in Bias [4] +/-	0.0013		0.0014					

NOTES:

[1] Table 10.b, International Handbook of Evaluated Criticality Safety Benchmark Experiments (Nuclear Energy Agency 2002).

[2] Table 9, International Handbook of Evaluated Criticality Safety Benchmark Experiments (Nuclear Energy Agency 2002).

[3] Method Bias = Mean - Mean Benchmark Model

[4] Uncertainty in Bias = (Standard Deviation^2 + Mean Benchmark Model Uncertainty^2)$^{0.5}$

[5] CSAS26 Bias = CSAS26; 238 k_{eff} - Benchmark Model k_{eff}.

Table 5. Summary of Grouped Statistics Results

Experiment Group	CSAS26/238GROUPNDF5			
	Mean	Standard Deviation (+/-)	Method Bias	Uncertainty in Bias (+/-)
All Experiments (Table 2)	1.0041	0.0044	0.0041	0.0117
No Cadmium (Table 3)	1.0075	0.0031	0.0075 [1]	0.0031
Cadmium Only (Table 4)	1.0004	0.0014	0.0004 [1]	0.0014

NOTE:

[1] Evaluated variation in CSAS26/238GROUPNDF method bias for systems "with" vs. "without" cadmium supplemental neutron absorber materials = -0.0071 = 0.0004 - 0.0075.

ATTACHMENT 7

INPUT AND OUTPUT FILES

The files listed in Figure 1 are provided on the attached compact disc media.

Figure 1 – Listing of Files on Attached Media

```
Volume in drive D is Part1Att7
 Volume Serial Number is 79BF-72FF

Directory of D:\

CASES          <DIR>        10-04-01  2:06p CASES
         0 file(s)              0 bytes

Directory of D:\CASES

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PC             <DIR>        10-04-01  2:06p PC
SUN            <DIR>        10-04-01  2:06p Sun
         0 file(s)              0 bytes

Directory of D:\CASES\PC

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
AOA1           <DIR>        10-04-01  2:06p AoA1
AOA2           <DIR>        10-04-01  2:06p AoA2
         0 file(s)              0 bytes

Directory of D:\CASES\PC\AoA1

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PST_001        <DIR>        10-04-01  2:06p PST_001
PST_002        <DIR>        10-04-01  2:06p PST_002
PST_003        <DIR>        10-04-01  2:06p PST_003
PST_004        <DIR>        10-04-01  2:06p PST_004
PST_005        <DIR>        10-04-01  2:06p PST_005
PST_006        <DIR>        10-04-01  2:06p PST_006
PST_008        <DIR>        10-04-01  2:06p PST_008
PST_011        <DIR>        10-04-01  2:06p PST_011
PST_014        <DIR>        10-04-01  2:06p PST_014
PST_015        <DIR>        10-04-01  2:06p PST_015
PST_016        <DIR>        10-04-01  2:06p PST_016
PST_017        <DIR>        10-04-01  2:06p PST_017
PST_020        <DIR>        10-04-01  2:06p PST_020
PST_025        <DIR>        10-04-01  2:06p PST_025
PST_026        <DIR>        10-04-01  2:06p PST_026
USL            <DIR>        10-04-01  2:06p usl
         0 file(s)              0 bytes

Directory of D:\CASES\PC\AoA1\PST_001

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6 OUT       799,698  05-31-01  3:27p PU_SOL_TH_001_5_T8A_k6.out
PU_SOL~8 INP         4,312  05-29-01  3:51p PU_SOL_TH_001_6_T8A_k6.inp
PU_SO~10 OUT       800,013  05-31-01  3:46p PU_SOL_TH_001_6_T8A_k6.out
PU_SO~12 INP         4,312  05-30-01 11:07a PU_SOL_TH_001_5_T8A_k6.inp
PU_SO~14 INP         4,312  05-30-01 11:07a PU_SOL_TH_001_1_T8A_k6.inp
PU_SO~16 OUT       797,910  05-31-01  2:05p PU_SOL_TH_001_1_T8A_k6.out
PU_SO~18 INP         4,311  05-29-01  3:51p PU_SOL_TH_001_2_T8A_k6.inp
PU_SO~20 OUT       793,956  05-31-01  2:26p PU_SOL_TH_001_2_T8A_k6.out
PU_SO~22 INP         4,311  05-29-01  3:51p PU_SOL_TH_001_3_T8A_k6.inp
PU_SO~24 OUT       799,854  05-31-01  2:46p PU_SOL_TH_001_3_T8A_k6.out
PU_SO~26 INP         4,312  05-29-01  3:51p PU_SOL_TH_001_4_T8A_k6.inp
PU_SO~28 OUT       801,932  05-31-01  3:07p PU_SOL_TH_001_4_T8A_k6.out
        12 file(s)      4,819,233 bytes

Directory of D:\CASES\PC\AoA1\PST_002

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
GETKEN~6 TXT           731  09-21-01  3:05p getkeno.txt-
PU_SOL~8 INP         4,079  06-01-01  6:14p PU_SOL_TH_002_3_k6_R2.inp
PU_SO~10 OUT       768,544  06-01-01  8:56p PU_SOL_TH_002_3_k6_R2.out
PU_SO~12 INP         4,065  05-29-01  3:50p PU_SOL_TH_002_3_k6.inp
PU_SO~14 INP         4,065  05-29-01  3:50p PU_SOL_TH_002_4_k6.inp
PU_SO~16 INP         4,065  05-29-01  3:50p PU_SOL_TH_002_5_k6.inp
PU_SO~18 INP         4,065  05-29-01  3:50p PU_SOL_TH_002_6_k6.inp
PU_SO~20 INP         4,065  05-29-01  3:50p PU_SOL_TH_002_7_k6.inp
PU_SO~22 OUT       770,538  05-31-01  4:51p PU_SOL_TH_002_3_k6.out
PU_SO~24 OUT       771,987  05-31-01  5:13p PU_SOL_TH_002_4_k6.out
PU_SO~26 OUT       773,611  05-31-01  5:34p PU_SOL_TH_002_5_k6.out
PU_SO~28 OUT       771,385  05-31-01  5:55p PU_SOL_TH_002_6_k6.out
PU_SO~30 OUT       772,891  05-31-01  6:16p PU_SOL_TH_002_7_k6.out
PU_SO~32 INP         4,065  05-29-01  3:50p PU_SOL_TH_002_1_k6.inp
PU_SO~34 OUT       772,314  05-31-01  4:08p PU_SOL_TH_002_1_k6.out
PU_SO~36 INP         4,080  06-01-01  6:12p PU_SOL_TH_002_1_k6_R2.inp
PU_SO~38 OUT       771,626  06-01-01  7:11p PU_SOL_TH_002_1_k6_R2.out
```

```
PU_SO~40 INP         4,065  05-29-01  3:50p PU_SOL_TH_002_2_k6.inp
PU_SO~42 OUT       769,185  05-31-01  4:30p PU_SOL_TH_002_2_k6.out
PU_SO~44 INP         4,079  06-01-01  6:14p PU_SOL_TH_002_2_k6_R2.inp
PU_SO~46 OUT       768,650  06-01-01  8:04p PU_SOL_TH_002_2_k6_R2.out
        21 file(s)      7,752,155 bytes

Directory of D:\CASES\PC\AoA1\PST_003

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6 INP         4,475  05-29-01  3:49p PU_SOL_TH_003_5_k6.inp
PU_SOL~8 INP         4,475  05-29-01  3:49p PU_SOL_TH_003_6_k6.inp
PU_SO~10 INP         4,475  05-29-01  3:49p PU_SOL_TH_003_7_k6.inp
PU_SO~12 INP         4,475  05-29-01  3:49p PU_SOL_TH_003_8_k6.inp
PU_SO~14 OUT       793,539  05-31-01  8:04p PU_SOL_TH_003_5_k6.out
PU_SO~16 OUT       792,015  05-31-01  8:25p PU_SOL_TH_003_6_k6.out
PU_SO~18 OUT       792,918  05-31-01  8:48p PU_SOL_TH_003_7_k6.out
PU_SO~20 OUT       788,215  05-31-01  9:10p PU_SOL_TH_003_8_k6.out
PU_SO~22 INP         4,475  05-29-01  3:49p PU_SOL_TH_003_1_k6.inp
PU_SO~24 OUT       787,931  05-31-01  6:38p PU_SOL_TH_003_1_k6.out
PU_SO~26 INP         4,475  05-29-01  3:49p PU_SOL_TH_003_2_k6.inp
PU_SO~28 OUT       789,006  05-31-01  7:00p PU_SOL_TH_003_2_k6.out
PU_SO~30 INP         4,475  05-29-01  3:49p PU_SOL_TH_003_3_k6.inp
PU_SO~32 OUT       792,714  05-31-01  7:21p PU_SOL_TH_003_3_k6.out
PU_SO~34 INP         4,475  05-29-01  3:49p PU_SOL_TH_003_4_k6.inp
PU_SO~36 OUT       792,646  05-31-01  7:43p PU_SOL_TH_003_4_k6.out
        16 file(s)      6,364,784 bytes

Directory of D:\CASES\PC\AoA1\PST_004

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6 INP         4,148  05-29-01  3:48p PU_SOL_TH_004_13_k6.inp
PU_SOL~8 INP         4,148  05-29-01  3:48p PU_SOL_TH_004_12_k6.inp
PU_SO~10 INP         4,066  05-29-01  3:48p PU_SOL_TH_004_10_k6.inp
PU_SO~12 INP         4,066  05-29-01  3:48p PU_SOL_TH_004_11_k6.inp
PU_SO~14 INP         4,066  05-29-01  3:47p PU_SOL_TH_004_08_k6.inp
PU_SO~16 INP         4,066  05-29-01  3:47p PU_SOL_TH_004_07_k6.inp
PU_SO~18 INP         4,066  05-29-01  3:47p PU_SOL_TH_004_06_k6.inp
PU_SO~20 INP         4,066  05-29-01  3:48p PU_SOL_TH_004_09_k6.inp
PU_SO~22 INP         4,066  05-29-01  3:47p PU_SOL_TH_004_05_k6.inp
PU_SO~24 OUT       766,296  06-01-01  1:53a PU_SOL_TH_004_13_k6.out
PU_SO~26 OUT       771,950  06-01-01  1:31a PU_SOL_TH_004_12_k6.out
PU_SO~28 OUT       775,140  06-01-01 12:49a PU_SOL_TH_004_10_k6.out
PU_SO~30 OUT       771,351  06-01-01  1:09a PU_SOL_TH_004_11_k6.out
PU_SO~32 OUT       772,067  05-31-01 11:01p PU_SOL_TH_004_05_k6.out
PU_SO~34 OUT       774,476  06-01-01 12:06a PU_SOL_TH_004_08_k6.out
PU_SO~36 OUT       765,432  05-31-01 11:45p PU_SOL_TH_004_07_k6.out
PU_SO~38 OUT       778,825  05-31-01 11:23p PU_SOL_TH_004_06_k6.out
PU_SO~40 OUT       770,913  06-01-01 12:28a PU_SOL_TH_004_09_k6.out
PU_SO~42 INP         4,066  05-29-01  3:47p PU_SOL_TH_004_01_k6.inp
PU_SO~44 OUT       772,413  05-31-01  9:33p PU_SOL_TH_004_01_k6.out
PU_SO~46 INP         4,066  05-29-01  3:48p PU_SOL_TH_004_02_k6.inp
PU_SO~48 OUT       771,390  05-31-01  9:55p PU_SOL_TH_004_02_k6.out
PU_SO~50 INP         4,066  05-29-01  3:48p PU_SOL_TH_004_03_k6.inp
PU_SO~52 OUT       772,206  05-31-01 10:17p PU_SOL_TH_004_03_k6.out
PU_SO~54 INP         4,066  05-29-01  3:48p PU_SOL_TH_004_04_k6.inp
PU_SO~56 OUT       768,429  05-31-01 10:39p PU_SOL_TH_004_04_k6.out
        26 file(s)     10,083,910 bytes

Directory of D:\CASES\PC\AoA1\PST_005

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6 INP         4,067  05-29-01  3:46p PU_SOL_TH_005_8_k6.inp
PU_SOL~8 INP         4,067  05-29-01  3:46p PU_SOL_TH_005_9_k6.inp
PU_SO~10 INP         4,067  05-29-01  3:46p PU_SOL_TH_005_5_k6.inp
PU_SO~12 INP         4,067  05-29-01  3:46p PU_SOL_TH_005_6_k6.inp
PU_SO~14 INP         4,067  05-29-01  3:46p PU_SOL_TH_005_7_k6.inp
PU_SO~16 OUT       772,706  06-01-01  4:42a PU_SOL_TH_005_8_k6.out
PU_SO~18 OUT       776,586  06-01-01  5:04a PU_SOL_TH_005_9_k6.out
PU_SO~20 OUT       768,648  06-01-01  3:40a PU_SOL_TH_005_5_k6.out
PU_SO~22 OUT       771,709  06-01-01  4:00a PU_SOL_TH_005_6_k6.out
PU_SO~24 OUT       773,424  06-01-01  4:21a PU_SOL_TH_005_7_k6.out
PU_SO~26 INP         4,067  05-29-01  3:45p PU_SOL_TH_005_1_k6.inp
PU_SO~28 OUT       775,768  06-01-01  2:15a PU_SOL_TH_005_1_k6.out
PU_SO~30 INP         4,067  05-29-01  3:46p PU_SOL_TH_005_2_k6.inp
PU_SO~32 OUT       772,675  06-01-01  2:36a PU_SOL_TH_005_2_k6.out
PU_SO~34 INP         4,067  05-29-01  3:46p PU_SOL_TH_005_3_k6.inp
PU_SO~36 OUT       772,332  06-01-01  2:58a PU_SOL_TH_005_3_k6.out
PU_SO~38 INP         4,067  05-29-01  3:46p PU_SOL_TH_005_4_k6.inp
PU_SO~40 OUT       770,292  06-01-01  3:19a PU_SOL_TH_005_4_k6.out
        18 file(s)      6,990,743 bytes

Directory of D:\CASES\PC\AoA1\PST_006

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6 INP         4,042  05-29-01  3:44p PU_SOL_TH_006_CASE_1_k6.inp
PU_SOL~8 OUT       768,057  06-01-01  5:26a PU_SOL_TH_006_CASE_1_k6.out
PU_SO~10 INP         4,042  05-29-01  3:44p PU_SOL_TH_006_CASE_2_k6.inp
PU_SO~12 OUT       771,522  06-01-01  5:47a PU_SOL_TH_006_CASE_2_k6.out
```

```
PU_SO~14 INP         4,042  05-29-01  3:45p PU_SOL_TH_006_CASE_3_k6.inp
PU_SO~16 OUT       773,418  06-01-01  6:09a PU_SOL_TH_006_CASE_3_k6.out
        6 file(s)      2,325,123 bytes

Directory of D:\CASES\PC\AoA1\PST_008

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6 INP         1,636  05-29-01  3:53p PU_SOL_TH_008_case12_k6.inp
PU_SOL~8 INP         1,561  05-29-01  3:54p PU_SOL_TH_008_case11_k6.inp
PU_SO~10 INP         1,561  05-29-01  3:53p PU_SOL_TH_008_case10_k6.inp
PU_SO~12 INP         1,746  05-29-01  3:55p PU_SOL_TH_008_case22_k6.inp
PU_SO~14 INP         1,746  05-29-01  3:55p PU_SOL_TH_008_case21_k6.inp
PU_SO~16 INP         1,661  05-29-01  3:54p PU_SOL_TH_008_case20_k6.inp
PU_SO~18 INP         1,778  05-29-01  3:56p PU_SOL_TH_008_case30_k6.inp
PU_SO~20 INP         1,637  05-29-01  3:56p PU_SOL_TH_008_case08_k6.inp
PU_SO~22 INP         1,561  05-29-01  3:56p PU_SOL_TH_008_case07_k6.inp
PU_SO~24 INP         1,561  05-29-01  3:56p PU_SOL_TH_008_case05_k6.inp
PU_SO~26 INP         1,637  05-29-01  3:53p PU_SOL_TH_008_case09_k6.inp
PU_SO~28 INP         1,779  05-29-01  3:54p PU_SOL_TH_008_case18_k6.inp
PU_SO~30 INP         1,776  05-29-01  3:54p PU_SOL_TH_008_case17_k6.inp
PU_SO~32 INP         1,664  05-29-01  3:54p PU_SOL_TH_008_case15_k6.inp
PU_SO~34 INP         1,749  05-29-01  3:54p PU_SOL_TH_008_case14_k6.inp
PU_SO~36 INP         1,636  05-29-01  3:54p PU_SOL_TH_008_case13_k6.inp
PU_SO~38 INP         1,661  05-29-01  3:54p PU_SOL_TH_008_case16_k6.inp
PU_SO~40 INP         1,661  05-29-01  3:54p PU_SOL_TH_008_case19_k6.inp
PU_SO~42 INP         1,840  05-29-01  3:55p PU_SOL_TH_008_case28_k6.inp
PU_SO~44 INP         1,840  05-29-01  3:55p PU_SOL_TH_008_case27_k6.inp
PU_SO~46 INP         1,866  05-29-01  3:55p PU_SOL_TH_008_case25_k6.inp
PU_SO~48 INP         1,661  05-29-01  3:55p PU_SOL_TH_008_case24_k6.inp
PU_SO~50 INP         1,661  05-29-01  3:55p PU_SOL_TH_008_case23_k6.inp
PU_SO~52 INP         1,749  05-29-01  3:55p PU_SOL_TH_008_case26_k6.inp
PU_SO~54 INP         1,779  05-29-01  3:56p PU_SOL_TH_008_case29_k6.inp
PU_SO~56 OUT       828,802  06-01-01  8:08a PU_SOL_TH_008_case08_k6.out
PU_SO~58 OUT       826,583  06-01-01  7:55a PU_SOL_TH_008_case07_k6.out
PU_SO~60 OUT       825,927  06-01-01  7:27a PU_SOL_TH_008_case05_k6.out
PU_SO~62 OUT       824,934  06-01-01  8:16a PU_SOL_TH_008_case09_k6.out
PU_SO~64 OUT       830,567  06-01-01 11:18a PU_SOL_TH_008_case18_k6.out
PU_SO~66 OUT       828,793  06-01-01 10:59a PU_SOL_TH_008_case17_k6.out
PU_SO~68 OUT       826,692  06-01-01 10:20a PU_SOL_TH_008_case15_k6.out
PU_SO~70 OUT       831,684  06-01-01  9:59a PU_SOL_TH_008_case14_k6.out
PU_SO~72 OUT       828,714  06-01-01  9:44a PU_SOL_TH_008_case13_k6.out
PU_SO~74 OUT       824,088  06-01-01 10:40a PU_SOL_TH_008_case16_k6.out
PU_SO~76 OUT       827,278  06-01-01 11:39a PU_SOL_TH_008_case19_k6.out
PU_SO~78 OUT       825,214  06-01-01  8:40a PU_SOL_TH_008_case10_k6.out
PU_SO~80 OUT       826,129  06-01-01  9:23a PU_SOL_TH_008_case12_k6.out
PU_SO~82 OUT       826,094  06-01-01  9:05a PU_SOL_TH_008_case11_k6.out
PU_SO~84 OUT       828,498  06-01-01  2:49p PU_SOL_TH_008_case28_k6.out
PU_SO~86 OUT       829,182  06-01-01  2:33p PU_SOL_TH_008_case27_k6.out
PU_SO~88 OUT       828,490  06-01-01  1:55p PU_SOL_TH_008_case25_k6.out
PU_SO~90 OUT       827,282  06-01-01  1:32p PU_SOL_TH_008_case24_k6.out
PU_SO~92 OUT       825,308  06-01-01  1:03p PU_SOL_TH_008_case23_k6.out
PU_SO~94 OUT       826,619  06-01-01  2:18p PU_SOL_TH_008_case26_k6.out
PU_SO~96 OUT       826,619  06-01-01  3:12p PU_SOL_TH_008_case29_k6.out
PU_SO~98 OUT       824,112  06-01-01 12:11p PU_SOL_TH_008_case20_k6.out
PU_S~100 OUT       825,474  06-01-01 12:36p PU_SOL_TH_008_case22_k6.out
PU_S~102 OUT       828,056  06-01-01 12:27p PU_SOL_TH_008_case21_k6.out
PU_S~104 OUT       823,251  06-01-01  3:35p PU_SOL_TH_008_case30_k6.out
PU_S~106 INP         1,561  05-29-01  3:56p PU_SOL_TH_008_case01_k6.inp
PU_S~108 OUT       826,186  06-01-01  6:26a PU_SOL_TH_008_case01_k6.out
PU_S~110 INP         1,561  05-29-01  3:55p PU_SOL_TH_008_case02_k6.inp
PU_S~112 OUT       820,943  06-01-01  6:40a PU_SOL_TH_008_case02_k6.out
PU_S~114 INP         1,561  05-29-01  3:56p PU_SOL_TH_008_case03_k6.inp
PU_S~116 OUT       825,181  06-01-01  6:55a PU_SOL_TH_008_case03_k6.out
PU_S~118 INP         1,561  05-29-01  3:56p PU_SOL_TH_008_case04_k6.inp
PU_S~120 OUT       832,211  06-01-01  7:09a PU_SOL_TH_008_case04_k6.out
       58 file(s)     24,027,562 bytes

Directory of D:\CASES\PC\AoA1\PST_011

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6 INP         3,221  05-29-01  4:08p PU_SOL_TH_011_C800_5_16_k6.inp
PU_SOL~8 INP         3,221  05-29-01  4:08p PU_SOL_TH_011_C800_3_16_k6.inp
PU_SO~10 INP         3,221  05-29-01  4:08p PU_SOL_TH_011_C800_4_16_k6.inp
PU_SO~12 INP         3,959  05-29-01  4:07p PU_SOL_TH_011_C800_7_18_k6.inp
PU_SO~14 INP         3,959  05-29-01  4:08p PU_SOL_TH_011_C800_5_18_k6.inp
PU_SO~16 INP         3,959  05-29-01  4:08p PU_SOL_TH_011_C800_3_18_k6.inp
PU_SO~18 INP         3,959  05-29-01  4:08p PU_SOL_TH_011_C800_4_18_k6.inp
PU_SO~20 INP         3,959  05-29-01  4:09p PU_SOL_TH_011_C800_6_18_k6.inp
PU_SO~22 OUT       750,934  05-31-01  4:25p PU_SOL_TH_011_C800_4_16_k6.out
PU_SO~24 OUT       745,332  05-31-01  4:39p PU_SOL_TH_011_C800_5_16_k6.out
PU_SO~26 OUT       743,710  05-31-01  4:10p PU_SOL_TH_011_C800_3_16_k6.out
PU_SO~28 OUT       760,850  05-31-01  4:34p PU_SOL_TH_011_C800_4_18_k6.out
PU_SO~30 OUT       752,779  05-31-01  4:55p PU_SOL_TH_011_C800_6_18_k6.out
PU_SO~32 OUT       760,669  05-31-01  5:04p PU_SOL_TH_011_C800_7_18_k6.out
PU_SO~34 OUT       757,132  05-31-01  4:48p PU_SOL_TH_011_C800_5_18_k6.out
PU_SO~36 OUT       758,864  05-31-01  4:20p PU_SOL_TH_011_C800_3_18_k6.out
PU_SO~38 INP         3,221  05-29-01  4:09p PU_SOL_TH_011_C800_1_16_k6.inp
PU_SO~40 OUT       744,560  05-31-01  3:40p PU_SOL_TH_011_C800_1_16_k6.out
PU_SO~42 INP         3,959  05-29-01  4:08p PU_SOL_TH_011_C800_1_18_k6.inp
PU_SO~44 OUT       759,250  05-31-01  3:50p PU_SOL_TH_011_C800_1_18_k6.out
```

```
PU_SO~46 INP         3,221  05-29-01  4:08p PU_SOL_TH_011_C800_2_16_k6.inp
PU_SO~48 OUT       747,789  05-31-01  3:55p PU_SOL_TH_011_C800_2_16_k6.out
PU_SO~50 INP         3,959  05-29-01  4:08p PU_SOL_TH_011_C800_2_18_k6.inp
PU_SO~52 OUT       756,582  05-31-01  4:05p PU_SOL_TH_011_C800_2_18_k6.out
        24 file(s)      9,082,269 bytes

Directory of D:\CASES\PC\AoA1\PST_014

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6 INP         6,633  05-30-01 11:16a PU_SOL_TH_014_19_k6.inp
PU_SOL~8 INP         6,633  05-30-01 11:16a PU_SOL_TH_014_17_k6.inp
PU_SO~10 INP         6,633  05-30-01 11:17a PU_SOL_TH_014_16_k6.inp
PU_SO~12 INP         6,633  05-30-01 11:17a PU_SOL_TH_014_15_k6.inp
PU_SO~14 INP         6,633  05-30-01 11:16a PU_SOL_TH_014_18_k6.inp
PU_SO~16 INP         6,633  05-30-01 11:17a PU_SOL_TH_014_12_k6.inp
PU_SO~18 INP         6,633  05-30-01 11:17a PU_SOL_TH_014_11_k6.inp
PU_SO~20 INP         6,633  05-30-01 11:17a PU_SOL_TH_014_14_k6.inp
PU_SO~22 INP         6,633  05-30-01 11:17a PU_SOL_TH_014_10_k6.inp
PU_SO~24 INP         6,633  05-30-01 11:17a PU_SOL_TH_014_13_k6.inp
PU_SO~26 INP         6,715  05-30-01 11:15a PU_SOL_TH_014_29_k6.inp
PU_SO~28 INP         6,715  05-30-01 11:15a PU_SOL_TH_014_27_k6.inp
PU_SO~30 INP         6,715  05-30-01 11:15a PU_SOL_TH_014_26_k6.inp
PU_SO~32 INP         6,715  05-30-01 11:16a PU_SOL_TH_014_25_k6.inp
PU_SO~34 INP         6,715  05-30-01 11:15a PU_SOL_TH_014_28_k6.inp
PU_SO~36 INP         6,633  05-30-01 11:16a PU_SOL_TH_014_22_k6.inp
PU_SO~38 INP         6,633  05-30-01 11:16a PU_SOL_TH_014_21_k6.inp
PU_SO~40 INP         6,715  05-30-01 11:16a PU_SOL_TH_014_24_k6.inp
PU_SO~42 INP         6,633  05-30-01 11:16a PU_SOL_TH_014_20_k6.inp
PU_SO~44 INP         6,633  05-30-01 11:16a PU_SOL_TH_014_23_k6.inp
PU_SO~46 INP         4,698  05-30-01 11:14a PU_SOL_TH_014_35_k6.inp
PU_SO~48 INP         6,750  05-30-01 11:15a PU_SOL_TH_014_32_k6.inp
PU_SO~50 INP         6,734  05-30-01 11:15a PU_SOL_TH_014_31_k6.inp
PU_SO~52 INP         6,753  05-30-01 11:15a PU_SOL_TH_014_34_k6.inp
PU_SO~54 INP         6,748  05-30-01 11:15a PU_SOL_TH_014_30_k6.inp
PU_SO~56 INP         6,717  05-30-01 11:15a PU_SOL_TH_014_33_k6.inp
PU_SO~58 INP         6,633  05-30-01 11:17a PU_SOL_TH_014_09_k6.inp
PU_SO~60 INP         6,633  05-30-01 11:14a PU_SOL_TH_014_07_k6.inp
PU_SO~62 INP         6,551  05-30-01 11:14a PU_SOL_TH_014_06_k6.inp
PU_SO~64 INP         6,551  05-30-01 11:14a PU_SOL_TH_014_05_k6.inp
PU_SO~66 INP         6,633  05-30-01 11:14a PU_SOL_TH_014_08_k6.inp
PU_SO~68 OUT       843,009  05-31-01  8:26p PU_SOL_TH_014_11_k6.out
PU_SO~70 OUT       842,492  05-31-01  9:24p PU_SOL_TH_014_14_k6.out
PU_SO~72 OUT       842,029  05-31-01  8:07p PU_SOL_TH_014_10_k6.out
PU_SO~74 OUT       842,846  05-31-01  9:05p PU_SOL_TH_014_13_k6.out
PU_SO~76 OUT       842,902  05-31-01  8:45p PU_SOL_TH_014_12_k6.out
PU_SO~78 OUT       842,986  05-31-01 11:38p PU_SOL_TH_014_21_k6.out
PU_SO~80 OUT       843,134  06-01-01 12:37a PU_SOL_TH_014_24_k6.out
PU_SO~82 OUT       841,973  05-31-01 11:19p PU_SOL_TH_014_20_k6.out
PU_SO~84 OUT       842,606  06-01-01 12:16a PU_SOL_TH_014_23_k6.out
PU_SO~86 OUT       842,807  05-31-01 11:57p PU_SOL_TH_014_22_k6.out
PU_SO~88 OUT       843,333  06-01-01  3:02a PU_SOL_TH_014_31_k6.out
PU_SO~90 OUT       844,041  06-01-01  4:04a PU_SOL_TH_014_34_k6.out
PU_SO~92 OUT       842,576  06-01-01  2:41a PU_SOL_TH_014_30_k6.out
PU_SO~94 OUT       843,572  06-01-01  3:43a PU_SOL_TH_014_33_k6.out
PU_SO~96 OUT       844,579  06-01-01  3:23a PU_SOL_TH_014_32_k6.out
PU_SO~98 OUT       842,666  05-31-01 11:00p PU_SOL_TH_014_19_k6.out
PU_S~100 OUT       842,373  05-31-01 10:21p PU_SOL_TH_014_17_k6.out
PU_S~102 OUT       842,926  05-31-01 10:02p PU_SOL_TH_014_16_k6.out
PU_S~104 OUT       843,709  05-31-01  9:43p PU_SOL_TH_014_15_k6.out
PU_S~106 OUT       845,453  05-31-01 10:40p PU_SOL_TH_014_18_k6.out
PU_S~108 OUT       843,543  06-01-01  2:20a PU_SOL_TH_014_29_k6.out
PU_S~110 OUT       845,154  06-01-01  1:39a PU_SOL_TH_014_27_k6.out
PU_S~112 OUT       843,087  06-01-01  1:18a PU_SOL_TH_014_26_k6.out
PU_S~114 OUT       843,233  06-01-01 12:58a PU_SOL_TH_014_25_k6.out
PU_S~116 OUT       843,197  06-01-01  1:59a PU_SOL_TH_014_28_k6.out
PU_S~118 OUT       841,728  06-01-01  4:25a PU_SOL_TH_014_35_k6.out
PU_S~120 OUT       843,043  05-31-01  7:48p PU_SOL_TH_014_09_k6.out
PU_S~122 OUT       842,571  05-31-01  7:10p PU_SOL_TH_014_07_k6.out
PU_S~124 OUT       843,181  05-31-01  6:50p PU_SOL_TH_014_06_k6.out
PU_S~126 OUT       842,375  05-31-01  6:33p PU_SOL_TH_014_05_k6.out
PU_S~128 OUT       843,337  05-31-01  7:29p PU_SOL_TH_014_08_k6.out
PU_S~130 INP         6,551  05-30-01 11:14a PU_SOL_TH_014_01_k6.inp
PU_S~132 OUT       841,771  05-31-01  5:22p PU_SOL_TH_014_01_k6.out
PU_S~134 INP         6,551  05-30-01 11:16a PU_SOL_TH_014_02_k6.inp
PU_S~136 OUT       841,900  05-31-01  5:40p PU_SOL_TH_014_02_k6.out
PU_S~138 INP         6,551  05-30-01 11:15a PU_SOL_TH_014_03_k6.inp
PU_S~140 OUT       842,217  05-31-01  5:58p PU_SOL_TH_014_03_k6.out
PU_S~142 INP         6,551  05-30-01 11:14a PU_SOL_TH_014_04_k6.inp
PU_S~144 OUT       842,233  05-31-01  6:15p PU_SOL_TH_014_04_k6.out
        70 file(s)     29,735,339 bytes

Directory of D:\CASES\PC\AoA1\PST_015

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6 INP         6,714  05-30-01 11:19a PU_SOL_TH_015_17_k6.inp
PU_SOL~8 INP         6,714  05-30-01 11:19a PU_SOL_TH_015_16_k6.inp
PU_SO~10 INP         6,714  05-30-01 11:19a PU_SOL_TH_015_15_k6.inp
PU_SO~12 INP         6,632  05-30-01 11:19a PU_SOL_TH_015_12_k6.inp
PU_SO~14 INP         6,632  05-30-01 11:19a PU_SOL_TH_015_11_k6.inp
PU_SO~16 INP         6,632  05-30-01 11:19a PU_SOL_TH_015_14_k6.inp
```

```
PU_SO~18 INP          6,632  05-30-01 11:19a PU_SOL_TH_015_10_k6.inp
PU_SO~20 INP          6,632  05-30-01 11:19a PU_SOL_TH_015_13_k6.inp
PU_SO~22 INP          6,632  05-30-01 11:20a PU_SOL_TH_015_09_k6.inp
PU_SO~24 INP          6,632  05-30-01 11:18a PU_SOL_TH_015_07_k6.inp
PU_SO~26 INP          6,468  05-30-01 11:18a PU_SOL_TH_015_06_k6.inp
PU_SO~28 INP          6,550  05-30-01 11:18a PU_SOL_TH_015_05_k6.inp
PU_SO~30 INP          6,632  05-30-01 11:18a PU_SOL_TH_015_08_k6.inp
PU_SO~32 OUT        845,491  06-01-01  7:41a PU_SOL_TH_015_11_k6.out
PU_SO~34 OUT        845,789  06-01-01  8:37a PU_SOL_TH_015_14_k6.out
PU_SO~36 OUT        845,195  06-01-01  7:22a PU_SOL_TH_015_10_k6.out
PU_SO~38 OUT        846,128  06-01-01  8:19a PU_SOL_TH_015_13_k6.out
PU_SO~40 OUT        845,704  06-01-01  8:00a PU_SOL_TH_015_12_k6.out
PU_SO~42 OUT        846,541  06-01-01  9:38a PU_SOL_TH_015_17_k6.out
PU_SO~44 OUT        847,128  06-01-01  9:18a PU_SOL_TH_015_16_k6.out
PU_SO~46 OUT        845,939  06-01-01  8:58a PU_SOL_TH_015_15_k6.out
PU_SO~48 OUT        846,146  06-01-01  7:04a PU_SOL_TH_015_09_k6.out
PU_SO~50 OUT        846,077  06-01-01  6:26a PU_SOL_TH_015_07_k6.out
PU_SO~52 OUT        843,437  06-01-01  6:07a PU_SOL_TH_015_06_k6.out
PU_SO~54 OUT        845,445  06-01-01  5:51a PU_SOL_TH_015_05_k6.out
PU_SO~56 OUT        845,635  06-01-01  6:45a PU_SOL_TH_015_08_k6.out
PU_SO~58 INP          6,550  05-30-01 11:18a PU_SOL_TH_015_01_k6.inp
PU_SO~60 OUT        831,314  06-01-01  4:42a PU_SOL_TH_015_01_k6.out
PU_SO~62 INP          6,550  05-30-01 11:19a PU_SOL_TH_015_02_k6.inp
PU_SO~64 OUT        843,969  06-01-01  5:00a PU_SOL_TH_015_02_k6.out
PU_SO~66 INP          6,550  05-30-01 11:19a PU_SOL_TH_015_03_k6.inp
PU_SO~68 OUT        844,700  06-01-01  5:17a PU_SOL_TH_015_03_k6.out
PU_SO~70 INP          6,550  05-30-01 11:18a PU_SOL_TH_015_04_k6.inp
PU_SO~72 OUT        845,212  06-01-01  5:34a PU_SOL_TH_015_04_k6.out
        34 file(s)     14,472,266 bytes

Directory of D:\CASES\PC\AoA1\PST_016

.              <DIR>         10-04-01  2:06p .
..             <DIR>         10-04-01  2:06p ..
PU_SOL~6 INP          6,715  05-30-01 11:21a PU_SOL_TH_016_09_k6.inp
PU_SOL~8 INP          6,879  05-30-01 11:21a PU_SOL_TH_016_07_k6.inp
PU_SO~10 INP          6,879  05-30-01 11:21a PU_SOL_TH_016_06_k6.inp
PU_SO~12 INP          6,879  05-30-01 11:21a PU_SOL_TH_016_05_k6.inp
PU_SO~14 INP          6,879  05-30-01 11:21a PU_SOL_TH_016_08_k6.inp
PU_SO~16 INP          6,715  05-30-01 11:21a PU_SOL_TH_016_11_k6.inp
PU_SO~18 INP          6,715  05-30-01 11:21a PU_SOL_TH_016_10_k6.inp
PU_SO~20 OUT        826,389  06-01-01 10:41a PU_SOL_TH_016_11_k6.out
PU_SO~22 OUT        824,532  06-01-01 10:34a PU_SOL_TH_016_10_k6.out
PU_SO~24 OUT        824,513  06-01-01 10:28a PU_SOL_TH_016_09_k6.out
PU_SO~26 OUT        816,088  06-01-01 10:15a PU_SOL_TH_016_07_k6.out
PU_SO~28 OUT        815,888  06-01-01 10:10a PU_SOL_TH_016_06_k6.out
PU_SO~30 OUT        812,582  06-01-01 10:04a PU_SOL_TH_016_05_k6.out
PU_SO~32 OUT        816,588  06-01-01 10:21a PU_SOL_TH_016_08_k6.out
PU_SO~34 INP          6,879  05-30-01 11:20a PU_SOL_TH_016_01_k6.inp
PU_SO~36 OUT        813,801  06-01-01  9:43a PU_SOL_TH_016_01_k6.out
PU_SO~38 INP          6,879  05-30-01 11:21a PU_SOL_TH_016_02_k6.inp
PU_SO~40 OUT        810,155  06-01-01  9:48a PU_SOL_TH_016_02_k6.out
PU_SO~42 INP          6,879  05-30-01 11:21a PU_SOL_TH_016_03_k6.inp
PU_SO~44 OUT        811,360  06-01-01  9:53a PU_SOL_TH_016_03_k6.out
PU_SO~46 INP          6,961  05-30-01 11:21a PU_SOL_TH_016_04_k6.inp
PU_SO~48 OUT        811,104  06-01-01  9:58a PU_SOL_TH_016_04_k6.out
        22 file(s)      9,058,259 bytes

Directory of D:\CASES\PC\AoA1\PST_017

.              <DIR>         10-04-01  2:06p .
..             <DIR>         10-04-01  2:06p ..
PU_SOL~6 INP          6,879  05-30-01 11:23a PU_SOL_TH_017_09_k6.inp
PU_SOL~8 INP          6,879  05-30-01 11:22a PU_SOL_TH_017_07_k6.inp
PU_SO~10 INP          6,879  05-30-01 11:22a PU_SOL_TH_017_06_k6.inp
PU_SO~12 INP          6,879  05-30-01 11:22a PU_SOL_TH_017_05_k6.inp
PU_SO~14 INP          6,879  05-30-01 11:22a PU_SOL_TH_017_08_k6.inp
PU_SO~16 INP          6,879  05-30-01 11:23a PU_SOL_TH_017_17_k6.inp
PU_SO~18 INP          6,879  05-30-01 11:23a PU_SOL_TH_017_16_k6.inp
PU_SO~20 INP          6,879  05-30-01 11:23a PU_SOL_TH_017_15_k6.inp
PU_SO~22 INP          6,879  05-30-01 11:23a PU_SOL_TH_017_18_k6.inp
PU_SO~24 INP          6,879  05-30-01 11:23a PU_SOL_TH_017_12_k6.inp
PU_SO~26 INP          6,551  05-30-01 11:23a PU_SOL_TH_017_11_k6.inp
PU_SO~28 INP          6,879  05-30-01 11:23a PU_SOL_TH_017_14_k6.inp
PU_SO~30 INP          6,879  05-30-01 11:23a PU_SOL_TH_017_10_k6.inp
PU_SO~32 INP          6,879  05-30-01 11:23a PU_SOL_TH_017_13_k6.inp
PU_SO~34 OUT        813,431  06-01-01 10:17a PU_SOL_TH_017_11_k6.out
PU_SO~36 OUT        813,585  06-01-01 10:35a PU_SOL_TH_017_14_k6.out
PU_SO~38 OUT        814,406  06-01-01 10:11a PU_SOL_TH_017_10_k6.out
PU_SO~40 OUT        813,546  06-01-01 10:29a PU_SOL_TH_017_13_k6.out
PU_SO~42 OUT        814,647  06-01-01 10:23a PU_SOL_TH_017_12_k6.out
PU_SO~44 OUT        814,063  06-01-01 10:05a PU_SOL_TH_017_09_k6.out
PU_SO~46 OUT        813,757  06-01-01  9:54a PU_SOL_TH_017_07_k6.out
PU_SO~48 OUT        813,330  06-01-01  9:48a PU_SOL_TH_017_06_k6.out
PU_SO~50 OUT        813,367  06-01-01  9:43a PU_SOL_TH_017_05_k6.out
PU_SO~52 OUT        813,509  06-01-01 10:00a PU_SOL_TH_017_08_k6.out
PU_SO~54 OUT        814,303  06-01-01 10:52a PU_SOL_TH_017_17_k6.out
PU_SO~56 OUT        813,316  06-01-01 10:47a PU_SOL_TH_017_16_k6.out
PU_SO~58 OUT        813,378  06-01-01 10:41a PU_SOL_TH_017_15_k6.out
PU_SO~60 OUT        813,431  06-01-01 10:58a PU_SOL_TH_017_18_k6.out
PU_SO~62 INP          6,551  05-30-01 11:22a PU_SOL_TH_017_01_k6.inp
PU_SO~64 OUT        812,775  06-01-01  9:21a PU_SOL_TH_017_01_k6.out
```

```
PU_SO~66 INP         6,879  05-30-01 11:22a PU_SOL_TH_017_02_k6.inp
PU_SO~68 OUT       813,845  06-01-01  9:26a PU_SOL_TH_017_02_k6.out
PU_SO~70 INP         6,879  05-30-01 11:22a PU_SOL_TH_017_03_k6.inp
PU_SO~72 OUT       813,625  06-01-01  9:32a PU_SOL_TH_017_03_k6.out
PU_SO~74 INP         6,879  05-30-01 11:22a PU_SOL_TH_017_04_k6.inp
PU_SO~76 OUT       814,250  06-01-01  9:37a PU_SOL_TH_017_04_k6.out
        36 file(s)     14,769,730 bytes

Directory of D:\CASES\PC\AoA1\PST_020

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6 INP         5,953  05-30-01  8:05a PU_SOL_TH_020_06_T8A_k6.inp
PU_SOL~8 INP         5,953  05-30-01  8:05a PU_SOL_TH_020_07_T8A_k6.inp
PU_SO~10 INP         6,691  05-30-01  8:05a PU_SOL_TH_020_08_T8A_k6.inp
PU_SO~12 INP         6,691  05-30-01  8:04a PU_SOL_TH_020_09_T8A_k6.inp
PU_SO~14 OUT       811,258  06-01-01  1:40p PU_SOL_TH_020_08_T8A_k6.out
PU_SO~16 INP         5,953  05-30-01  8:05a PU_SOL_TH_020_12_T8B_k6.inp
PU_SO~18 OUT       810,496  06-01-01  2:04p PU_SOL_TH_020_09_T8A_k6.out
PU_SO~20 INP         5,953  05-30-01  8:04a PU_SOL_TH_020_13_T8B_k6.inp
PU_SO~22 OUT       801,154  06-01-01 12:51p PU_SOL_TH_020_06_T8A_k6.out
PU_SO~24 INP         6,691  05-30-01  8:05a PU_SOL_TH_020_14_T8B_k6.inp
PU_SO~26 INP         5,953  05-30-01  8:04a PU_SOL_TH_020_10_T8B_k6.inp
PU_SO~28 OUT       799,761  06-01-01  1:18p PU_SOL_TH_020_07_T8A_k6.out
PU_SO~30 INP         6,691  05-30-01  8:05a PU_SOL_TH_020_15_T8B_k6.inp
PU_SO~32 INP         5,953  05-30-01  8:04a PU_SOL_TH_020_11_T8B_k6.inp
PU_SO~34 OUT       809,983  06-01-01  4:11p PU_SOL_TH_020_14_T8B_k6.out
PU_SO~36 OUT       800,426  06-01-01  2:30p PU_SOL_TH_020_10_T8B_k6.out
PU_SO~38 OUT       813,938  06-01-01  4:34p PU_SOL_TH_020_15_T8B_k6.out
PU_SO~40 OUT       801,397  06-01-01  2:57p PU_SOL_TH_020_11_T8B_k6.out
PU_SO~42 OUT       802,884  06-01-01  3:23p PU_SOL_TH_020_12_T8B_k6.out
PU_SO~44 OUT       801,048  06-01-01  3:48p PU_SOL_TH_020_13_T8B_k6.out
PU_SO~46 INP         5,951  06-06-01  3:20p PU_SOL_TH_020_01_T8A_k6.inp
PU_SO~48 OUT       493,523  06-06-01  3:45p PU_SOL_TH_020_01_T8A_k6.out
PU_SO~50 INP         5,953  05-30-01  8:05a PU_SOL_TH_020_02_T8A_k6.inp
PU_SO~52 OUT       800,092  06-01-01 11:33a PU_SOL_TH_020_02_T8A_k6.out
PU_SO~54 INP         5,953  05-30-01  8:05a PU_SOL_TH_020_03_T8A_k6.inp
PU_SO~56 OUT       802,537  06-01-01 12:01p PU_SOL_TH_020_03_T8A_k6.out
PU_SO~58 INP         5,953  05-30-01  8:05a PU_SOL_TH_020_05_T8A_k6.inp
PU_SO~60 OUT       801,805  06-01-01 12:26p PU_SOL_TH_020_05_T8A_k6.out
        28 file(s)     11,036,594 bytes

Directory of D:\CASES\PC\AoA1\PST_025

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PSTH02~6 INP         8,250  08-22-01  1:06p psth025_case3_c6.inp
PSTH02~8 INP         8,250  08-23-01  4:03p psth025_case4_c6.inp
PSTH0~10 INP         8,250  08-22-01  1:06p psth025_case5_c6.inp
PSTH0~12 INP         8,250  08-22-01  1:06p psth025_case6_c6.inp
PSTH0~14 GIF         2,193  08-23-01  4:20a psth025_case3_c6.plot0001.gif
PSTH0~16 GIF         2,064  08-23-01  4:20a psth025_case3_c6.plot0000.gif
PSTH0~18 GIF         2,180  08-23-01 11:14p psth025_case4_c6.plot0001.gif
PSTH0~20 GIF         2,054  08-23-01 11:14p psth025_case4_c6.plot0000.gif
PSTH0~22 GIF         2,176  08-23-01  9:03a psth025_case5_c6.plot0001.gif
PSTH0~24 GIF         2,061  08-23-01  9:03a psth025_case5_c6.plot0000.gif
PSTH0~26 GIF         2,188  08-24-01  3:57a psth025_case6_c6.plot0001.gif
PSTH0~28 GIF         2,062  08-24-01  3:57a psth025_case6_c6.plot0000.gif
PSTH0~30 OUT       989,570  08-23-01  9:03a psth025_case5_c6.out
PSTH0~32 OUT       989,461  08-24-01  3:57a psth025_case6_c6.out
PSTH0~34 GIF         2,068  08-22-01 10:56a psth025_case1_c6.plot0000.gif
PSTH0~36 INP         1,813  08-21-01  4:38p psth025_case1_c5toc6.inp
PSTH0~38 OUT       988,969  08-22-01 10:56a psth025_case1_c6.out
PSTH0~40 TXT         1,754  08-21-01  4:34p psth025_case1_c5.txt
PSTH0~42 GIF         2,161  08-22-01 10:56a psth025_case1_c6.plot0001.gif
PSTH0~44 INP         8,250  08-21-01  7:13p psth025_case1_c6.inp
PSTH0~46 OUT       988,625  08-22-01 11:38p psth025_case2_c6.out
PSTH0~48 GIF         2,054  08-22-01 11:38p psth025_case2_c6.plot0000.gif
PSTH0~50 INP         8,247  08-21-01  4:40p psth025_case1_c6_NEA.inp
PSTH0~52 OUT       989,463  08-23-01  4:20a psth025_case3_c6.out
PSTH0~54 GIF         2,191  08-22-01 11:38p psth025_case2_c6.plot0001.gif
PSTH0~56 INP         8,250  08-22-01  1:06p psth025_case2_c6.inp
PSTH0~58 OUT       989,412  08-23-01 11:14p psth025_case4_c6.out
        27 file(s)      6,022,266 bytes

Directory of D:\CASES\PC\AoA1\PST_026

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PSTH02~6 OUT        47,651  08-21-01  7:10p psth026_case3_c5toc6.out
PSTH02~8 GIF         2,069  08-22-01  6:13a psth026_case3_c6.plot0001.gif
PSTH0~10 INP        10,544  08-21-01  7:12p psth026_case3_c6.inp
PSTH0~12 GIF         1,897  08-22-01  6:13a psth026_case3_c6.plot0000.gif
PSTH0~14 OUT     1,029,352  08-22-01  6:13a psth026_case3_c6.out
PSTH0~16 INP         2,234  08-21-01  7:08p psth026_case3_c5toc6.inp
PSTH0~18 GIF         1,907  08-21-01 10:54p psth026_case1_c6.plot0000.gif
PSTH0~20 INP         2,234  08-21-01  7:06p psth026_case1_c5toc6.inp
PSTH0~22 OUT        47,651  08-21-01  7:10p psth026_case1_c5toc6.out
PSTH0~24 TXT         2,222  08-21-01  7:02p psth026_case1_c5.txt
PSTH0~26 GIF         2,069  08-21-01 10:54p psth026_case1_c6.plot0001.gif
PSTH0~28 INP        10,544  08-21-01  7:12p psth026_case1_c6.inp
PSTH0~30 OUT     1,023,990  08-21-01 10:54p psth026_case1_c6.out
```

```
PSTH0~32 TXT         2,222  08-21-01  7:01p psth026_case2_c5.txt
PSTH0~34 GIF         1,907  08-22-01  2:34a psth026_case2_c6.plot0000.gif
PSTH0~36 INP         2,234  08-21-01  7:09p psth026_case2_c5toc6.inp
PSTH0~38 OUT        47,651  08-21-01  7:10p psth026_case2_c5toc6.out
PSTH0~40 TXT         2,222  08-21-01  7:03p psth026_case3_c5.txt
PSTH0~42 GIF         2,069  08-22-01  2:34a psth026_case2_c6.plot0001.gif
PSTH0~44 INP        10,544  08-21-01  7:12p psth026_case2_c6.inp
PSTH0~46 OUT     1,022,828  08-22-01  2:34a psth026_case2_c6.out
        21 file(s)      3,276,041 bytes

Directory of D:\CASES\PC\AoA1\usl

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
CONCRE~5       <DIR>        10-04-01  2:06p Concrete Reflector
FULLSE~7       <DIR>        10-04-01  2:06p Full Set
PUCONT~9       <DIR>        10-04-01  2:06p Pu content
WATER~11       <DIR>        10-04-01  2:06p Water Cadmium Reflector
WATER~13       <DIR>        10-04-01  2:06p Water Reflector
         0 file(s)              0 bytes

Directory of D:\CASES\PC\AoA1\usl\Concrete Reflector

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU-NIT~6 INP           911  09-25-01 10:32a Pu-Nitrite_Concrete_Reflector_EALF.inp
PU-NIT~8 OUT         5,122  09-25-01 10:34a Pu-Nitrite_Concrete_Reflector_EALF.out
         2 file(s)          6,033 bytes

Directory of D:\CASES\PC\AoA1\usl\Full Set

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU-NIT~6 INP         6,042  09-24-01  2:01p Pu-Nitrite-EALF.inp
PU-NIT~8 OUT        13,566  09-24-01  2:03p Pu-Nitrite-EALF.out
PU-NI~10 INP         5,599  09-24-01  2:03p Pu-Nitrite-HPu.inp
PU-NI~12 OUT        13,566  09-24-01  2:05p Pu-Nitrite-HPu.out
REDUC~14 INP         5,757  09-24-01  4:29p reduced_set_162_exp.inp
REDUC~16 OUT        12,047  09-24-01  4:31p reduced_set_162_exp.out
         6 file(s)         56,577 bytes

Directory of D:\CASES\PC\AoA1\usl\Pu content

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU-NIT~6 INP         1,211  09-24-01  2:09p Pu-Nitrite-Pu.inp
PU-NIT~8 OUT         5,956  09-24-01  2:10p Pu-Nitrite-Pu.out
         2 file(s)          7,167 bytes

Directory of D:\CASES\PC\AoA1\usl\Water Cadmium Reflector

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
         0 file(s)              0 bytes

Directory of D:\CASES\PC\AoA1\usl\Water Reflector

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
         0 file(s)              0 bytes

Directory of D:\CASES\PC\AoA2

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
MCT_002        <DIR>        10-04-01  2:06p MCT_002
MCT_003        <DIR>        10-04-01  2:06p MCT_003
MCT_004        <DIR>        10-04-01  2:06p MCT_004
MCT_005        <DIR>        10-04-01  2:06p MCT_005
MCT_009        <DIR>        10-04-01  2:06p MCT_009
USL            <DIR>        10-04-01  2:06p usl
         0 file(s)              0 bytes

Directory of D:\CASES\PC\AoA2\MCT_002

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
MIX_CO~6 INP        25,223  05-30-01 10:51a MIX_COMP_THERM_002_PNL35_k6.inp
MIX_CO~8 INP        25,223  05-30-01 10:52a MIX_COMP_THERM_002_PNL34_k6.inp
MIX_C~10 OUT     1,037,434  05-31-01  8:10a MIX_COMP_THERM_002_PNL35_k6.out
MIX_C~12 OUT     1,016,579  05-31-01  7:17a MIX_COMP_THERM_002_PNL34_k6.out
MIX_C~14 INP        25,223  05-30-01 10:52a MIX_COMP_THERM_002_PNL30_k6.inp
MIX_C~16 OUT     1,023,755  05-30-01  2:00p MIX_COMP_THERM_002_PNL30_k6.out
MIX_C~18 INP        25,223  05-30-01 10:51a MIX_COMP_THERM_002_PNL31_k6.inp
MIX_C~20 OUT     1,043,498  05-30-01  2:51p MIX_COMP_THERM_002_PNL31_k6.out
MIX_C~22 INP        25,223  05-30-01 10:52a MIX_COMP_THERM_002_PNL32_k6.inp
MIX_C~24 OUT     1,016,958  05-30-01  4:10p MIX_COMP_THERM_002_PNL32_k6.out
MIX_C~26 INP        25,223  05-30-01 10:51a MIX_COMP_THERM_002_PNL33_k6.inp
MIX_C~28 OUT     1,034,110  05-30-01  4:57p MIX_COMP_THERM_002_PNL33_k6.out
        12 file(s)      6,323,672 bytes

Directory of D:\CASES\PC\AoA2\MCT_003
```

```
.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
MIX_CO~6 OUT     1,013,112  05-31-01  4:26p MIX_COMP_THERM_003_cas4_k6.out
MIX_CO~8 OUT     1,008,733  05-31-01  5:59p MIX_COMP_THERM_003_cas5_k6.out
MIX_C~10 OUT     1,010,552  05-31-01  7:39p MIX_COMP_THERM_003_cas6_k6.out
MIX_C~12 INP        23,666  05-30-01 10:58a MIX_COMP_THERM_003_cas4_k6.inp
MIX_C~14 INP        23,666  05-30-01 10:58a MIX_COMP_THERM_003_cas5_k6.inp
MIX_C~16 INP        23,666  05-30-01 10:58a MIX_COMP_THERM_003_cas6_k6.inp
MIX_C~18 INP        23,666  05-30-01 10:56a MIX_COMP_THERM_003_cas1_k6.inp
MIX_C~20 OUT     1,010,990  05-31-01 10:46a MIX_COMP_THERM_003_cas1_k6.out
MIX_C~22 INP        23,666  05-30-01 10:57a MIX_COMP_THERM_003_cas2-1_k6.inp
MIX_C~24 OUT     1,015,766  05-31-01 12:11p MIX_COMP_THERM_003_cas2-1_k6.out
MIX_C~26 INP        23,666  05-30-01 10:57a MIX_COMP_THERM_003_cas2-2_k6.inp
MIX_C~28 OUT     1,014,981  05-31-01  1:36p MIX_COMP_THERM_003_cas2-2_k6.out
MIX_C~30 INP        23,830  05-30-01 10:58a MIX_COMP_THERM_003_cas3_k6.inp
MIX_C~32 OUT     1,016,672  05-31-01  2:50p MIX_COMP_THERM_003_cas3_k6.out
        14 file(s)      7,256,632 bytes

Directory of D:\CASES\PC\AoA2\MCT_004

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
MIX_CO~6 INP        21,704  05-30-01 11:01a MIX_COMP_THERM_004_cas05_k6.inp
MIX_CO~8 INP        21,704  05-30-01 10:59a MIX_COMP_THERM_004_cas10_k6.inp
MIX_C~10 INP        21,704  05-30-01 10:59a MIX_COMP_THERM_004_cas11_k6.inp
MIX_C~12 INP        21,704  05-30-01 11:01a MIX_COMP_THERM_004_cas08_k6.inp
MIX_C~14 INP        21,704  05-30-01 11:01a MIX_COMP_THERM_004_cas07_k6.inp
MIX_C~16 INP        21,704  05-30-01 11:01a MIX_COMP_THERM_004_cas06_k6.inp
MIX_C~18 INP        21,704  05-30-01 11:02a MIX_COMP_THERM_004_cas09_k6.inp
MIX_C~20 OUT     1,130,763  06-01-01  7:04a MIX_COMP_THERM_004_cas08_k6.out
MIX_C~22 OUT     1,130,696  06-01-01  5:35a MIX_COMP_THERM_004_cas07_k6.out
MIX_C~24 OUT     1,131,072  06-01-01  4:06a MIX_COMP_THERM_004_cas06_k6.out
MIX_C~26 OUT     1,130,707  06-01-01  8:34a MIX_COMP_THERM_004_cas09_k6.out
MIX_C~28 OUT     1,131,850  06-01-01  2:41a MIX_COMP_THERM_004_cas05_k6.out
MIX_C~30 OUT     1,131,403  06-01-01 10:07a MIX_COMP_THERM_004_cas10_k6.out
MIX_C~32 OUT     1,131,388  06-01-01 11:40a MIX_COMP_THERM_004_cas11_k6.out
MIX_C~34 INP        21,704  05-30-01 10:59a MIX_COMP_THERM_004_cas01_k6.inp
MIX_C~36 OUT     1,132,379  05-31-01  9:03p MIX_COMP_THERM_004_cas01_k6.out
MIX_C~38 INP        21,700  05-30-01 11:00a MIX_COMP_THERM_004_cas02_k6.inp
MIX_C~40 OUT     1,133,040  05-31-01 10:26p MIX_COMP_THERM_004_cas02_k6.out
MIX_C~42 INP        21,704  05-30-01 11:00a MIX_COMP_THERM_004_cas03_k6.inp
MIX_C~44 OUT     1,133,002  05-31-01 11:49p MIX_COMP_THERM_004_cas03_k6.out
MIX_C~46 INP        21,704  05-30-01 11:00a MIX_COMP_THERM_004_cas04_k6.inp
MIX_C~48 OUT     1,131,131  06-01-01  1:15a MIX_COMP_THERM_004_cas04_k6.out
        22 file(s)     12,686,171 bytes

Directory of D:\CASES\PC\AoA2\MCT_005

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
MIXCT_~6 INP        92,572  05-30-01 11:03a mixct_005_case5_k6.inp
MIXCT_~8 INP        92,572  05-30-01 11:03a mixct_005_case6_k6.inp
MIXCT~10 OUT     1,399,151  06-02-01  2:31a mixct_005_case5_k6.out
MIXCT~12 OUT     1,394,434  06-02-01  5:38a mixct_005_case6_k6.out
MIXCT~14 INP        92,735  08-30-01  5:48p mixct_005_case1_k6.inp
MIXCT~16 OUT     1,404,842  08-30-01 10:52p mixct_005_case1_k6.out
MIXCT~18 INP        92,763  05-30-01 11:02a mixct_005_case2_k6.inp
MIXCT~20 OUT     1,410,062  06-01-01  6:22p mixct_005_case2_k6.out
MIXCT~22 INP        92,572  05-30-01 11:03a mixct_005_case3_k6.inp
MIXCT~24 OUT     1,405,905  06-01-01  8:34p mixct_005_case3_k6.out
MIXCT~26 INP        92,572  05-30-01 11:03a mixct_005_case4_k6.inp
MIXCT~28 OUT     1,404,528  06-01-01 11:11p mixct_005_case4_k6.out
        12 file(s)      8,974,708 bytes

Directory of D:\CASES\PC\AoA2\MCT_009

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
MIXCT_~6 INP       145,340  05-30-01 11:04a mixct_009_case5_k6.inp
MIXCT_~8 INP       145,318  05-30-01 11:05a mixct_009_case6_k6.inp
MIXCT~10 OUT     1,706,982  06-01-01  9:55p mixct_009_case5_k6.out
MIXCT~12 OUT     1,715,630  06-01-01 10:58p mixct_009_case6_k6.out
MIXCT~14 INP       146,078  05-30-01 11:04a mixct_009_case1_k6.inp
MIXCT~16 OUT     1,713,599  06-01-01  5:55p mixct_009_case1_k6.out
MIXCT~18 INP       145,564  05-30-01 11:05a mixct_009_case2_k6.inp
MIXCT~20 OUT     1,716,847  06-01-01  6:54p mixct_009_case2_k6.out
MIXCT~22 INP       145,362  05-30-01 11:04a mixct_009_case3_k6.inp
MIXCT~24 OUT     1,704,225  06-01-01  7:52p mixct_009_case3_k6.out
MIXCT~26 INP       145,236  05-30-01 11:04a mixct_009_case4_k6.inp
MIXCT~28 OUT     1,715,819  06-01-01  8:52p mixct_009_case4_k6.out
        12 file(s)     11,146,000 bytes

Directory of D:\CASES\PC\AoA2\usl

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
FULLSE~5       <DIR>        10-04-01  2:06p Full Set
         0 file(s)              0 bytes

Directory of D:\CASES\PC\AoA2\usl\Full Set
```

```
.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
MIX_FU~6 INP         1,104  09-24-01  3:10p MIX_Full_Set_EALF.inp
MIX_FU~8 OUT         5,407  09-24-01  3:17p MIX_Full_Set_EALF.out
MIX_F~10 INP         1,297  09-24-01  3:09p MIX_Full_Set_PuO2.inp
MIX_F~12 OUT         5,407  09-24-01  3:18p MIX_Full_Set_PuO2.out
MIX_F~14 INP         1,113  09-24-01  3:15p MIX_Full_Set_VmVf.inp
MIX_F~16 OUT         5,619  09-24-01  3:16p MIX_Full_Set_VmVf.out
         6 file(s)         19,947 bytes

Directory of D:\CASES\Sun

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
AOA1           <DIR>        10-04-01  2:06p AoA1
AOA2           <DIR>        10-04-01  2:06p AoA2
         0 file(s)              0 bytes

Directory of D:\CASES\Sun\AoA1

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PST_001        <DIR>        10-04-01  2:06p PST_001
PST_002        <DIR>        10-04-01  2:06p PST_002
PST_003        <DIR>        10-04-01  2:06p PST_003
PST_004        <DIR>        10-04-01  2:06p PST_004
PST_005        <DIR>        10-04-01  2:06p PST_005
PST_006        <DIR>        10-04-01  2:06p PST_006
PST_008        <DIR>        10-04-01  2:06p PST_008
PST_011        <DIR>        10-04-01  2:06p PST_011
PST_014        <DIR>        10-04-01  2:06p PST_014
PST_015        <DIR>        10-04-01  2:06p PST_015
PST_016        <DIR>        10-04-01  2:06p PST_016
PST_017        <DIR>        10-04-01  2:06p PST_017
PST_020        <DIR>        10-04-01  2:06p PST_020
PST_025        <DIR>        10-04-01  2:06p PST_025
PST_026        <DIR>        10-04-01  2:06p PST_026
PU_SO~35       <DIR>        10-04-01  2:06p PU_SOL_THERM
USL            <DIR>        10-04-01  2:06p usl
         0 file(s)              0 bytes

Directory of D:\CASES\Sun\AoA1\PST_001

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
001_INP        <DIR>        10-04-01  2:06p 001_INP
001_OUT        <DIR>        10-04-01  2:06p 001_OUT
         0 file(s)              0 bytes

Directory of D:\CASES\Sun\AoA1\PST_001\001_INP

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6             4,311  03-30-01 10:08a PU_SOL_TH_001_6_T8A_k6
PU_SOL~8             4,311  03-30-01 10:08a PU_SOL_TH_001_5_T8A_k6
PU_SO~10             4,311  03-30-01 10:08a PU_SOL_TH_001_1_T8A_k6
PU_SO~12             4,311  03-30-01 10:08a PU_SOL_TH_001_2_T8A_k6
PU_SO~14             4,311  03-30-01 10:08a PU_SOL_TH_001_3_T8A_k6
PU_SO~16             4,311  03-30-01 10:08a PU_SOL_TH_001_4_T8A_k6
         6 file(s)         25,866 bytes

Directory of D:\CASES\Sun\AoA1\PST_001\001_OUT

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6 OUT       509,114  03-30-01 10:08a PU_SOL_TH_001_5_T8A_k6.out
PU_SOL~8 OUT       506,625  03-30-01 10:08a PU_SOL_TH_001_6_T8A_k6.out
PU_SO~10 OUT       505,514  03-30-01 10:08a PU_SOL_TH_001_1_T8A_k6.out
PU_SO~12 OUT       506,385  03-30-01 10:08a PU_SOL_TH_001_2_T8A_k6.out
PU_SO~14 OUT       505,604  03-30-01 10:08a PU_SOL_TH_001_3_T8A_k6.out
PU_SO~16 OUT       513,418  03-30-01 10:08a PU_SOL_TH_001_4_T8A_k6.out
         6 file(s)      3,046,660 bytes

Directory of D:\CASES\Sun\AoA1\PST_002

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
002_INP        <DIR>        10-04-01  2:06p 002_inp
002_OUT        <DIR>        10-04-01  2:06p 002_out
         0 file(s)              0 bytes

Directory of D:\CASES\Sun\AoA1\PST_002\002_inp

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6             4,065  03-30-01 10:08a PU_SOL_TH_002_5_k6
PU_SOL~8             4,065  03-30-01 10:08a PU_SOL_TH_002_7_k6
PU_SO~10             4,065  03-30-01 10:08a PU_SOL_TH_002_6_k6
PU_SO~12             4,065  03-30-01 10:08a PU_SOL_TH_002_1_k6
PU_SO~14             4,065  03-30-01 10:08a PU_SOL_TH_002_2_k6
PU_SO~16             4,065  03-30-01 10:08a PU_SOL_TH_002_3_k6
PU_SO~18             4,065  03-30-01 10:08a PU_SOL_TH_002_4_k6
```

```
        7 file(s)         28,455 bytes

Directory of D:\CASES\Sun\AoA1\PST_002\002_out

.               <DIR>        10-04-01  2:06p .
..              <DIR>        10-04-01  2:06p ..
PU_SOL~6 OUT        474,734  03-30-01 10:08a PU_SOL_TH_002_5_k6.out
PU_SOL~8 OUT        477,965  03-30-01 10:08a PU_SOL_TH_002_6_k6.out
PU_SO~10 OUT        479,903  03-30-01 10:08a PU_SOL_TH_002_7_k6.out
PU_SO~12 OUT        483,825  03-30-01 10:08a PU_SOL_TH_002_1_k6.out
PU_SO~14 OUT        476,325  03-30-01 10:08a PU_SOL_TH_002_2_k6.out
PU_SO~16 OUT        474,751  03-30-01 10:08a PU_SOL_TH_002_3_k6.out
PU_SO~18 OUT        477,309  03-30-01 10:08a PU_SOL_TH_002_4_k6.out
        7 file(s)      3,344,812 bytes

Directory of D:\CASES\Sun\AoA1\PST_003

.               <DIR>        10-04-01  2:06p .
..              <DIR>        10-04-01  2:06p ..
003_INP         <DIR>        10-04-01  2:06p 003_inp
003_OUT         <DIR>        10-04-01  2:06p 003_out
        0 file(s)              0 bytes

Directory of D:\CASES\Sun\AoA1\PST_003\003_inp

.               <DIR>        10-04-01  2:06p .
..              <DIR>        10-04-01  2:06p ..
PU_SOL~6              4,475  03-30-01 10:08a PU_SOL_TH_003_6_k6
PU_SOL~8              4,475  03-30-01 10:08a PU_SOL_TH_003_8_k6
PU_SO~10              4,475  03-30-01 10:08a PU_SOL_TH_003_5_k6
PU_SO~12              4,475  03-30-01 10:08a PU_SOL_TH_003_7_k6
PU_SO~14              4,475  03-30-01 10:08a PU_SOL_TH_003_1_k6
PU_SO~16              4,475  03-30-01 10:08a PU_SOL_TH_003_2_k6
PU_SO~18              4,475  03-30-01 10:08a PU_SOL_TH_003_3_k6
PU_SO~20              4,475  03-30-01 10:08a PU_SOL_TH_003_4_k6
        8 file(s)         35,800 bytes

Directory of D:\CASES\Sun\AoA1\PST_003\003_out

.               <DIR>        10-04-01  2:06p .
..              <DIR>        10-04-01  2:06p ..
PU_SOL~6 OUT        502,223  03-30-01 10:08a PU_SOL_TH_003_5_k6.out
PU_SOL~8 OUT        491,381  03-30-01 10:08a PU_SOL_TH_003_6_k6.out
PU_SO~10 OUT        498,887  03-30-01 10:08a PU_SOL_TH_003_7_k6.out
PU_SO~12 OUT        499,680  03-30-01 10:08a PU_SOL_TH_003_8_k6.out
PU_SO~14 OUT        498,323  03-30-01 10:08a PU_SOL_TH_003_1_k6.out
PU_SO~16 OUT        502,936  03-30-01 10:08a PU_SOL_TH_003_2_k6.out
PU_SO~18 OUT        496,892  03-30-01 10:08a PU_SOL_TH_003_3_k6.out
PU_SO~20 OUT        498,300  03-30-01 10:08a PU_SOL_TH_003_4_k6.out
        8 file(s)      3,988,622 bytes

Directory of D:\CASES\Sun\AoA1\PST_004

.               <DIR>        10-04-01  2:06p .
..              <DIR>        10-04-01  2:06p ..
004_INP         <DIR>        10-04-01  2:06p 004_inp
004_OUT         <DIR>        10-04-01  2:06p 004_out
        0 file(s)              0 bytes

Directory of D:\CASES\Sun\AoA1\PST_004\004_inp

.               <DIR>        10-04-01  2:06p .
..              <DIR>        10-04-01  2:06p ..
PU_SOL~6              4,065  03-30-01 10:08a PU_SOL_TH_004_2_k6
PU_SOL~8              4,065  03-30-01 10:08a PU_SOL_TH_004_4_k6
PU_SO~10              4,065  03-30-01 10:08a PU_SOL_TH_004_6_k6
PU_SO~12              4,065  03-30-01 10:08a PU_SOL_TH_004_8_k6
PU_SO~14              4,065  03-30-01 10:08a PU_SOL_TH_004_1_k6
PU_SO~16              4,065  03-30-01 10:08a PU_SOL_TH_004_3_k6
PU_SO~18              4,065  03-30-01 10:08a PU_SOL_TH_004_5_k6
PU_SO~20              4,065  03-30-01 10:08a PU_SOL_TH_004_7_k6
PU_SO~22              4,065  03-30-01 10:08a PU_SOL_TH_004_9_k6
PU_SO~24              4,065  03-30-01 10:08a PU_SOL_TH_004_10_k6
PU_SO~26              4,065  03-30-01 10:08a PU_SOL_TH_004_11_k6
PU_SO~28              4,147  03-30-01 10:08a PU_SOL_TH_004_12_k6
PU_SO~30              4,147  03-30-01 10:08a PU_SOL_TH_004_13_k6
       13 file(s)         53,009 bytes

Directory of D:\CASES\Sun\AoA1\PST_004\004_out

.               <DIR>        10-04-01  2:06p .
..              <DIR>        10-04-01  2:06p ..
PU_SOL~6 OUT        479,228  03-30-01 10:08a PU_SOL_TH_004_13_k6.out
PU_SOL~8 OUT        478,606  03-30-01 10:08a PU_SOL_TH_004_12_k6.out
PU_SO~10 OUT        484,119  03-30-01 10:08a PU_SOL_TH_004_10_k6.out
PU_SO~12 OUT        478,737  03-30-01 10:08a PU_SOL_TH_004_11_k6.out
PU_SO~14 OUT        483,728  03-30-01 10:08a PU_SOL_TH_004_05_k6.out
PU_SO~16 OUT        479,515  03-30-01 10:08a PU_SOL_TH_004_08_k6.out
PU_SO~18 OUT        479,228  03-30-01 10:08a PU_SOL_TH_004_07_k6.out
PU_SO~20 OUT        478,577  03-30-01 10:08a PU_SOL_TH_004_06_k6.out
PU_SO~22 OUT        481,675  03-30-01 10:08a PU_SOL_TH_004_09_k6.out
PU_SO~24 OUT        485,163  03-30-01 10:08a PU_SOL_TH_004_01_k6.out
```

```
PU_SO-26 OUT       479,590  03-30-01 10:08a PU_SOL_TH_004_02_k6.out
PU_SO-28 OUT       488,046  03-30-01 10:08a PU_SOL_TH_004_03_k6.out
PU_SO-30 OUT       478,713  03-30-01 10:08a PU_SOL_TH_004_04_k6.out
        13 file(s)      6,254,925 bytes

Directory of D:\CASES\Sun\AoA1\PST_005

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
005_INP        <DIR>        10-04-01  2:06p 005_inp
005_OUT        <DIR>        10-04-01  2:06p 005_out
         0 file(s)              0 bytes

Directory of D:\CASES\Sun\AoA1\PST_005\005_inp

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6                4,065  03-30-01 10:08a PU_SOL_TH_005_5_k6
PU_SOL~8                4,065  03-30-01 10:08a PU_SOL_TH_005_7_k6
PU_SO~10                4,065  03-30-01 10:08a PU_SOL_TH_005_9_k6
PU_SO~12                4,065  03-30-01 10:08a PU_SOL_TH_005_6_k6
PU_SO~14                4,065  03-30-01 10:08a PU_SOL_TH_005_8_k6
PU_SO~16                4,065  03-30-01 10:08a PU_SOL_TH_005_1_k6
PU_SO~18                4,065  03-30-01 10:08a PU_SOL_TH_005_2_k6
PU_SO~20                4,065  03-30-01 10:08a PU_SOL_TH_005_3_k6
PU_SO~22                4,065  03-30-01 10:08a PU_SOL_TH_005_4_k6
         9 file(s)         36,585 bytes

Directory of D:\CASES\Sun\AoA1\PST_005\005_out

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6 OUT       483,604  03-30-01 10:08a PU_SOL_TH_005_8_k6.out
PU_SOL~8 OUT       487,283  03-30-01 10:08a PU_SOL_TH_005_9_k6.out
PU_SO~10 OUT       480,770  03-30-01 10:08a PU_SOL_TH_005_5_k6.out
PU_SO~12 OUT       480,616  03-30-01 10:08a PU_SOL_TH_005_6_k6.out
PU_SO~14 OUT       483,781  03-30-01 10:08a PU_SOL_TH_005_7_k6.out
PU_SO~16 OUT       488,300  03-30-01 10:08a PU_SOL_TH_005_1_k6.out
PU_SO~18 OUT       482,387  03-30-01 10:08a PU_SOL_TH_005_2_k6.out
PU_SO~20 OUT       478,276  03-30-01 10:08a PU_SOL_TH_005_3_k6.out
PU_SO~22 OUT       480,040  03-30-01 10:08a PU_SOL_TH_005_4_k6.out
         9 file(s)      4,345,057 bytes

Directory of D:\CASES\Sun\AoA1\PST_006

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
CALCUL~6                5,383  09-20-01  8:33a calcul_mod
CONC                       11  09-20-01  8:33a conc
CONCPU                     25  09-20-01  8:33a concpu
LANCE_C6                  108  09-20-01  8:33a lance_c6
LANCE_K6                  101  09-20-01  8:33a lance_k6
PU_SO~16                1,033  09-20-01  8:33a PU_SOL_TH_006_CASE_2_toc6
PU_SO~18                1,014  09-20-01  8:33a PU_SOL_TH_006_CASE_3_toc6
PU_SO~20                  934  09-20-01  8:33a PU_SOL_TH_006_CASE_3
PU_SO~22                4,042  09-20-01  8:33a PU_SOL_TH_006_CASE_2_k6
PU_SO~24                4,042  09-20-01  8:33a PU_SOL_TH_006_CASE_3_k6
PU_SO~26                  966  09-20-01  8:33a PU_SOL_TH_006_CASE_1
PU_SO~28 MSG               54  09-20-01  8:33a PU_SOL_TH_006_CASE_1_k6.msgs
PU_SO~30 OUT       792,524  09-20-01  8:33a PU_SOL_TH_006_CASE_1_k6.out
PU_SO~32                4,042  09-20-01  8:33a PU_SOL_TH_006_CASE_1_k6
PU_SO~34 MSG               54  09-20-01  8:33a PU_SOL_TH_006_CASE_2_k6.msgs
PU_SO~36 OUT       790,778  09-20-01  8:33a PU_SOL_TH_006_CASE_2_k6.out
PU_SO~38                1,046  09-20-01  8:33a PU_SOL_TH_006_CASE_1_toc6
PU_SO~40 MSG               54  09-20-01  8:33a PU_SOL_TH_006_CASE_3_k6.msgs
PU_SO~42 OUT       791,938  09-20-01  8:33a PU_SOL_TH_006_CASE_3_k6.out
PU_SO~44                  953  09-20-01  8:33a PU_SOL_TH_006_CASE_2
RESULT                    414  09-20-01  8:33a result
TOTO                       96  09-20-01  8:33a toto
        22 file(s)      2,399,612 bytes

Directory of D:\CASES\Sun\AoA1\PST_008

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
008_INP        <DIR>        10-04-01  2:06p 008_INP
008_OUT        <DIR>        10-04-01  2:06p 008_OUT
         0 file(s)              0 bytes

Directory of D:\CASES\Sun\AoA1\PST_008\008_INP

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6                1,776  03-30-01 10:09a PU_SOL_TH_008_case30_k6
PU_SOL~8                1,744  03-30-01 10:09a PU_SOL_TH_008_case21_k6
PU_SO~10                1,659  03-30-01 10:09a PU_SOL_TH_008_case20_k6
PU_SO~12                1,744  03-30-01 10:09a PU_SOL_TH_008_case22_k6
PU_SO~14                1,662  03-30-01 10:09a PU_SOL_TH_008_case15_k6
PU_SO~16                1,747  03-30-01 10:09a PU_SOL_TH_008_case14_k6
PU_SO~18                1,659  03-30-01 10:09a PU_SOL_TH_008_case16_k6
PU_SO~20                1,864  03-30-01 10:09a PU_SOL_TH_008_case25_k6
PU_SO~22                1,659  03-30-01 10:09a PU_SOL_TH_008_case24_k6
```

```
PU_SO~24             1,659  03-30-01 10:09a PU_SOL_TH_008_case23_k6
PU_SO~26             1,747  03-30-01 10:09a PU_SOL_TH_008_case26_k6
PU_SO~28             1,659  03-30-01 10:09a PU_SOL_TH_008_case19_k6
PU_SO~30             1,777  03-30-01 10:09a PU_SOL_TH_008_case18_k6
PU_SO~32             1,774  03-30-01 10:09a PU_SOL_TH_008_case17_k6
PU_SO~34             1,777  03-30-01 10:09a PU_SOL_TH_008_case29_k6
PU_SO~36             1,838  03-30-01 10:09a PU_SOL_TH_008_case28_k6
PU_SO~38             1,838  03-30-01 10:09a PU_SOL_TH_008_case27_k6
PU_SO~40             1,559  03-30-01 10:09a PU_SOL_TH_008_case4_k6
PU_SO~42             1,635  03-30-01 10:09a PU_SOL_TH_008_case8_k6
PU_SO~44             1,559  03-30-01 10:09a PU_SOL_TH_008_case2_k6
PU_SO~46             1,559  03-30-01 10:09a PU_SOL_TH_008_case5_k6
PU_SO~48             1,559  03-30-01 10:09a PU_SOL_TH_008_case7_k6
PU_SO~50             1,635  03-30-01 10:09a PU_SOL_TH_008_case9_k6
PU_SO~52             1,559  03-30-01 10:09a PU_SOL_TH_008_case1_k6
PU_SO~54             1,559  03-30-01 10:09a PU_SOL_TH_008_case3_k6
PU_SO~56             1,559  03-30-01 10:09a PU_SOL_TH_008_case10_k6
PU_SO~58             1,559  03-30-01 10:09a PU_SOL_TH_008_case11_k6
PU_SO~60             1,634  03-30-01 10:09a PU_SOL_TH_008_case12_k6
PU_SO~62             1,634  03-30-01 10:09a PU_SOL_TH_008_case13_k6
        29 file(s)         48,593 bytes

Directory of D:\CASES\Sun\AoA1\PST_008\008_OUT

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6 OUT       599,801  03-30-01 10:09a PU_SOL_TH_008_case08_k6.out
PU_SOL~8 OUT       606,952  03-30-01 10:09a PU_SOL_TH_008_case07_k6.out
PU_SO~10 OUT       602,226  03-30-01 10:09a PU_SOL_TH_008_case05_k6.out
PU_SO~12 OUT       601,801  03-30-01 10:09a PU_SOL_TH_008_case09_k6.out
PU_SO~14 OUT       606,846  03-30-01 10:09a PU_SOL_TH_008_case18_k6.out
PU_SO~16 OUT       605,607  03-30-01 10:09a PU_SOL_TH_008_case17_k6.out
PU_SO~18 OUT       597,379  03-30-01 10:09a PU_SOL_TH_008_case15_k6.out
PU_SO~20 OUT       608,433  03-30-01 10:09a PU_SOL_TH_008_case14_k6.out
PU_SO~22 OUT       605,229  03-30-01 10:09a PU_SOL_TH_008_case13_k6.out
PU_SO~24 OUT       604,823  03-30-01 10:09a PU_SOL_TH_008_case16_k6.out
PU_SO~26 OUT       607,906  03-30-01 10:09a PU_SOL_TH_008_case19_k6.out
PU_SO~28 OUT       603,652  03-30-01 10:09a PU_SOL_TH_008_case10_k6.out
PU_SO~30 OUT       597,916  03-30-01 10:09a PU_SOL_TH_008_case12_k6.out
PU_SO~32 OUT       596,495  03-30-01 10:09a PU_SOL_TH_008_case11_k6.out
PU_SO~34 OUT       612,757  03-30-01 10:09a PU_SOL_TH_008_case28_k6.out
PU_SO~36 OUT       603,782  03-30-01 10:09a PU_SOL_TH_008_case27_k6.out
PU_SO~38 OUT       598,986  03-30-01 10:09a PU_SOL_TH_008_case25_k6.out
PU_SO~40 OUT       606,819  03-30-01 10:09a PU_SOL_TH_008_case24_k6.out
PU_SO~42 OUT       606,425  03-30-01 10:09a PU_SOL_TH_008_case23_k6.out
PU_SO~44 OUT       604,022  03-30-01 10:09a PU_SOL_TH_008_case26_k6.out
PU_SO~46 OUT       599,197  03-30-01 10:09a PU_SOL_TH_008_case29_k6.out
PU_SO~48 OUT       599,110  03-30-01 10:09a PU_SOL_TH_008_case20_k6.out
PU_SO~50 OUT       605,615  03-30-01 10:09a PU_SOL_TH_008_case22_k6.out
PU_SO~52 OUT       604,439  03-30-01 10:09a PU_SOL_TH_008_case21_k6.out
PU_SO~54 OUT       606,788  03-30-01 10:09a PU_SOL_TH_008_case30_k6.out
PU_SO~56 OUT       605,351  03-30-01 10:09a PU_SOL_TH_008_case01_k6.out
PU_SO~58 OUT       600,727  03-30-01 10:09a PU_SOL_TH_008_case02_k6.out
PU_SO~60 OUT       601,667  03-30-01 10:09a PU_SOL_TH_008_case03_k6.out
PU_SO~62 OUT       605,366  03-30-01 10:09a PU_SOL_TH_008_case04_k6.out
        29 file(s)     17,506,117 bytes

Directory of D:\CASES\Sun\AoA1\PST_011

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
011_INP        <DIR>        10-04-01  2:06p 011_inp
011_OUT        <DIR>        10-04-01  2:06p 011_out
         0 file(s)              0 bytes

Directory of D:\CASES\Sun\AoA1\PST_011\011_inp

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6             3,216  03-30-01 10:09a PU_SOL_TH_011_C800_4_16_k6
PU_SOL~8             3,216  03-30-01 10:09a PU_SOL_TH_011_C800_3_16_k6
PU_SO~10             3,216  03-30-01 10:09a PU_SOL_TH_011_C800_5_16_k6
PU_SO~12             3,954  03-30-01 10:09a PU_SOL_TH_011_C800_4_18_k6
PU_SO~14             3,954  03-30-01 10:09a PU_SOL_TH_011_C800_3_18_k6
PU_SO~16             3,953  03-30-01 10:09a PU_SOL_TH_011_C800_6_18_k6
PU_SO~18             3,953  03-30-01 10:09a PU_SOL_TH_011_C800_5_18_k6
PU_SO~20             3,953  03-30-01 10:09a PU_SOL_TH_011_C800_7_18_k6
PU_SO~22             3,216  03-30-01 10:09a PU_SOL_TH_011_C800_1_16_k6
PU_SO~24             3,953  03-30-01 10:09a PU_SOL_TH_011_C800_1_18_k6
PU_SO~26             3,216  03-30-01 10:09a PU_SOL_TH_011_C800_2_16_k6
PU_SO~28             3,954  03-30-01 10:09a PU_SOL_TH_011_C800_2_18_k6
        12 file(s)         43,754 bytes

Directory of D:\CASES\Sun\AoA1\PST_011\011_out

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6 OUT       589,039  03-30-01 10:09a PU_SOL_TH_011_C800_4_16_k6.out
PU_SOL~8 OUT       582,080  03-30-01 10:09a PU_SOL_TH_011_C800_5_16_k6.out
PU_SO~10 OUT       584,397  03-30-01 10:09a PU_SOL_TH_011_C800_3_16_k6.out
PU_SO~12 OUT       598,184  03-30-01 10:09a PU_SOL_TH_011_C800_4_18_k6.out
PU_SO~14 OUT       591,374  03-30-01 10:09a PU_SOL_TH_011_C800_6_18_k6.out
```

```
PU_SO~16 OUT       590,956  03-30-01 10:09a PU_SOL_TH_011_C800_7_18_k6.out
PU_SO~18 OUT       592,516  03-30-01 10:09a PU_SOL_TH_011_C800_5_18_k6.out
PU_SO~20 OUT       590,503  03-30-01 10:09a PU_SOL_TH_011_C800_3_18_k6.out
PU_SO~22 OUT       581,094  03-30-01 10:09a PU_SOL_TH_011_C800_1_16_k6.out
PU_SO~24 OUT       592,678  03-30-01 10:09a PU_SOL_TH_011_C800_1_18_k6.out
PU_SO~26 OUT       582,742  03-30-01 10:09a PU_SOL_TH_011_C800_2_16_k6.out
PU_SO~28 OUT       593,244  03-30-01 10:09a PU_SOL_TH_011_C800_2_18_k6.out
        12 file(s)      7,068,807 bytes

Directory of D:\CASES\Sun\AoA1\PST_014

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
014_INP        <DIR>        10-04-01  2:06p 014_inp
014_OUT        <DIR>        10-04-01  2:06p 014_out
         0 file(s)              0 bytes

Directory of D:\CASES\Sun\AoA1\PST_014\014_inp

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6                 6,551  03-30-01 10:10a PU_SOL_TH_014_2_k6
PU_SOL~8                 6,551  03-30-01 10:10a PU_SOL_TH_014_4_k6
PU_SO~10                 6,551  03-30-01 10:10a PU_SOL_TH_014_6_k6
PU_SO~12                 6,633  03-30-01 10:10a PU_SOL_TH_014_8_k6
PU_SO~14                 6,551  03-30-01 10:10a PU_SOL_TH_014_1_k6
PU_SO~16                 6,551  03-30-01 10:10a PU_SOL_TH_014_3_k6
PU_SO~18                 6,551  03-30-01 10:10a PU_SOL_TH_014_5_k6
PU_SO~20                 6,633  03-30-01 10:10a PU_SOL_TH_014_7_k6
PU_SO~22                 6,633  03-30-01 10:10a PU_SOL_TH_014_9_k6
PU_SO~24 TXT             6,717  05-17-01  5:52p PU_SOL_TH_014_34_k6.txt
PU_SO~26                 6,633  03-30-01 10:10a PU_SOL_TH_014_20_k6
PU_SO~28                 6,717  05-22-01  2:28p PU_SOL_TH_014_30_k6
PU_SO~30                 6,633  03-30-01 10:10a PU_SOL_TH_014_23_k6
PU_SO~32                 6,633  03-30-01 10:10a PU_SOL_TH_014_22_k6
PU_SO~34                 6,633  03-30-01 10:10a PU_SOL_TH_014_21_k6
PU_SO~36                 6,715  03-30-01 10:10a PU_SOL_TH_014_24_k6
PU_SO~38                 6,717  05-22-01  2:28p PU_SOL_TH_014_33_k6
PU_SO~40                 6,717  05-22-01  2:28p PU_SOL_TH_014_32_k6
PU_SO~42                 6,717  05-22-01  2:28p PU_SOL_TH_014_31_k6
PU_SO~44                 6,717  05-22-01  2:28p PU_SOL_TH_014_34_k6
PU_SO~46                 6,633  03-30-01 10:10a PU_SOL_TH_014_14_k6
PU_SO~48                 6,715  03-30-01 10:10a PU_SOL_TH_014_27_k6
PU_SO~50                 6,715  03-30-01 10:10a PU_SOL_TH_014_26_k6
PU_SO~52                 6,715  03-30-01 10:10a PU_SOL_TH_014_25_k6
PU_SO~54                 6,715  03-30-01 10:10a PU_SOL_TH_014_28_k6
PU_SO~56                 4,696  05-22-01  2:28p PU_sol_th_014_35_k6
PU_SO~58                 6,633  03-30-01 10:10a PU_SOL_TH_014_17_k6
PU_SO~60                 6,633  03-30-01 10:10a PU_SOL_TH_014_16_k6
PU_SO~62                 6,633  03-30-01 10:10a PU_SOL_TH_014_15_k6
PU_SO~64                 6,633  03-30-01 10:10a PU_SOL_TH_014_18_k6
PU_SO~66                 6,715  03-30-01 10:10a PU_SOL_TH_014_29_k6
PU_SO~68                 6,633  03-30-01 10:10a PU_SOL_TH_014_19_k6
PU_SO~70                 6,633  03-30-01 10:10a PU_SOL_TH_014_10_k6
PU_SO~72 TXT             6,717  05-17-01  5:50p PU_SOL_TH_014_30_k6.txt
PU_SO~74                 6,633  03-30-01 10:10a PU_SOL_TH_014_11_k6
PU_SO~76 TXT             6,717  05-17-01  5:51p PU_SOL_TH_014_31_k6.txt
PU_SO~78                 6,633  03-30-01 10:10a PU_SOL_TH_014_12_k6
PU_SO~80 TXT             6,717  05-17-01  5:51p PU_SOL_TH_014_32_k6.txt
PU_SO~82                 6,633  03-30-01 10:10a PU_SOL_TH_014_13_k6
PU_SO~84 TXT             6,717  05-17-01  5:52p PU_SOL_TH_014_33_k6.txt
        40 file(s)        264,223 bytes

Directory of D:\CASES\Sun\AoA1\PST_014\014_out

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6 OUT       555,491  03-30-01 10:10a PU_SOL_TH_014_11_k6.out
PU_SOL~8 OUT       555,666  03-30-01 10:10a PU_SOL_TH_014_14_k6.out
PU_SO~10 OUT       555,521  03-30-01 10:10a PU_SOL_TH_014_10_k6.out
PU_SO~12 OUT       555,814  03-30-01 10:10a PU_SOL_TH_014_13_k6.out
PU_SO~14 OUT       555,733  03-30-01 10:10a PU_SOL_TH_014_12_k6.out
PU_SO~16 OUT       555,818  03-30-01 10:10a PU_SOL_TH_014_21_k6.out
PU_SO~18 OUT       556,590  03-30-01 10:10a PU_SOL_TH_014_24_k6.out
PU_SO~20 OUT       555,767  03-30-01 10:10a PU_SOL_TH_014_20_k6.out
PU_SO~22 OUT       555,905  03-30-01 10:10a PU_SOL_TH_014_23_k6.out
PU_SO~24 OUT       555,982  03-30-01 10:10a PU_SOL_TH_014_22_k6.out
PU_SO~26 OUT       796,934  05-22-01  2:35p PU_SOL_TH_014_31_k6.out
PU_SO~28 OUT       796,473  05-22-01  2:35p PU_SOL_TH_014_34_k6.out
PU_SO~30 OUT       796,572  05-22-01  2:35p PU_SOL_TH_014_30_k6.out
PU_SO~32 OUT       797,020  05-22-01  2:35p PU_SOL_TH_014_33_k6.out
PU_SO~34 OUT       797,833  05-22-01  2:35p PU_SOL_TH_014_32_k6.out
PU_SO~36 OUT       555,799  03-30-01 10:10a PU_SOL_TH_014_19_k6.out
PU_SO~38 OUT       555,870  03-30-01 10:10a PU_SOL_TH_014_17_k6.out
PU_SO~40 OUT       555,944  03-30-01 10:10a PU_SOL_TH_014_16_k6.out
PU_SO~42 OUT       556,234  03-30-01 10:10a PU_SOL_TH_014_15_k6.out
PU_SO~44 OUT       554,033  03-30-01 10:10a PU_SOL_TH_014_18_k6.out
PU_SO~46 OUT       556,773  03-30-01 10:10a PU_SOL_TH_014_29_k6.out
PU_SO~48 OUT       556,561  03-30-01 10:10a PU_SOL_TH_014_27_k6.out
PU_SO~50 OUT       556,630  03-30-01 10:10a PU_SOL_TH_014_26_k6.out
PU_SO~52 OUT       556,734  03-30-01 10:10a PU_SOL_TH_014_25_k6.out
PU_SO~54 OUT       556,470  03-30-01 10:10a PU_SOL_TH_014_28_k6.out
```

```
PU_SO~56 OUT       796,588  05-22-01  2:35p PU_SOL_TH_014_35_k6.out
PU_SO~58 OUT       555,862  03-30-01 10:10a PU_SOL_TH_014_09_k6.out
PU_SO~60 OUT       556,652  03-30-01 10:10a PU_SOL_TH_014_07_k6.out
PU_SO~62 OUT       554,943  03-30-01 10:10a PU_SOL_TH_014_06_k6.out
PU_SO~64 OUT       555,460  03-30-01 10:10a PU_SOL_TH_014_05_k6.out
PU_SO~66 OUT       555,661  03-30-01 10:10a PU_SOL_TH_014_08_k6.out
PU_SO~68 OUT       555,262  03-30-01 10:10a PU_SOL_TH_014_01_k6.out
PU_SO~70 OUT       555,127  03-30-01 10:10a PU_SOL_TH_014_02_k6.out
PU_SO~72 OUT       692,844  03-30-01 10:10a PU_SOL_TH_014_03_k6.out
PU_SO~74 OUT       555,343  03-30-01 10:10a PU_SOL_TH_014_04_k6.out
        35 file(s)     21,037,909 bytes

Directory of D:\CASES\Sun\AoA1\PST_015

.               <DIR>        10-04-01  2:06p .
..              <DIR>        10-04-01  2:06p ..
015_INP         <DIR>        10-04-01  2:06p 015_inp
015_OUT         <DIR>        10-04-01  2:06p 015_out
         0 file(s)              0 bytes

Directory of D:\CASES\Sun\AoA1\PST_015\015_inp

.               <DIR>        10-04-01  2:06p .
..              <DIR>        10-04-01  2:06p ..
PU_SOL~6                 6,551  03-30-01 10:10a PU_SOL_TH_015_1_k6
PU_SOL~8                 6,551  03-30-01 10:10a PU_SOL_TH_015_3_k6
PU_SO~10                 6,551  03-30-01 10:10a PU_SOL_TH_015_5_k6
PU_SO~12                 6,633  03-30-01 10:10a PU_SOL_TH_015_7_k6
PU_SO~14                 6,633  03-30-01 10:10a PU_SOL_TH_015_9_k6
PU_SO~16                 6,551  03-30-01 10:10a PU_SOL_TH_015_2_k6
PU_SO~18                 6,551  03-30-01 10:10a PU_SOL_TH_015_4_k6
PU_SO~20                 6,469  03-30-01 10:10a PU_SOL_TH_015_6_k6
PU_SO~22                 6,633  03-30-01 10:10a PU_SOL_TH_015_8_k6
PU_SO~24                 6,633  03-30-01 10:10a PU_SOL_TH_015_14_k6
PU_SO~26                 6,715  03-30-01 10:10a PU_SOL_TH_015_17_k6
PU_SO~28                 6,715  03-30-01 10:10a PU_SOL_TH_015_16_k6
PU_SO~30                 6,715  03-30-01 10:10a PU_SOL_TH_015_15_k6
PU_SO~32                 6,633  03-30-01 10:10a PU_SOL_TH_015_10_k6
PU_SO~34                 6,633  03-30-01 10:10a PU_SOL_TH_015_11_k6
PU_SO~36                 6,633  03-30-01 10:10a PU_SOL_TH_015_12_k6
PU_SO~38                 6,633  03-30-01 10:10a PU_SOL_TH_015_13_k6
        17 file(s)        112,433 bytes

Directory of D:\CASES\Sun\AoA1\PST_015\015_out

.               <DIR>        10-04-01  2:06p .
..              <DIR>        10-04-01  2:06p ..
PU_SOL~6 OUT       554,676  03-30-01 10:10a PU_SOL_TH_015_11_k6.out
PU_SOL~8 OUT       554,375  03-30-01 10:10a PU_SOL_TH_015_14_k6.out
PU_SO~10 OUT       555,262  03-30-01 10:10a PU_SOL_TH_015_10_k6.out
PU_SO~12 OUT       554,257  03-30-01 10:10a PU_SOL_TH_015_13_k6.out
PU_SO~14 OUT       553,858  03-30-01 10:10a PU_SOL_TH_015_12_k6.out
PU_SO~16 OUT       555,437  03-30-01 10:10a PU_SOL_TH_015_17_k6.out
PU_SO~18 OUT       554,751  03-30-01 10:10a PU_SOL_TH_015_16_k6.out
PU_SO~20 OUT       555,349  03-30-01 10:10a PU_SOL_TH_015_15_k6.out
PU_SO~22 OUT       554,178  03-30-01 10:10a PU_SOL_TH_015_09_k6.out
PU_SO~24 OUT       553,922  03-30-01 10:10a PU_SOL_TH_015_07_k6.out
PU_SO~26 OUT       553,116  03-30-01 10:10a PU_SOL_TH_015_06_k6.out
PU_SO~28 OUT       553,712  03-30-01 10:10a PU_SOL_TH_015_05_k6.out
PU_SO~30 OUT       554,094  03-30-01 10:10a PU_SOL_TH_015_08_k6.out
PU_SO~32 OUT       540,543  03-30-01 10:10a PU_SOL_TH_015_01_k6.out
PU_SO~34 OUT       553,264  03-30-01 10:10a PU_SOL_TH_015_02_k6.out
PU_SO~36 OUT       552,804  03-30-01 10:10a PU_SOL_TH_015_03_k6.out
PU_SO~38 OUT       554,162  03-30-01 10:10a PU_SOL_TH_015_04_k6.out
        17 file(s)      9,407,760 bytes

Directory of D:\CASES\Sun\AoA1\PST_016

.               <DIR>        10-04-01  2:06p .
..              <DIR>        10-04-01  2:06p ..
016_INP         <DIR>        10-04-01  2:06p 016_inp
016_OUT         <DIR>        10-04-01  2:06p 016_out
         0 file(s)              0 bytes

Directory of D:\CASES\Sun\AoA1\PST_016\016_inp

.               <DIR>        10-04-01  2:06p .
..              <DIR>        10-04-01  2:06p ..
PU_SOL~6                 6,879  03-30-01 10:10a PU_SOL_TH_016_3_k6
PU_SOL~8                 6,879  03-30-01 10:10a PU_SOL_TH_016_5_k6
PU_SO~10                 6,879  03-30-01 10:10a PU_SOL_TH_016_7_k6
PU_SO~12                 6,715  03-30-01 10:10a PU_SOL_TH_016_9_k6
PU_SO~14                 6,961  03-30-01 10:10a PU_SOL_TH_016_4_k6
PU_SO~16                 6,879  03-30-01 10:10a PU_SOL_TH_016_6_k6
PU_SO~18                 6,879  03-30-01 10:10a PU_SOL_TH_016_8_k6
PU_SO~20                 6,715  03-30-01 10:10a PU_SOL_TH_016_10_k6
PU_SO~22                 6,715  03-30-01 10:10a PU_SOL_TH_016_11_k6
PU_SO~24                 6,879  03-30-01 10:10a PU_SOL_TH_016_1_k6
PU_SO~26                 6,879  03-30-01 10:10a PU_SOL_TH_016_2_k6
        11 file(s)         75,259 bytes

Directory of D:\CASES\Sun\AoA1\PST_016\016_out
```

```
.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6 OUT       665,670  03-30-01 10:10a PU_SOL_TH_016_11_k6.out
PU_SOL~8 OUT       665,622  03-30-01 10:10a PU_SOL_TH_016_10_k6.out
PU_SO~10 OUT       666,156  03-30-01 10:10a PU_SOL_TH_016_09_k6.out
PU_SO~12 OUT       647,246  03-30-01 10:10a PU_SOL_TH_016_07_k6.out
PU_SO~14 OUT       647,373  03-30-01 10:10a PU_SOL_TH_016_06_k6.out
PU_SO~16 OUT       647,957  03-30-01 10:10a PU_SOL_TH_016_05_k6.out
PU_SO~18 OUT       646,727  03-30-01 10:10a PU_SOL_TH_016_08_k6.out
PU_SO~20 OUT       645,608  03-30-01 10:10a PU_SOL_TH_016_01_k6.out
PU_SO~22 OUT       648,605  03-30-01 10:10a PU_SOL_TH_016_02_k6.out
PU_SO~24 OUT       648,471  03-30-01 10:10a PU_SOL_TH_016_03_k6.out
PU_SO~26 OUT       648,610  03-30-01 10:10a PU_SOL_TH_016_04_k6.out
        11 file(s)      7,178,045 bytes

Directory of D:\CASES\Sun\AoA1\PST_017

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
017_INP        <DIR>        10-04-01  2:06p 017_inp
017_OUT        <DIR>        10-04-01  2:06p 017_out
         0 file(s)              0 bytes

Directory of D:\CASES\Sun\AoA1\PST_017\017_inp

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6             6,879  03-30-01 10:11a PU_SOL_TH_017_2_k6
PU_SOL~8             6,879  03-30-01 10:11a PU_SOL_TH_017_4_k6
PU_SO~10             6,879  03-30-01 10:11a PU_SOL_TH_017_6_k6
PU_SO~12             6,879  03-30-01 10:11a PU_SOL_TH_017_8_k6
PU_SO~14             6,551  03-30-01 10:10a PU_SOL_TH_017_1_k6
PU_SO~16             6,879  03-30-01 10:11a PU_SOL_TH_017_3_k6
PU_SO~18             6,879  03-30-01 10:11a PU_SOL_TH_017_5_k6
PU_SO~20             6,879  03-30-01 10:11a PU_SOL_TH_017_7_k6
PU_SO~22             6,879  03-30-01 10:11a PU_SOL_TH_017_9_k6
PU_SO~24             6,879  03-30-01 10:10a PU_SOL_TH_017_14_k6
PU_SO~26             6,879  03-30-01 10:10a PU_SOL_TH_017_17_k6
PU_SO~28             6,879  03-30-01 10:10a PU_SOL_TH_017_16_k6
PU_SO~30             6,879  03-30-01 10:10a PU_SOL_TH_017_15_k6
PU_SO~32             6,879  03-30-01 10:10a PU_SOL_TH_017_18_k6
PU_SO~34             6,879  03-30-01 10:10a PU_SOL_TH_017_10_k6
PU_SO~36             6,551  03-30-01 10:10a PU_SOL_TH_017_11_k6
PU_SO~38             6,879  03-30-01 10:10a PU_SOL_TH_017_12_k6
PU_SO~40             6,879  03-30-01 10:10a PU_SOL_TH_017_13_k6
        18 file(s)        123,166 bytes

Directory of D:\CASES\Sun\AoA1\PST_017\017_out

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6 OUT       651,144  03-30-01 10:10a PU_SOL_TH_017_11_k6.out
PU_SOL~8 OUT       653,112  03-30-01 10:10a PU_SOL_TH_017_14_k6.out
PU_SO~10 OUT       652,830  03-30-01 10:10a PU_SOL_TH_017_10_k6.out
PU_SO~12 OUT       652,387  03-30-01 10:10a PU_SOL_TH_017_13_k6.out
PU_SO~14 OUT       651,684  03-30-01 10:10a PU_SOL_TH_017_12_k6.out
PU_SO~16 OUT       652,312  03-30-01 10:11a PU_SOL_TH_017_09_k6.out
PU_SO~18 OUT       652,205  03-30-01 10:11a PU_SOL_TH_017_07_k6.out
PU_SO~20 OUT       651,984  03-30-01 10:11a PU_SOL_TH_017_06_k6.out
PU_SO~22 OUT       652,230  03-30-01 10:11a PU_SOL_TH_017_05_k6.out
PU_SO~24 OUT       652,722  03-30-01 10:11a PU_SOL_TH_017_08_k6.out
PU_SO~26 OUT       652,194  03-30-01 10:10a PU_SOL_TH_017_17_k6.out
PU_SO~28 OUT       652,297  03-30-01 10:10a PU_SOL_TH_017_16_k6.out
PU_SO~30 OUT       651,457  03-30-01 10:10a PU_SOL_TH_017_15_k6.out
PU_SO~32 OUT       652,271  03-30-01 10:10a PU_SOL_TH_017_18_k6.out
PU_SO~34 OUT       651,348  03-30-01 10:11a PU_SOL_TH_017_01_k6.out
PU_SO~36 OUT       652,086  03-30-01 10:11a PU_SOL_TH_017_02_k6.out
PU_SO~38 OUT       651,969  03-30-01 10:11a PU_SOL_TH_017_03_k6.out
PU_SO~40 OUT       652,239  03-30-01 10:11a PU_SOL_TH_017_04_k6.out
        18 file(s)     11,738,471 bytes

Directory of D:\CASES\Sun\AoA1\PST_020

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
020_INP        <DIR>        10-04-01  2:06p 020_inp
020_OUT        <DIR>        10-04-01  2:06p 020_out
         0 file(s)              0 bytes

Directory of D:\CASES\Sun\AoA1\PST_020\020_inp

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6             6,689  03-30-01 10:11a PU_SOL_TH_020_14_T8B_k6
PU_SOL~8             6,689  03-30-01 10:11a PU_SOL_TH_020_15_T8B_k6
PU_SO~10             5,951  03-30-01 10:11a PU_SOL_TH_020_7_T8A_k6
PU_SO~12             6,689  03-30-01 10:11a PU_SOL_TH_020_8_T8A_k6
PU_SO~14             5,951  03-30-01 10:11a PU_SOL_TH_020_1_T8A_k6
PU_SO~16             6,689  03-30-01 10:11a PU_SOL_TH_020_9_T8A_k6
PU_SO~18             5,951  03-30-01 10:11a PU_SOL_TH_020_2_T8A_k6
PU_SO~20             5,951  03-30-01 10:11a PU_SOL_TH_020_3_T8A_k6
```

```
PU_SO~22             5,951  03-30-01 10:11a PU_SOL_TH_020_5_T8A_k6
PU_SO~24             5,951  03-30-01 10:11a PU_SOL_TH_020_6_T8A_k6
PU_SO~26             5,951  03-30-01 10:11a PU_SOL_TH_020_10_T8B_k6
PU_SO~28             5,951  03-30-01 10:11a PU_SOL_TH_020_11_T8B_k6
PU_SO~30             5,951  03-30-01 10:11a PU_SOL_TH_020_12_T8B_k6
PU_SO~32             5,951  03-30-01 10:11a PU_SOL_TH_020_13_T8B_k6
        14 file(s)         86,266 bytes

Directory of D:\CASES\Sun\AoA1\PST_020\020_out

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6 OUT       524,926  03-30-01 10:11a PU_SOL_TH_020_08_T8A_k6.out
PU_SOL~8 OUT       528,489  03-30-01 10:11a PU_SOL_TH_020_09_T8A_k6.out
PU_SO~10 OUT       512,816  03-30-01 10:11a PU_SOL_TH_020_06_T8A_k6.out
PU_SO~12 OUT       513,040  03-30-01 10:11a PU_SOL_TH_020_07_T8A_k6.out
PU_SO~14 OUT       528,204  03-30-01 10:11a PU_SOL_TH_020_14_T8B_k6.out
PU_SO~16 OUT       513,934  03-30-01 10:11a PU_SOL_TH_020_10_T8B_k6.out
PU_SO~18 OUT       529,181  03-30-01 10:11a PU_SOL_TH_020_15_T8B_k6.out
PU_SO~20 OUT       513,671  03-30-01 10:11a PU_SOL_TH_020_11_T8B_k6.out
PU_SO~22 OUT       513,116  03-30-01 10:11a PU_SOL_TH_020_12_T8B_k6.out
PU_SO~24 OUT       512,027  03-30-01 10:11a PU_SOL_TH_020_13_T8B_k6.out
PU_SO~26 OUT       506,195  03-30-01 10:11a PU_SOL_TH_020_01_T8A_k6.out
PU_SO~28 OUT       509,693  03-30-01 10:11a PU_SOL_TH_020_02_T8A_k6.out
PU_SO~30 OUT       515,117  03-30-01 10:11a PU_SOL_TH_020_03_T8A_k6.out
PU_SO~32 OUT       511,731  03-30-01 10:11a PU_SOL_TH_020_05_T8A_k6.out
        14 file(s)      7,232,140 bytes

Directory of D:\CASES\Sun\AoA1\PST_025

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
LANCE_K6               204  09-20-01  8:32a lance_k6
PSTH02~8 INP         8,239  09-20-01  8:33a psth025_case5_c6.inp
PSTH0~10 INP         8,239  09-20-01  8:33a psth025_case6_c6.inp
PSTH0~12 MSG            54  09-20-01  8:33a psth025_case5_c6.msgs
PSTH0~14 MSG            54  09-20-01  8:33a psth025_case6_c6.msgs
PSTH0~16 OUT     1,008,402  09-20-01  8:33a psth025_case5_c6.out
PSTH0~18 OUT     1,008,504  09-20-01  8:33a psth025_case6_c6.out
PSTH0~20 INP         8,239  09-20-01  8:32a psth025_case1_c6.inp
PSTH0~22 MSG            54  09-20-01  8:32a psth025_case1_c6.msgs
PSTH0~24 OUT     1,009,099  09-20-01  8:32a psth025_case1_c6.out
PSTH0~26 INP         8,239  09-20-01  8:33a psth025_case2_c6.inp
PSTH0~28 MSG            54  09-20-01  8:33a psth025_case2_c6.msgs
PSTH0~30 OUT     1,009,181  09-20-01  8:33a psth025_case2_c6.out
PSTH0~32 INP         8,239  09-20-01  8:33a psth025_case3_c6.inp
PSTH0~34 MSG            54  09-20-01  8:33a psth025_case3_c6.msgs
PSTH0~36 OUT     1,008,523  09-20-01  8:33a psth025_case3_c6.out
PSTH0~38 INP         8,239  09-20-01  8:33a psth025_case4_c6.inp
PSTH0~40 MSG            54  09-20-01  8:33a psth025_case4_c6.msgs
PSTH0~42 OUT     1,009,235  09-20-01  8:33a psth025_case4_c6.out
PU_SO~44               720  09-20-01  8:32a PU_SOL_TH_025_res
        20 file(s)      6,103,626 bytes

Directory of D:\CASES\Sun\AoA1\PST_026

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
LANCE_K6               111  09-20-01  8:32a lance_k6
PSTH02~8 INP        10,445  09-20-01  8:32a psth026_case1_c6.inp
PSTH0~10 MSG            54  09-20-01  8:32a psth026_case1_c6.msgs
PSTH0~12 OUT     1,038,262  09-20-01  8:32a psth026_case1_c6.out
PSTH0~14 INP        10,445  09-20-01  8:32a psth026_case2_c6.inp
PSTH0~16 MSG            54  09-20-01  8:32a psth026_case2_c6.msgs
PSTH0~18 OUT     1,041,327  09-20-01  8:32a psth026_case2_c6.out
PSTH0~20 INP        10,445  09-20-01  8:32a psth026_case3_c6.inp
PSTH0~22 MSG            54  09-20-01  8:32a psth026_case3_c6.msgs
PSTH0~24 OUT     1,048,835  09-20-01  8:32a psth026_case3_c6.out
PU_SO~26               414  09-20-01  8:32a PU_SOL_TH_026_res
SORTI~28               414  09-20-01  8:32a sortie_tmp
        12 file(s)      3,160,860 bytes

Directory of D:\CASES\Sun\AoA1\PU_SOL_THERM

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
001_INP        <DIR>        10-04-01  2:06p 001_INP
002_INP        <DIR>        10-04-01  2:06p 002_inp
003_INP        <DIR>        10-04-01  2:06p 003_inp
004_INP        <DIR>        10-04-01  2:06p 004_inp
005_INP        <DIR>        10-04-01  2:06p 005_inp
006_INP        <DIR>        10-04-01  2:06p 006_inp
011_INP        <DIR>        10-04-01  2:06p 011_inp
014_INP        <DIR>        10-04-01  2:06p 014_inp
015_INP        <DIR>        10-04-01  2:06p 015_inp
016_INP        <DIR>        10-04-01  2:06p 016_inp
017_INP        <DIR>        10-04-01  2:06p 017_inp
020_INP        <DIR>        10-04-01  2:06p 020_inp
         0 file(s)              0 bytes

Directory of D:\CASES\Sun\AoA1\PU_SOL_THERM\001_INP
```

```
.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6             4,311  03-30-01 10:08a PU_SOL_TH_001_6_T8A_k6
PU_SOL~8             4,311  03-30-01 10:08a PU_SOL_TH_001_5_T8A_k6
PU_SO~10             4,311  03-30-01 10:08a PU_SOL_TH_001_1_T8A_k6
PU_SO~12             4,311  03-30-01 10:08a PU_SOL_TH_001_2_T8A_k6
PU_SO~14             4,311  03-30-01 10:08a PU_SOL_TH_001_3_T8A_k6
PU_SO~16             4,311  03-30-01 10:08a PU_SOL_TH_001_4_T8A_k6
         6 file(s)         25,866 bytes

Directory of D:\CASES\Sun\AoA1\PU_SOL_THERM\002_inp

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6             4,065  03-30-01 10:08a PU_SOL_TH_002_5_k6
PU_SOL~8             4,065  03-30-01 10:08a PU_SOL_TH_002_7_k6
PU_SO~10             4,065  03-30-01 10:08a PU_SOL_TH_002_6_k6
PU_SO~12             4,065  03-30-01 10:08a PU_SOL_TH_002_1_k6
PU_SO~14             4,065  03-30-01 10:08a PU_SOL_TH_002_2_k6
PU_SO~16             4,065  03-30-01 10:08a PU_SOL_TH_002_3_k6
PU_SO~18             4,065  03-30-01 10:08a PU_SOL_TH_002_4_k6
         7 file(s)         28,455 bytes

Directory of D:\CASES\Sun\AoA1\PU_SOL_THERM\003_inp

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6             4,475  03-30-01 10:08a PU_SOL_TH_003_6_k6
PU_SOL~8             4,475  03-30-01 10:08a PU_SOL_TH_003_8_k6
PU_SO~10             4,475  03-30-01 10:08a PU_SOL_TH_003_5_k6
PU_SO~12             4,475  03-30-01 10:08a PU_SOL_TH_003_7_k6
PU_SO~14             4,475  03-30-01 10:08a PU_SOL_TH_003_1_k6
PU_SO~16             4,475  03-30-01 10:08a PU_SOL_TH_003_2_k6
PU_SO~18             4,475  03-30-01 10:08a PU_SOL_TH_003_3_k6
PU_SO~20             4,475  03-30-01 10:08a PU_SOL_TH_003_4_k6
         8 file(s)         35,800 bytes

Directory of D:\CASES\Sun\AoA1\PU_SOL_THERM\004_inp

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6             4,065  03-30-01 10:08a PU_SOL_TH_004_2_k6
PU_SOL~8             4,065  03-30-01 10:08a PU_SOL_TH_004_4_k6
PU_SO~10             4,065  03-30-01 10:08a PU_SOL_TH_004_6_k6
PU_SO~12             4,065  03-30-01 10:08a PU_SOL_TH_004_8_k6
PU_SO~14             4,065  03-30-01 10:08a PU_SOL_TH_004_1_k6
PU_SO~16             4,065  03-30-01 10:08a PU_SOL_TH_004_3_k6
PU_SO~18             4,065  03-30-01 10:08a PU_SOL_TH_004_5_k6
PU_SO~20             4,065  03-30-01 10:08a PU_SOL_TH_004_7_k6
PU_SO~22             4,065  03-30-01 10:08a PU_SOL_TH_004_9_k6
PU_SO~24             4,065  03-30-01 10:08a PU_SOL_TH_004_10_k6
PU_SO~26             4,065  03-30-01 10:08a PU_SOL_TH_004_11_k6
PU_SO~28             4,147  03-30-01 10:08a PU_SOL_TH_004_12_k6
PU_SO~30             4,147  03-30-01 10:08a PU_SOL_TH_004_13_k6
        13 file(s)         53,009 bytes

Directory of D:\CASES\Sun\AoA1\PU_SOL_THERM\005_inp

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6             4,065  03-30-01 10:08a PU_SOL_TH_005_5_k6
PU_SOL~8             4,065  03-30-01 10:08a PU_SOL_TH_005_7_k6
PU_SO~10             4,065  03-30-01 10:08a PU_SOL_TH_005_9_k6
PU_SO~12             4,065  03-30-01 10:08a PU_SOL_TH_005_6_k6
PU_SO~14             4,065  03-30-01 10:08a PU_SOL_TH_005_8_k6
PU_SO~16             4,065  03-30-01 10:08a PU_SOL_TH_005_1_k6
PU_SO~18             4,065  03-30-01 10:08a PU_SOL_TH_005_2_k6
PU_SO~20             4,065  03-30-01 10:08a PU_SOL_TH_005_3_k6
PU_SO~22             4,065  03-30-01 10:08a PU_SOL_TH_005_4_k6
         9 file(s)         36,585 bytes

Directory of D:\CASES\Sun\AoA1\PU_SOL_THERM\006_inp

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6             4,041  03-30-01 10:08a PU_SOL_TH_006_CASE_1_k6
PU_SOL~8             4,041  03-30-01 10:08a PU_SOL_TH_006_CASE_2_k6
PU_SO~10             4,041  03-30-01 10:08a PU_SOL_TH_006_CASE_3_k6
         3 file(s)         12,123 bytes

Directory of D:\CASES\Sun\AoA1\PU_SOL_THERM\011_inp

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
PU_SOL~6             3,216  03-30-01 10:09a PU_SOL_TH_011_C800_4_16_k6
PU_SOL~8             3,216  03-30-01 10:09a PU_SOL_TH_011_C800_3_16_k6
PU_SO~10             3,216  03-30-01 10:09a PU_SOL_TH_011_C800_5_16_k6
PU_SO~12             3,954  03-30-01 10:09a PU_SOL_TH_011_C800_4_18_k6
PU_SO~14             3,954  03-30-01 10:09a PU_SOL_TH_011_C800_3_18_k6
PU_SO~16             3,953  03-30-01 10:09a PU_SOL_TH_011_C800_6_18_k6
PU_SO~18             3,953  03-30-01 10:09a PU_SOL_TH_011_C800_5_18_k6
PU_SO~20             3,953  03-30-01 10:09a PU_SOL_TH_011_C800_7_18_k6
```

```
PU_SO~22                 3,216  03-30-01 10:09a PU_SOL_TH_011_C800_1_16_k6
PU_SO~24                 3,953  03-30-01 10:09a PU_SOL_TH_011_C800_1_18_k6
PU_SO~26                 3,216  03-30-01 10:09a PU_SOL_TH_011_C800_2_16_k6
PU_SO~28                 3,954  03-30-01 10:09a PU_SOL_TH_011_C800_2_18_k6
          12 file(s)         43,754 bytes

Directory of D:\CASES\Sun\AoA1\PU_SOL_THERM\014_inp

.                  <DIR>        10-04-01  2:06p .
..                 <DIR>        10-04-01  2:06p ..
PU_SOL~6                 6,551  03-30-01 10:10a PU_SOL_TH_014_2_k6
PU_SOL~8                 6,551  03-30-01 10:10a PU_SOL_TH_014_4_k6
PU_SO~10                 6,551  03-30-01 10:10a PU_SOL_TH_014_6_k6
PU_SO~12                 6,633  03-30-01 10:10a PU_SOL_TH_014_8_k6
PU_SO~14                 6,551  03-30-01 10:10a PU_SOL_TH_014_1_k6
PU_SO~16                 6,551  03-30-01 10:10a PU_SOL_TH_014_3_k6
PU_SO~18                 6,551  03-30-01 10:10a PU_SOL_TH_014_5_k6
PU_SO~20                 6,633  03-30-01 10:10a PU_SOL_TH_014_7_k6
PU_SO~22                 6,633  03-30-01 10:10a PU_SOL_TH_014_9_k6
PU_SO~24                 6,633  03-30-01 10:10a PU_SOL_TH_014_20_k6
PU_SO~26                 6,715  03-30-01 10:10a PU_SOL_TH_014_30_k6
PU_SO~28                 6,633  03-30-01 10:10a PU_SOL_TH_014_23_k6
PU_SO~30                 6,633  03-30-01 10:10a PU_SOL_TH_014_22_k6
PU_SO~32                 6,633  03-30-01 10:10a PU_SOL_TH_014_21_k6
PU_SO~34                 6,715  03-30-01 10:10a PU_SOL_TH_014_24_k6
PU_SO~36                 6,715  03-30-01 10:10a PU_SOL_TH_014_33_k6
PU_SO~38                 6,715  03-30-01 10:10a PU_SOL_TH_014_32_k6
PU_SO~40                 6,715  03-30-01 10:10a PU_SOL_TH_014_31_k6
PU_SO~42                 6,715  03-30-01 10:10a PU_SOL_TH_014_34_k6
PU_SO~44                 6,633  03-30-01 10:10a PU_SOL_TH_014_14_k6
PU_SO~46                 6,715  03-30-01 10:10a PU_SOL_TH_014_27_k6
PU_SO~48                 6,715  03-30-01 10:10a PU_SOL_TH_014_26_k6
PU_SO~50                 6,715  03-30-01 10:10a PU_SOL_TH_014_25_k6
PU_SO~52                 6,715  03-30-01 10:10a PU_SOL_TH_014_28_k6
PU_SO~54                 6,633  03-30-01 10:10a PU_SOL_TH_014_17_k6
PU_SO~56                 6,633  03-30-01 10:10a PU_SOL_TH_014_16_k6
PU_SO~58                 6,633  03-30-01 10:10a PU_SOL_TH_014_15_k6
PU_SO~60                 6,633  03-30-01 10:10a PU_SOL_TH_014_18_k6
PU_SO~62                 6,715  03-30-01 10:10a PU_SOL_TH_014_29_k6
PU_SO~64                 6,633  03-30-01 10:10a PU_SOL_TH_014_19_k6
PU_SO~66                 6,633  03-30-01 10:10a PU_SOL_TH_014_10_k6
PU_SO~68                 6,633  03-30-01 10:10a PU_SOL_TH_014_11_k6
PU_SO~70                 6,633  03-30-01 10:10a PU_SOL_TH_014_12_k6
PU_SO~72                 6,633  03-30-01 10:10a PU_SOL_TH_014_13_k6
          34 file(s)        225,932 bytes

Directory of D:\CASES\Sun\AoA1\PU_SOL_THERM\015_inp

.                  <DIR>        10-04-01  2:06p .
..                 <DIR>        10-04-01  2:06p ..
PU_SOL~6                 6,551  03-30-01 10:10a PU_SOL_TH_015_1_k6
PU_SOL~8                 6,551  03-30-01 10:10a PU_SOL_TH_015_3_k6
PU_SO~10                 6,551  03-30-01 10:10a PU_SOL_TH_015_5_k6
PU_SO~12                 6,633  03-30-01 10:10a PU_SOL_TH_015_7_k6
PU_SO~14                 6,633  03-30-01 10:10a PU_SOL_TH_015_9_k6
PU_SO~16                 6,551  03-30-01 10:10a PU_SOL_TH_015_2_k6
PU_SO~18                 6,551  03-30-01 10:10a PU_SOL_TH_015_4_k6
PU_SO~20                 6,469  03-30-01 10:10a PU_SOL_TH_015_6_k6
PU_SO~22                 6,633  03-30-01 10:10a PU_SOL_TH_015_8_k6
PU_SO~24                 6,633  03-30-01 10:10a PU_SOL_TH_015_14_k6
PU_SO~26                 6,715  03-30-01 10:10a PU_SOL_TH_015_17_k6
PU_SO~28                 6,715  03-30-01 10:10a PU_SOL_TH_015_16_k6
PU_SO~30                 6,715  03-30-01 10:10a PU_SOL_TH_015_15_k6
PU_SO~32                 6,633  03-30-01 10:10a PU_SOL_TH_015_10_k6
PU_SO~34                 6,633  03-30-01 10:10a PU_SOL_TH_015_11_k6
PU_SO~36                 6,633  03-30-01 10:10a PU_SOL_TH_015_12_k6
PU_SO~38                 6,633  03-30-01 10:10a PU_SOL_TH_015_13_k6
          17 file(s)        112,433 bytes

Directory of D:\CASES\Sun\AoA1\PU_SOL_THERM\016_inp

.                  <DIR>        10-04-01  2:06p .
..                 <DIR>        10-04-01  2:06p ..
PU_SOL~6                 6,879  03-30-01 10:10a PU_SOL_TH_016_3_k6
PU_SOL~8                 6,879  03-30-01 10:10a PU_SOL_TH_016_5_k6
PU_SO~10                 6,879  03-30-01 10:10a PU_SOL_TH_016_7_k6
PU_SO~12                 6,715  03-30-01 10:10a PU_SOL_TH_016_9_k6
PU_SO~14                 6,961  03-30-01 10:10a PU_SOL_TH_016_4_k6
PU_SO~16                 6,879  03-30-01 10:10a PU_SOL_TH_016_6_k6
PU_SO~18                 6,879  03-30-01 10:10a PU_SOL_TH_016_8_k6
PU_SO~20                 6,715  03-30-01 10:10a PU_SOL_TH_016_10_k6
PU_SO~22                 6,715  03-30-01 10:10a PU_SOL_TH_016_11_k6
PU_SO~24                 6,879  03-30-01 10:10a PU_SOL_TH_016_1_k6
PU_SO~26                 6,879  03-30-01 10:10a PU_SOL_TH_016_2_k6
          11 file(s)         75,259 bytes

Directory of D:\CASES\Sun\AoA1\PU_SOL_THERM\017_inp

.                  <DIR>        10-04-01  2:06p .
..                 <DIR>        10-04-01  2:06p ..
PU_SOL~6                 6,879  03-30-01 10:11a PU_SOL_TH_017_2_k6
PU_SOL~8                 6,879  03-30-01 10:11a PU_SOL_TH_017_4_k6
```

```
PU_SO~10                 6,879  03-30-01 10:11a PU_SOL_TH_017_6_k6
PU_SO~12                 6,879  03-30-01 10:11a PU_SOL_TH_017_8_k6
PU_SO~14                 6,551  03-30-01 10:10a PU_SOL_TH_017_1_k6
PU_SO~16                 6,879  03-30-01 10:11a PU_SOL_TH_017_3_k6
PU_SO~18                 6,879  03-30-01 10:11a PU_SOL_TH_017_5_k6
PU_SO~20                 6,879  03-30-01 10:11a PU_SOL_TH_017_7_k6
PU_SO~22                 6,879  03-30-01 10:11a PU_SOL_TH_017_9_k6
PU_SO~24                 6,879  03-30-01 10:10a PU_SOL_TH_017_14_k6
PU_SO~26                 6,879  03-30-01 10:10a PU_SOL_TH_017_17_k6
PU_SO~28                 6,879  03-30-01 10:10a PU_SOL_TH_017_16_k6
PU_SO~30                 6,879  03-30-01 10:10a PU_SOL_TH_017_15_k6
PU_SO~32                 6,879  03-30-01 10:10a PU_SOL_TH_017_18_k6
PU_SO~34                 6,879  03-30-01 10:10a PU_SOL_TH_017_10_k6
PU_SO~36                 6,551  03-30-01 10:10a PU_SOL_TH_017_11_k6
PU_SO~38                 6,879  03-30-01 10:10a PU_SOL_TH_017_12_k6
PU_SO~40                 6,879  03-30-01 10:10a PU_SOL_TH_017_13_k6
       18 file(s)       123,166 bytes

Directory of D:\CASES\Sun\AoA1\PU_SOL_THERM\020_inp

.             <DIR>       10-04-01  2:06p .
..            <DIR>       10-04-01  2:06p ..
PU_SOL~6                 5,951  03-30-01 10:11a PU_SOL_TH_020_7_T8A_k6
PU_SOL~8                 5,951  03-30-01 10:11a PU_SOL_TH_020_1_T8A_k6
PU_SO~10                 5,951  03-30-01 10:11a PU_SOL_TH_020_2_T8A_k6
PU_SO~12                 5,951  03-30-01 10:11a PU_SOL_TH_020_3_T8A_k6
PU_SO~14                 5,951  03-30-01 10:11a PU_SOL_TH_020_5_T8A_k6
PU_SO~16                 5,951  03-30-01 10:11a PU_SOL_TH_020_6_T8A_k6
PU_SO~18                 5,951  03-30-01 10:11a PU_SOL_TH_020_10_T8B_k6
PU_SO~20                 5,951  03-30-01 10:11a PU_SOL_TH_020_11_T8B_k6
PU_SO~22                 5,951  03-30-01 10:11a PU_SOL_TH_020_12_T8B_k6
PU_SO~24                 5,951  03-30-01 10:11a PU_SOL_TH_020_13_T8B_k6
       10 file(s)        59,510 bytes

Directory of D:\CASES\Sun\AoA1\usl

.             <DIR>       10-04-01  2:06p .
..            <DIR>       10-04-01  2:06p ..
CONCRE~5      <DIR>       10-04-01  2:06p Concrete Reflector
FULLSE~7      <DIR>       10-04-01  2:06p Full Set
PUCONT~9      <DIR>       10-04-01  2:06p Pu content
WATER~11      <DIR>       10-04-01  2:06p Water Cadmium Reflector
WATER~13      <DIR>       10-04-01  2:06p Water Reflector
        0 file(s)             0 bytes

Directory of D:\CASES\Sun\AoA1\usl\Concrete Reflector

.             <DIR>       10-04-01  2:06p .
..            <DIR>       10-04-01  2:06p ..
        0 file(s)             0 bytes

Directory of D:\CASES\Sun\AoA1\usl\Full Set

.             <DIR>       10-04-01  2:06p .
..            <DIR>       10-04-01  2:06p ..
PU_FUL~6 INP       5,999  09-19-01  9:44a Pu_Full_Set_EALF.inp
PU_FUL~8 OUT      13,566  09-17-01  3:18p Pu_Full_Set_EALF.out
PU_FU~10 INP       5,375  09-20-01 11:14a Pu_Full_Set_HPu.inp
PU_FU~12 OUT      13,566  09-20-01 11:15a Pu_Full_Set_HPu.out
        4 file(s)        38,506 bytes

Directory of D:\CASES\Sun\AoA1\usl\Pu content

.             <DIR>       10-04-01  2:06p .
..            <DIR>       10-04-01  2:06p ..
PU_NIT~6 INP       1,215  09-24-01  2:24p Pu_Nitrite_Pu_content.inp
PU_NIT~8 OUT       5,956  09-24-01  2:25p Pu_Nitrite_Pu_content.out
        2 file(s)         7,171 bytes

Directory of D:\CASES\Sun\AoA1\usl\Water Cadmium Reflector

.             <DIR>       10-04-01  2:06p .
..            <DIR>       10-04-01  2:06p ..
        0 file(s)             0 bytes

Directory of D:\CASES\Sun\AoA1\usl\Water Reflector

.             <DIR>       10-04-01  2:06p .
..            <DIR>       10-04-01  2:06p ..
        0 file(s)             0 bytes

Directory of D:\CASES\Sun\AoA2

.             <DIR>       10-04-01  2:06p .
..            <DIR>       10-04-01  2:06p ..
MCT_002       <DIR>       10-04-01  2:06p MCT_002
MCT_003       <DIR>       10-04-01  2:06p MCT_003
MCT_004       <DIR>       10-04-01  2:06p MCT_004
MCT_005       <DIR>       10-04-01  2:06p MCT_005
MCT_009       <DIR>       10-04-01  2:06p MCT_009
MIX_C~15      <DIR>       10-04-01  2:06p MIX_COMP_THERM
USL           <DIR>       10-04-01  2:06p usl
```

```
               0 file(s)              0 bytes

 Directory of D:\CASES\Sun\AoA2\MCT_002

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
002_INP        <DIR>        10-04-01  2:06p 002_INP
002_OUT        <DIR>        10-04-01  2:06p 002_OUT
               0 file(s)              0 bytes

 Directory of D:\CASES\Sun\AoA2\MCT_002\002_INP

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
MIX_CO~6                25,221  03-30-01 10:04a MIX_COMP_THERM_002_PNL34_k6
MIX_CO~8                25,221  03-30-01 10:04a MIX_COMP_THERM_002_PNL35_k6
MIX_C~10                25,221  03-30-01 10:04a MIX_COMP_THERM_002_PNL30_k6
MIX_C~12                25,221  03-30-01 10:04a MIX_COMP_THERM_002_PNL31_k6
MIX_C~14                25,221  03-30-01 10:04a MIX_COMP_THERM_002_PNL32_k6
MIX_C~16                25,221  03-30-01 10:04a MIX_COMP_THERM_002_PNL33_k6
               6 file(s)        151,326 bytes

 Directory of D:\CASES\Sun\AoA2\MCT_002\002_OUT

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
MIX_CO~6 OUT           729,052  03-30-01 10:04a MIX_COMP_THERM_002_PNL35_k6.out
MIX_CO~8 OUT           719,703  03-30-01 10:04a MIX_COMP_THERM_002_PNL34_k6.out
MIX_C~10 OUT           727,942  03-30-01 10:04a MIX_COMP_THERM_002_PNL30_k6.out
MIX_C~12 OUT           733,070  03-30-01 10:04a MIX_COMP_THERM_002_PNL31_k6.out
MIX_C~14 OUT           718,342  03-30-01 10:04a MIX_COMP_THERM_002_PNL32_k6.out
MIX_C~16 OUT           734,674  03-30-01 10:04a MIX_COMP_THERM_002_PNL33_k6.out
               6 file(s)      4,362,783 bytes

 Directory of D:\CASES\Sun\AoA2\MCT_003

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
003_INP        <DIR>        10-04-01  2:06p 003_INP
003_OUT        <DIR>        10-04-01  2:06p 003_OUT
               0 file(s)              0 bytes

 Directory of D:\CASES\Sun\AoA2\MCT_003\003_INP

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
MIX_CO~6                23,663  03-30-01 10:04a MIX_COMP_THERM_003_cas4_k6
MIX_CO~8                23,663  03-30-01 10:04a MIX_COMP_THERM_003_cas6_k6
MIX_C~10                23,663  03-30-01 10:04a MIX_COMP_THERM_003_cas5_k6
MIX_C~12                23,663  03-30-01 10:04a MIX_COMP_THERM_003_cas1_k6
MIX_C~14                23,663  03-30-01 10:04a MIX_COMP_THERM_003_cas2~1_k6
MIX_C~16                23,663  03-30-01 10:04a MIX_COMP_THERM_003_cas2~2_k6
MIX_C~18                23,827  03-30-01 10:04a MIX_COMP_THERM_003_cas3_k6
               7 file(s)        165,805 bytes

 Directory of D:\CASES\Sun\AoA2\MCT_003\003_OUT

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
FOO~6    TXT               830  09-14-01  6:19p foo.txt~
MIX_CO~8 OUT           804,258  03-30-01 10:04a MIX_COMP_THERM_003_cas4_k6.out
MIX_C~10 OUT           805,845  03-30-01 10:04a MIX_COMP_THERM_003_cas5_k6.out
MIX_C~12 OUT           788,464  03-30-01 10:04a MIX_COMP_THERM_003_cas6_k6.out
MIX_C~14 OUT           813,073  03-30-01 10:04a MIX_COMP_THERM_003_cas1_k6.out
MIX_C~16 OUT           809,282  03-30-01 10:04a MIX_COMP_THERM_003_cas2~1_k6.out
MIX_C~18 OUT           810,555  03-30-01 10:04a MIX_COMP_THERM_003_cas2~2_k6.out
MIX_C~20 OUT           820,517  03-30-01 10:04a MIX_COMP_THERM_003_cas3_k6.out
               8 file(s)      5,652,824 bytes

 Directory of D:\CASES\Sun\AoA2\MCT_004

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
004_INP        <DIR>        10-04-01  2:06p 004_inp
004_OUT        <DIR>        10-04-01  2:06p 004_out
               0 file(s)              0 bytes

 Directory of D:\CASES\Sun\AoA2\MCT_004\004_inp

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
MIX_CO~6                21,701  03-30-01 10:04a MIX_COMP_THERM_004_cas4_k6
MIX_CO~8                21,695  03-30-01 10:04a MIX_COMP_THERM_004_cas6_k6
MIX_C~10                21,695  03-30-01 10:04a MIX_COMP_THERM_004_cas8_k6
MIX_C~12                21,695  03-30-01 10:04a MIX_COMP_THERM_004_cas3_k6
MIX_C~14                21,695  03-30-01 10:04a MIX_COMP_THERM_004_cas5_k6
MIX_C~16                21,695  03-30-01 10:04a MIX_COMP_THERM_004_cas7_k6
MIX_C~18                21,695  03-30-01 10:04a MIX_COMP_THERM_004_cas9_k6
MIX_C~20                21,695  03-30-01 10:04a MIX_COMP_THERM_004_cas10_k6
MIX_C~22                21,695  03-30-01 10:04a MIX_COMP_THERM_004_cas11_k6
MIX_C~24                21,695  03-30-01 10:04a MIX_COMP_THERM_004_cas1_k6
MIX_C~26                21,691  03-30-01 10:04a MIX_COMP_THERM_004_cas2_k6
```

```
        11 file(s)        238,647 bytes

Directory of D:\CASES\Sun\AoA2\MCT_004\004_out

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
MIX_CO~6 OUT       839,181  03-30-01 10:04a MIX_COMP_THERM_004_cas08_k6.out
MIX_CO~8 OUT       839,200  03-30-01 10:04a MIX_COMP_THERM_004_cas07_k6.out
MIX_C~10 OUT       839,090  03-30-01 10:04a MIX_COMP_THERM_004_cas06_k6.out
MIX_C~12 OUT       839,289  03-30-01 10:04a MIX_COMP_THERM_004_cas09_k6.out
MIX_C~14 OUT       839,496  03-30-01 10:04a MIX_COMP_THERM_004_cas05_k6.out
MIX_C~16 OUT       839,830  03-30-01 10:04a MIX_COMP_THERM_004_cas10_k6.out
MIX_C~18 OUT       839,568  03-30-01 10:04a MIX_COMP_THERM_004_cas11_k6.out
MIX_C~20 OUT       840,873  03-30-01 10:04a MIX_COMP_THERM_004_cas01_k6.out
MIX_C~22 OUT       840,927  03-30-01 10:04a MIX_COMP_THERM_004_cas02_k6.out
MIX_C~24 OUT       840,826  03-30-01 10:04a MIX_COMP_THERM_004_cas03_k6.out
MIX_C~26 OUT       837,923  03-30-01 10:04a MIX_COMP_THERM_004_cas04_k6.out
        11 file(s)      9,236,203 bytes

Directory of D:\CASES\Sun\AoA2\MCT_005

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
005_INP        <DIR>        10-04-01  2:06p 005_inp
005_OUT        <DIR>        10-04-01  2:06p 005_out
         0 file(s)              0 bytes

Directory of D:\CASES\Sun\AoA2\MCT_005\005_inp

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
MIXCT_~6            92,571  03-30-01 10:04a mixct_005_case5_k6
MIXCT_~8            92,571  03-30-01 10:04a mixct_005_case6_k6
MIXCT~10            92,707  03-30-01 10:04a mixct_005_case1_k6
MIXCT~12            92,778  03-30-01 10:04a mixct_005_case2_k6
MIXCT~14            92,571  03-30-01 10:04a mixct_005_case3_k6
MIXCT~16            92,571  03-30-01 10:04a mixct_005_case4_k6
         6 file(s)        555,769 bytes

Directory of D:\CASES\Sun\AoA2\MCT_005\005_out

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
MIXCT_~6 OUT     1,023,158  03-30-01 10:04a mixct_005_case5_k6.out
MIXCT_~8 OUT     1,012,740  03-30-01 10:04a mixct_005_case6_k6.out
MIXCT~10 OUT     1,099,719  03-30-01 10:04a mixct_005_case1_k6.out
MIXCT~12 OUT     1,053,120  03-30-01 10:04a mixct_005_case2_k6.out
MIXCT~14 OUT     1,075,638  03-30-01 10:04a mixct_005_case3_k6.out
MIXCT~16 OUT     1,051,149  03-30-01 10:04a mixct_005_case4_k6.out
         6 file(s)      6,315,524 bytes

Directory of D:\CASES\Sun\AoA2\MCT_009

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
009_INP        <DIR>        10-04-01  2:06p 009_inp
009_OUT        <DIR>        10-04-01  2:06p 009_out
         0 file(s)              0 bytes

Directory of D:\CASES\Sun\AoA2\MCT_009\009_inp

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
MIXCT_~6           145,339  03-30-01 10:04a mixct_009_case5_k6
MIXCT_~8           145,317  03-30-01 10:04a mixct_009_case6_k6
MIXCT~10           146,077  03-30-01 10:04a mixct_009_case1_k6
MIXCT~12           145,563  03-30-01 10:04a mixct_009_case2_k6
MIXCT~14           145,361  03-30-01 10:04a mixct_009_case3_k6
MIXCT~16           145,235  03-30-01 10:04a mixct_009_case4_k6
         6 file(s)        872,892 bytes

Directory of D:\CASES\Sun\AoA2\MCT_009\009_out

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
FOO~6    TXT           990  09-17-01 10:36a foo.txt~
MIXCT_~8 OUT     1,489,916  03-30-01 10:04a mixct_009_case5_k6.out
MIXCT~10 OUT     1,498,329  03-30-01 10:04a mixct_009_case6_k6.out
MIXCT~12 OUT     1,496,420  03-30-01 10:04a mixct_009_case1_k6.out
MIXCT~14 OUT     1,500,064  03-30-01 10:04a mixct_009_case2_k6.out
MIXCT~16 OUT     1,486,748  03-30-01 10:04a mixct_009_case3_k6.out
MIXCT~18 OUT     1,498,017  03-30-01 10:04a mixct_009_case4_k6.out
         7 file(s)      8,970,484 bytes

Directory of D:\CASES\Sun\AoA2\MIX_COMP_THERM

.              <DIR>        10-04-01  2:06p .
..             <DIR>        10-04-01  2:06p ..
002_INP        <DIR>        10-04-01  2:06p 002_INP
003_INP        <DIR>        10-04-01  2:06p 003_INP
004_INP        <DIR>        10-04-01  2:06p 004_inp
005_INP        <DIR>        10-04-01  2:06p 005_inp
```

```
009_INP        <DIR>         10-04-01  2:06p 009_inp
        0 file(s)             0 bytes

Directory of D:\CASES\Sun\AoA2\MIX_COMP_THERM\002_INP

.              <DIR>         10-04-01  2:06p .
..             <DIR>         10-04-01  2:06p ..
MIX_CO~6            25,221  03-30-01 10:04a MIX_COMP_THERM_002_PNL34_k6
MIX_CO~8            25,221  03-30-01 10:04a MIX_COMP_THERM_002_PNL35_k6
MIX_C~10            25,221  03-30-01 10:04a MIX_COMP_THERM_002_PNL30_k6
MIX_C~12            25,221  03-30-01 10:04a MIX_COMP_THERM_002_PNL31_k6
MIX_C~14            25,221  03-30-01 10:04a MIX_COMP_THERM_002_PNL32_k6
MIX_C~16            25,221  03-30-01 10:04a MIX_COMP_THERM_002_PNL33_k6
        6 file(s)        151,326 bytes

Directory of D:\CASES\Sun\AoA2\MIX_COMP_THERM\003_INP

.              <DIR>         10-04-01  2:06p .
..             <DIR>         10-04-01  2:06p ..
MIX_CO~6            23,663  03-30-01 10:04a MIX_COMP_THERM_003_cas4_k6
MIX_CO~8            23,663  03-30-01 10:04a MIX_COMP_THERM_003_cas6_k6
MIX_C~10            23,663  03-30-01 10:04a MIX_COMP_THERM_003_cas5_k6
MIX_C~12            23,663  03-30-01 10:04a MIX_COMP_THERM_003_cas1_k6
MIX_C~14            23,663  03-30-01 10:04a MIX_COMP_THERM_003_cas2-1_k6
MIX_C~16            23,663  03-30-01 10:04a MIX_COMP_THERM_003_cas2-2_k6
MIX_C~18            23,827  03-30-01 10:04a MIX_COMP_THERM_003_cas3_k6
        7 file(s)        165,805 bytes

Directory of D:\CASES\Sun\AoA2\MIX_COMP_THERM\004_inp

.              <DIR>         10-04-01  2:06p .
..             <DIR>         10-04-01  2:06p ..
MIX_CO~6            21,701  03-30-01 10:04a MIX_COMP_THERM_004_cas4_k6
MIX_CO~8            21,695  03-30-01 10:04a MIX_COMP_THERM_004_cas6_k6
MIX_C~10            21,695  03-30-01 10:04a MIX_COMP_THERM_004_cas8_k6
MIX_C~12            21,695  03-30-01 10:04a MIX_COMP_THERM_004_cas3_k6
MIX_C~14            21,695  03-30-01 10:04a MIX_COMP_THERM_004_cas5_k6
MIX_C~16            21,695  03-30-01 10:04a MIX_COMP_THERM_004_cas7_k6
MIX_C~18            21,695  03-30-01 10:04a MIX_COMP_THERM_004_cas9_k6
MIX_C~20            21,695  03-30-01 10:04a MIX_COMP_THERM_004_cas10_k6
MIX_C~22            21,695  03-30-01 10:04a MIX_COMP_THERM_004_cas11_k6
MIX_C~24            21,695  03-30-01 10:04a MIX_COMP_THERM_004_cas1_k6
MIX_C~26            21,691  03-30-01 10:04a MIX_COMP_THERM_004_cas2_k6
       11 file(s)        238,647 bytes

Directory of D:\CASES\Sun\AoA2\MIX_COMP_THERM\005_inp

.              <DIR>         10-04-01  2:06p .
..             <DIR>         10-04-01  2:06p ..
MIXCT_~6            92,571  03-30-01 10:04a mixct_005_case5_k6
MIXCT_~8            92,571  03-30-01 10:04a mixct_005_case6_k6
MIXCT~10            92,707  03-30-01 10:04a mixct_005_case1_k6
MIXCT~12            92,778  03-30-01 10:04a mixct_005_case2_k6
MIXCT~14            92,571  03-30-01 10:04a mixct_005_case3_k6
MIXCT~16            92,571  03-30-01 10:04a mixct_005_case4_k6
        6 file(s)        555,769 bytes

Directory of D:\CASES\Sun\AoA2\MIX_COMP_THERM\009_inp

.              <DIR>         10-04-01  2:06p .
..             <DIR>         10-04-01  2:06p ..
MIXCT_~6           145,339  03-30-01 10:04a mixct_009_case5_k6
MIXCT_~8           145,317  03-30-01 10:04a mixct_009_case6_k6
MIXCT~10           146,077  03-30-01 10:04a mixct_009_case1_k6
MIXCT~12           145,563  03-30-01 10:04a mixct_009_case2_k6
MIXCT~14           145,361  03-30-01 10:04a mixct_009_case3_k6
MIXCT~16           145,235  03-30-01 10:04a mixct_009_case4_k6
        6 file(s)        872,892 bytes

Directory of D:\CASES\Sun\AoA2\usl

.              <DIR>         10-04-01  2:06p .
..             <DIR>         10-04-01  2:06p ..
FULLSE~5       <DIR>         10-04-01  2:06p Full Set
        0 file(s)             0 bytes

Directory of D:\CASES\Sun\AoA2\usl\Full Set

.              <DIR>         10-04-01  2:06p .
..             <DIR>         10-04-01  2:06p ..
MIX_FU~6 INP         1,068  09-24-01  3:43p Mix_Full_Set_EALF.inp
MIX_FU~8 OUT         5,491  09-24-01  3:32p Mix_Full_Set_EALF.out
MIX_F~10 INP         1,337  09-24-01  3:30p Mix_Full_Set_Pu_content.inp
MIX_F~12 OUT         5,491  09-24-01  3:33p Mix_Full_Set_Pu_content.out
MIX_F~14 INP         1,370  09-24-01  3:39p Mix_Full_Set_Vm.Vf.inp
MIX_F~16 OUT         5,703  09-24-01  3:40p Mix_Full_Set_Vm.Vf.out
        6 file(s)         20,460 bytes

Total files listed:
     1,194 file(s)    360,444,738 bytes
       348 dir(s)               0 bytes free
```

DUKE COGEMA
STONE & WEBSTER

Mixed Oxide Fuel Fabrication Facility

Criticality Code Validation
Part II

Revision 2

Docket Number 070-03098

Prepared by
Duke Cogema Stone & Webster

June 2003

Under
U.S. Department of Energy
Contract DE-AC02-99-CH10888

REVISION DESCRIPTION SHEET

REVISION NUMBER	DESCRIPTION
0	Initial Issue October 2001
1	Incorporate benchmark experiments identified using ORNL sensitivity and uncertainty analysis. Affected pages: 8, 18-19, 24-34, 38-56. Editorial and typographical corrections: various pages.
2	Define area of applicability based on key parameter ranges of input design applications used in sensitivity and uncertainty analysis. Remove waste store and laboratory from typical design applications for AOA(3) since these units can be analyzed using ANSI-ANS-8.1 limits. Affected pages: 36-38, 42-44. Editorial and typographical corrections: various pages.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

ANS	American Nuclear Society
ANSI	American National Standards Institute
AOA	area of applicability
CFR	Code of Federal Regulations
DCS	Duke Cogema Stone & Webster
DOE	U.S. Department of Energy
EALF	energy of average lethargy causing fission
FA	fuel assembly
LTB	lower tolerance band
MFFF	Mixed Oxide Fuel Fabrication Facility
MOX	mixed oxide
NRC	U.S. Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
RSICC	Radiation Safety Information Computational Center
USL	upper safety limit
S/U	Sensitivity and uncertainty

EXECUTIVE SUMMARY

This report documents the validation of the nuclear criticality safety codes to be used in the design of the Mixed Oxide (MOX) Fuel Fabrication Facility (MFFF), to be owned by the U.S. Department of Energy (DOE) and operated by the licensee, Duke Cogema Stone & Webster (DCS). This report is applicable to the validation of the SCALE 4.4a code packages [1] using the CSAS26 (KENOVI) sequence and the 238 energy group cross section library 238GROUPNDF5.

Title 10 Code of Federal Regulations (CFR) §70.61(d) requires that all nuclear processes remain subcritical under all normal and credible abnormal conditions. In order to establish that a system or process will be subcritical under all normal and credible abnormal conditions, it is necessary to establish acceptable subcritical limits for the operation and then show that the proposed operation will not exceed those values. In order to comply with this requirement, the *American National Standard for Nuclear Criticality in Operations with Fissionable Material Outside Reactors* [2] and the U.S. Nuclear Regulatory Commission (NRC) *Standard Review Plan for the Review of an Application for a Mixed Oxide (MOX) Fuel Fabrication Facility* [3] require that a validation be performed that (1) demonstrates the adequacy of the margin of subcriticality for safety by assuring that the margin is large compared to the uncertainty in the calculated value of k_{eff} and (2) determines the area(s) of applicability (AOA) and use of the code within the AOA, including justification for extending the AOA by using trends in the bias.

A number of design AOAs are established to cover the range of processes and fissile materials in the MFFF. AOAs covering Pu and MOX applications are as follows: (1) Pu-nitrate aqueous solutions, (2) MOX pellets, fuel rods, and fuel assemblies, (3) PuO_2 powders, (4) MOX powders, and (5) aqueous solutions of Pu compounds (Pu-oxalate solutions). The first two AOAs are validated in the validation report Part I [16]. The present report addresses the third and fourth AOAs: (3) PuO_2 powders (homogeneous systems), and (4) MOX powders (homogeneous systems). The AOA(5) will be addressed in the Part III [17].

The report concludes that the upper safety limit (USL) for the third design AOA (i.e., PuO_2 powder) is 0.9345, and the USL for the fourth design AOA (i.e., MOX powder) is 0.9323. The USL accounts for the computational bias, uncertainties, and a 0.05 administrative margin.

1. INTRODUCTION

1.1 PURPOSE

The purpose of this report is to validate the criticality codes and determine the upper safety limit (USL) to be used for performing nuclear criticality safety calculations and analyses of the Mixed Oxide (MOX) Fuel Fabrication Facility (MFFF), to be owned by the U.S. Department of Energy (DOE) and operated by the licensee, Duke Cogema Stone & Webster (DCS).

1.2 SCOPE

The scope of this report is limited to the validation of the CSAS26 sequence of the SCALE 4.4a code packages [1] with the 238 energy group cross-section library 238GROUPNDF5 on the PC platform for nuclear criticality safety calculations of the MFFF.

1.3 APPLICABILITY

The following areas of applicability (AOAs) are identified to cover a range of processes and fissile materials in the MFFF:

- Pu-nitrate aqueous solutions
- MOX pellets, fuel rods, and fuel assemblies
- PuO_2 powders
- MOX powders
- Aqueous solutions of Pu compounds (e.g., Pu-oxalate solutions).

This report addresses the third and fourth AOAs:

- PuO_2 powder mixture (homogeneous systems),
- MOX powder mixture (homogeneous systems).

1.4 BACKGROUND

1.4.1 Overall MFFF Design

The MFFF is designed to produce MOX fuel assemblies on an industrial scale from a mixture of depleted uranium and plutonium oxides for use in mission light-water reactors. The MFFF will be constructed at a DOE site and will be licensed by the U.S. Nuclear Regulatory Commission (NRC) under Title 10 Code of Federal Regulations (CFR) Part 70. The facility is designed to applicable U.S. codes and standards and operated by DCS, a private consortium under contract to DOE. The goal of the contract is to design, construct, and operate a facility to fabricate MOX fuel based on existing technology from the Cogema MELOX and La Hague plants in France. To maximize the benefit of the existing technology, process and equipment designs from the MELOX and La Hague plants are duplicated, to the maximum extent possible, in the design of the new plant.

The feed material is depleted uranium dioxide and surplus plutonium dioxide (from the Pit Disassembly and Conversion Facility) supplied by DOE. The impurities in the plutonium dioxide feed are extracted by the Aqueous Polishing process. The MOX fuel fabrication process blends this "polished" plutonium dioxide with depleted uranium dioxide to form mixed oxide pellets. These pellets are loaded into the fuel rods, which are integrated into fuel assemblies. The nuclear fuel assemblies are transported for use in specific U.S. commercial reactors as nuclear fuel. The MFFF is designed to process 3.5 metric tons annually, for a total disposition of 33 metric tons of plutonium (as dioxide).

1.4.2 Regulatory Requirements, Guidance, and Industrial Standards

Title 10 CFR §70.61(d) requires that "*under normal and credible abnormal conditions, all nuclear processes are subcritical, including use of an approved margin of subcriticality for safety.*" In order to comply with this requirement, NUREG 1718 [3] and ANSI/ANS-8.1 [2] require a validation report that (1) demonstrates the adequacy of the margin of subcriticality for safety by assuring that the margin is large compared to the uncertainty in the calculated value of keff and (2) determines the AOAs and use of the code within the AOA, including justification for extending the AOA by using trends in the bias.

NUREG 1718 [3] further states that the validation report should contain:

> A description of the AOA that identifies the range of values for which valid results have been obtained for the parameters used in the methodology. As defined in ANSI/ANS 8.1–1983, the AOA is the range of material compositions and geometric arrangements within which the bias of a calculational method is established. Other variables that may affect the neutronic behavior of the calculational method should also be specified in the definition of the AOA. Particular attention should be given to validating the code for calculations involving mixed oxides of differing isotopics and defining the isotopic ranges covered by the available benchmark experiments. In accordance with the provisions in ANSI/ANS 8.1–1983 (applicable section is Section 4.3.2), any extrapolation of the AOA beyond the physical range of the data should be supported by an established mathematical methodology.

2. CALCULATIONAL METHOD

The SCALE 4.4a code package [1] is the computational system used for MFFF criticality analyses. The code package is available from the Radiation Safety Information Computational Center (RSICC). The SCALE 4.4a code package is installed and verified on the SGN PC hardware platform [4].

SCALE 4.4a is a collection of modules designed to perform nuclear criticality, shielding, and thermal calculations. Each SCALE functional module may be run individually, or a sequence of functional modules may be executed using a special module referred to as a control module. For criticality analyses, various criticality safety analysis sequence (CSAS) control modules are available which differ in the specific functional modules executed and in the processing of cross sections used as input. In general, MFFF criticality analyses are performed using the CSAS26 control module and the 238 energy group cross-section library 238GROUPNDF5, based on ENDF/B-V data. These modules perform cross section processing using the BONAMI and NITAWL-II functional modules, and the calculation of k_{eff} is performed using the KENO VI Monte Carlo transport code.

Recent KENO-VI updates, up to and including Update 3 available from the SCALE Download web site, have been applied to SCALE 4.4a used for calculations presented here. Comparison between patched and unpatched SCALE 4.4a versions do not indicate statistically significant differences [15].

3. CRITICALITY CODE VALIDATION METHODOLOGY

In order to establish that a system or process will be subcritical under all normal and credible abnormal conditions, it is necessary to establish acceptable subcritical limits for the operation and then show that the proposed operation will not exceed those values.

Figure 3-1 shows how the validation process fits within the overall MFFF nuclear criticality analysis process. The first step involves the procurement, installation, and verification of the criticality software on a specific computer platform. For the MFFF, the SCALE 4.4a code packages has been procured, installed, and verified on the SGN PC [4] hardware platform. This step is followed by the validation of the criticality software, which is the purpose of this report. The final step involves the criticality safety design analysis calculations, which are performed and presented in separate reports.

The criticality code validation methodology can be divided into four steps:

- Identify general MFFF design applications
- Select applicable benchmark experiments and group them into AOAs
- Model and calculate k_{eff} values of selected critical benchmark experiments
- Perform statistical analysis of results to determine computational bias and upper safety limit (USL).

The first step is to identify the MFFF design applications and key parameters associated with the normal and upset design conditions. Table 3-2 lists some of the key parameters for the MFFF.

The second step involves several substeps. First, based on the key parameters, the AOA and expected range of the key parameter are identified. ANSI/ANS-8.1 [2] defines the AOA as "*the limiting range of material composition, geometric arrangements, neutron energy spectra, and other relevant parameters (such as heterogeneity, leakage interaction, absorption, etc.) within which the bias of a computational method is established.*" AOAs covering Pu and MOX applications are as follows: (1) Pu-nitrate solutions; (2) MOX pellets, fuel rods, and fuel assemblies; (3) PuO_2 powders; (4) MOX powders; and (5) aqueous solutions of Pu compounds. These AOAs are defined and presented in Section 4. After identifying the AOAs, a set of critical benchmark experiments is selected. Benchmark experiments for the AOAs are selected from the references listed in the *International Handbook of Evaluated Criticality Safety Benchmark Experiments [5]*, the *Guide to Verification and Validation of the SCALE-4 Criticality Safety Software [6]*, and the *Neutronics Benchmarks for the Utilization of Mixed-Oxide Fuel [7]*. A description of all relevant experiments used for each AOA considered here is provided in Section 5.

The third step involves modeling the critical experiments and calculating the k_{eff} values of the selected critical benchmark experiments[1].

The final step involves the statistical analysis of the results in order to calculate the computational bias and USL. Section 6 presents the computational bias and USL results.

---

[1] Note that these models contain simplifications of critical experiments geometry. These simplifications lead to additional uncertainties, included in the statistical analysis of the results.

3.1 DETERMINATION OF BIAS

ANSI/ANS–8.1–1998 [2] requires a determination of the calculational bias by "*correlating the results of critical and exponential experiments with results obtained for these same systems by the calculational method being validated.*" The correlation must be sufficient to determine if major changes in the bias can occur over the range of variables in the operation being analyzed. The standard permits the use of trends in the bias to justify extension of the area of applicability of the method outside the range of experimental conditions.

Calculational bias is the systematic difference between experimental data and calculated results. The simplest technique is to find the difference between the average value of the calculated results of critical benchmark experiments and 1.0. This technique gives a constant bias over a defined range of applicability.

Another technique is to find the difference between a regression fit of the calculated results of critical benchmark experiments and 1.0, as a function of an independent variable (e.g., enrichment, moderator-to-fuel ratio, etc.). As a rule, the bias is not a constant, but is dependent upon an independent variable, usually the degree of moderation of the neutrons. For example, the bias for an unmoderated system in which fission occurs with fast neutrons would not be expected to be the same as for a moderated system in which fission occurs with thermal neutrons. The AOA for the bias is the limiting range of material composition, geometric arrangement, etc., over which the bias is collectively established.

The recommended approach for establishing subcriticality based on numerical calculations of the neutron multiplication factor is prescribed in Section 5.1 of ANSI/ANS-8.17 [8]. The criteria to establish subcriticality requires that for a design application (system) to be considered as subcritical, the calculated multiplication factor for the system, k_s, must be less than or equal to an established maximum allowed multiplication factor based on benchmark calculations and uncertainty terms that is:

$$k_s \leq k_c - \Delta k_s - \Delta k_c - \Delta k_m \qquad \text{(Eq. 3.1)}$$

where:

k_s = the calculated allowable maximum multiplication factor, (k_{eff}) of the design application (system)

k_c = the mean k_{eff} value resulting from the calculation of benchmark critical experiments using a specific calculation method and data

Δk_s = the uncertainty in the value of k_s

Δk_c = the uncertainty in the value of k_c

Δk_m = the administrative margin to ensure subcriticality.

Sources of uncertainty that determine Δk_s include:

- statistical and/or convergence uncertainties
- material and fabrication tolerances
- limitations in the geometric and/or material representations used.

Sources of uncertainty that determine Δk_c include:

- uncertainties in critical experiments
- statistical and/or convergence uncertainties in the computation
- extrapolation outside of the range of experimental data
- limitations in the geometric and/or material representations used.

An assurance of subcriticality requires the determination of an acceptable margin based on known biases and uncertainties. The USL is defined as the upper bound for an acceptable calculation.

Critical benchmark experiments used to determine calculational bias (β) should be similar in composition, configuration, and nuclear characteristics to the system under examination. The range of applicability may be extended beyond the range of conditions represented by the benchmark experiments by extrapolating the trends established for the bias. β is related to k_c as follows:

$$\beta = k_c - 1 \qquad \text{(Eq. 3.2)}$$

$$\Delta\beta = \Delta k_c \qquad \text{(Eq. 3.3)}$$

Using this definition of bias, the condition for subcriticality in Eq. 3.1 is rewritten as:

$$k_s + \Delta k_s \leq 1 - \Delta k_m + \beta - \Delta\beta \qquad \text{(Eq. 3.4)}$$

A system is acceptably subcritical if a calculated k_{eff} plus calculational uncertainties lies at or below the USL.

$$k_s + \Delta k_s \leq USL \qquad \text{(Eq. 3.5)}$$

The USL can be written as:

$$USL = 1 - \Delta k_m + \beta - \Delta\beta \qquad \text{(Eq. 3.6)}$$

Bias is negative if $k_c < 1$ and positive if $k_c > 1$. For conservatism, a positive bias is set equal to zero for the purpose of defining the USL. $\Delta\beta$ is typically determined at the 95% confidence level.

The USL takes into account bias, uncertainties, and administrative and/or statistical margins such that the calculated configuration will be subcritical with a high degree of confidence.

β is related to system parameters and may not be constant over the range of a parameter of interest. If k_{eff} values for benchmark experiments vary as a function of a system parameter, such as enrichment or degree of moderation, then β can be determined from a best fit as a function of the parameter upon which it is dependent. Extrapolation outside the range of validation must take into account trends in the bias.

Both $\Delta\beta$ and β can vary with a given parameter, and the USL is typically expressed as a function of the parameter. Normally, the most important system parameter that affects bias is the degree of moderation of the neutrons. This parameter can be expressed in several different ways, such as the energy of average lethargy causing fission (EALF), moderator-to-fuel volume ratio (v^m/v^f), or moderator-to-fuel atomic ratio (H/Pu ratio).

In general, the "bias" can be broken down into components caused by system modeling error, code modeling inaccuracies, cross-sectional inaccuracies, etc. Biases associated with individual inaccuracies are usually combined into a total bias to represent the combined effect from all sources that prevent code and cross-sections from calculating the experimental value of k_{eff} (see Section 0).

One or two calculations are insufficient to determine calculational bias. In practice, it is necessary to determine the "average bias" for a group of experiments. A statistical analysis of the variation of biases around this average value is used to establish an uncertainty associated with the bias value when it is applied to a future calculation of a similar critical system. The lower limit of this band of uncertainty establishes an upper bound for which a future calculation of k_{eff} for a similar critical system can be considered subcritical with a high degree of confidence.

3.2 USL DETERMINATION METHODS

NUREG/CR-6361 [9] describes two parametric statistical methods for the determination of an USL from the bias and uncertainty terms associated with the calculation of criticality. The first method applies a statistical calculation of the bias and its uncertainty, plus an administrative margin, to a linear fit of critical experimental benchmark data. The second method applies a statistical calculation to determine a combined lower confidence band and subcritical margin. Both methods assume that the distribution of data points is normal. The following discussion of each method is taken from NUREG/CR-6361 [9] and is based on equations and techniques described in Dryer, Jordan, and Cain [10], Easter[11], Bowden and Graybill [12], Johnson [13], and Cain [14].

The parametric statistical methods described in NUREG/CR-6361 require the benchmark data to be normally distributed. In cases where the data fails a test for normality, a nonparametric technique is described which is based on rank order statistics. In this analysis, the nonparametric technique described in NUREG/CR-6361 [9] is employed.

3.2.1 USL Method 1: Confidence Band with Administrative Margin

This method applies a statistical calculation of the bias (β) and its uncertainty ($\Delta\beta$) plus an administrative safety margin (Δk_m) to a linear fit of calculated results for a selected set of critical experiments. A confidence band (W) is determined statistically based on the existing data and a specified level of confidence; the greater the standard deviation in the data or the larger the confidence desired, the larger the band width will be. This confidence band, W, accounts for uncertainties in the experiments, the calculational approach, and calculational data (e.g., cross sections) and is therefore a statistical basis for $\Delta\beta$, the uncertainty in the value of β. W is defined for a confidence level of $(1-\gamma_1)$ using the relationship:

$$W = \max\{w(x)|_{x\,min,\,x\,max}\} \qquad \text{(Eq. 3.7)}$$

where

$$w(x) = t_{1-\gamma_1} s_p \left[1 + \frac{1}{n} + \frac{(x-\bar{x})^2}{\sum_{i=1,n}(x_i-\bar{x})^2} \right]^{\frac{1}{2}} \qquad \text{(Eq. 3.8)}$$

and

n = the number of critical calculations used in establishing $k_c(x)$

$t_{1-\gamma_1}$ = the Student - t distribution for $1-\gamma_1$ and n - 2 degrees of freedom

$\bar{x}$ = the mean value of parameter x in the set of calculations

s_p = the pooled standard deviation for the set of criticality calculations.

The function w(x) is a curvilinear function. For simplicity, it is desirable to obtain a constant width margin. Therefore, for conservatism, the confidence band, W, is defined as the maximum of $(w(x_{min}), w(x_{max}))$, where x_{min} and x_{max} are the minimum and maximum values of the independent parameter x, respectively. Typically, W is determined at a 95% confidence level.

The pooled standard deviation is obtained from the pooled variance $S_p = \sqrt{S_p^2}$, where S_p is given as:

$$s_p^2 = s_{k(x)}^2 + s_w^2 \qquad \text{(Eq. 3.9)}$$

Where $S_{k(x)}^2$ is the variance (or mean square error) of the regression fit, and is given by:

$$s_{k(x)}^2 = \frac{1}{(n-2)} \left[\sum_{i=1,n}(k_i-\bar{k})^2 - \frac{\left\{\sum_{i=1,n}(x_i-\bar{x})(k_i-\bar{k})\right\}^2}{\sum_{i=1,n}(x_i-\bar{x})^2} \right] \qquad \text{(Eq. 3.10)}$$

and S_w^2 is the within-variance of the data:

$$s_w^2 = \frac{1}{n} \sum_{i=1,n} \sigma_i^2 \qquad \text{(Eq. 3.11)}$$

where σ_i is the standard deviation associated with k_i for a Monte Carlo calculation. It is recommended that the individual standard deviations for Monte Carlo calculations be roughly uniform in value for the best results. For deterministic codes that do not have a standard deviation associated with a computed value of k, the standard deviation is zero. However, this term can also be used as a mechanism to include known uncertainties in experimental data.

In USL Method 1, Δk_m is given an arbitrary administrative value. NUREG-1718 [3] states that a "minimum subcritical margin (Δk_m) of 0.05 is generally considered acceptable without additional justification when both the bias and its uncertainty are determined to be negligible." The MFFF criticality analyses use a value of 0.05. Section 0 provides further justification for the 0.05 administrative margin.

Having determined the constant W and substituting for $\Delta\beta$ in equation 3.6, the expression for the USL may be written as:

$$USL_1(x) = 1.0 - \Delta k_m - W + \beta(x). \qquad \text{(Eq. 3.12)}$$

3.2.2 USL Method 2: Single-Sided Uniform Width Closed Interval Approach

In USL Method 2, sometimes referred to as a lower tolerance band (LTB) approach, statistical techniques are applied to determine a combined lower confidence band plus subcritical margin. In USL Method 1, Δk_m and $\Delta\beta$ are determined independently, and in USL Method 2 (LTB method), a combined statistical lower bound is determined.

The purpose of this method is to determine a uniform tolerance band over a specified closed interval for a linear least-squares model. The level of confidence in the limit being calculated is α and is typically in the range of 0.90 to 0.999.

The USL Method 2 is defined as:

$$USL_2(x) = 1.0 - (C_{\alpha/P} \cdot s_p) + \beta(x) \qquad \text{(Eq. 3.13)}$$

where s_p is the pooled variance of k_c described earlier. The term $C_{\alpha/P} \cdot s_p$ provides a band for which there is a probability P with a confidence α that an additional calculation of k_{eff} for a critical system will lie within the band. For example, a $C_{95/99.5}$ multiplier produces a USL for which there is a 95% confidence that 995 out of 1000 future calculations of critical systems will yield a value of keff above the USL.

The analysis is over the closed interval from $x = a$ to $x = b$. $C_{\alpha/P}$ is calculated according to the following equations:

$$g = \sqrt{\frac{1}{n} + \frac{(a-\bar{x})^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}} \qquad \text{(Eq. 3.14)}$$

$$h = \sqrt{\frac{1}{n} + \frac{(b-\bar{x})^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}} \qquad \text{(Eq. 3.15)}$$

$$\rho = \frac{1}{gh} \cdot \left\{ \frac{1}{n} + \frac{(a-\bar{x})(b-\bar{x})}{\sum_{i=1}^{n} (x_i - \bar{x})^2} \right\} \qquad \text{(Eq. 3.16)}$$

$$A = \frac{g}{h} \qquad \text{(Eq. 3.17)}$$

A, ρ, and $(n\text{-}2)$ are used to determine the value of D from Table 3 in Bowden [12], which covers values of $0.5 \leq A \leq 1.5$. The procedure to follow when A is in this range is:

$$C^* = D \cdot g. \qquad \text{(Eq. 3.18)}$$

When A is outside the above range, A is replaced by $1/A$ for the determination of D, and C^* is given by:

$$C^* = D \cdot h. \qquad \text{(Eq. 3.19)}$$

Next,

$$C_{\alpha/P} = C^* + z_p \cdot \sqrt{\frac{n-2}{\chi^2}}, \qquad \text{(Eq. 3.20)}$$

where

z_p = the Student t statistic depending on n and P
χ^2 = the chi square distribution, a function of n-2 and α.

This approach provides a statistically based subcritical margin, Δk_m which can be determined as the difference $(C_{\alpha/P} \cdot s_p)$-W. In criticality safety applications, such a statistically determined approach generally, but not necessarily, yields a margin of less than 0.05, which serves to illustrate the adequacy of the administrative margin specified in USL Method 1. The recommended purpose of USL Method 2 is to apply it in tandem with USL Method 1 to verify that the administrative margin is conservative relative to a purely statistical basis.

3.2.3 Non-Normal Distributions

In cases where the benchmark results fail the χ^2 test for normality, the nonparametric technique described in NUREG-6698 [18] is applied to the data. This statistical technique is based on a rank order analysis of the data. The USL is established according to

USL = Smallest k_{eff} value – Uncertainty for smallest k_{eff} – Nonparametric margin – Δk_m (Eq. 3.1)

Where the nonparametric margin is an additional margin intended to account for small sample size, and Δk_m is the administrative margin. Recommended values for the nonparametric margin as a function of the degree of confidence are obtained from Table 2.2 of NUREG-6698, which is reproduced in Table 3-1.

The degree of confidence β that a fraction q of the population is greater than the lowest observed value is established for a given sample size n according to

$$\beta = 1 - q^n \quad \text{(Eq. 3.2)}$$

For a desired population fraction of 95%, this becomes

$$\beta = 1 - 0.95^n \quad \text{(Eq. 3.3)}$$

In order to obtain a 95% confidence that 95% of the population is larger than the smallest observed sample, at least 59 critical experiments are required.

Table 3-1 Recommended Non-Parametric Margin Values from NUREG-6698

Degree of Confidence for 95% of the Population	**Non-parametric Margin (NPM)**
>90%	0.00
>80%	0.01
>70%	0.02
>60%	0.03
>50%	0.04
>40%	0.05
≤40%	Additional data needed. (This corresponds to less than 10 data points.)

3.3 UNCERTAINTIES

Uncertainties, as used in this report, refer to the uncertainty in k_{eff} associated with experimental unknowns or assumptions and to the uncertainty values associated with Monte Carlo analyses.

Experimental uncertainty (σ_e) – Modeling of validation experiments frequently result in assumptions about experimental conditions. In addition, experimental uncertainties (such as measurement tolerances) influence the development of a computer model. Recent efforts by the OECD – NEA [5] have resulted in the quantification of these uncertainties in validation experiments.

Statistical uncertainty (σ_s) – Monte Carlo calculation techniques result in a statistical uncertainty associated with the actual calculation. This type of uncertainty is dependent upon many factors, including number of neutron generations performed, variance reduction techniques employed, and problem geometry. For this document, σ_s refers to the statistical Monte Carlo uncertainty associated with the computer modeled validation experiment.

Total uncertainty –This is the total uncertainty associated with a calculated k_{eff} on a benchmark experiment. The total uncertainty for an individual benchmark is the combined error of the experimental and statistical uncertainties:

$$\sigma_i = \sqrt{\sigma_{e,i}^2 + \sigma_{s,i}^2} \qquad \text{(Eq. 3.21)}$$

where the subscript (i) refers to an individual benchmark calculation.

3.4 NORMALIZING K_{EFF}

In many instances, benchmark experiments used for validation may not be exactly critical. Experimental results may show that the experiment is slightly above or below a k_{eff} = 1.0. For these cases, the calculated k_{eff} values should be normalized to the experimental value. This assumes that any inherent bias in the calculation is not affected by the normalization, which is valid for small differences in k_{eff}. To normalize k_{eff}, the following formula applies:

$$k_{eff}\,(\text{normalized}) = k_{eff}\,(\text{calculated}) \,/\, k_{eff}\,(\text{experimental}) \qquad \text{(Eq. 3.22)}$$

The normalized k_{eff} values are to be used in the determination of the USL. Since only small adjustments to the calculated k_{eff} value are made as a result of normalization, no adjustment to the total uncertainty, σ_i, is made.

3.5 APPLICATION OF THE USL

The equations for USL Methods 1 and 2 (equations 3.12 and 3.13) represent an upper bound to assure subcriticality for a given configuration when the calculated k_{eff} plus uncertainty for the configuration is less than the USL. USLs may be calculated for a number of independent parameters for a given system. Here, the subcritical limit is taken as the minimum of all USLs computed for the specific parameters of the system. This approach is conservative with respect to the guidance provided in NUREG/CR-6361 [9] in which the USL is determined based on the statistical results for the parameter "*with the strongest correlation to the calculated k_{eff} values.*"

Another advantage of the USL is that it may also be used to establish guidelines for quantitatively determining the applicability of the bias (or validation) to specific applications. For a given parameter, the USL is valid over the range of that parameter in the set of calculations used to determine the USL. However, ANSI/ANS-8.1 [2] allows the range of applicability to be extended beyond this range by extrapolating the trends established for the bias. No precise guidelines are specified for the limits of extrapolation. Thus, engineering judgment should be applied when extrapolating beyond the range of the parameter bounds.

Appendix C in NUREG/CR-6361 [9] documents the USLSTATS computer program that was developed to perform the required statistical analysis and calculate USLs based on USL Methods 1 and 2.

In this validation report, USLSTATS is used to trend the following parameters:

- Moderator to fuel atomic ratio (H/Pu)
- Energy of Average Lethargy Causing Fission (EALF)

- ^{240}Pu and PuO_2 content (percentage by weight)

The H/Pu ratio is a parameter that describes the moderation of the neutrons in the fissile medium. The EALF parameter is a measure of the energy dependent fission efficiency of the fissile medium.

The administrative margin, Δk_m, is fixed in order to have a sufficient confidence that the calculated results are subcritical.

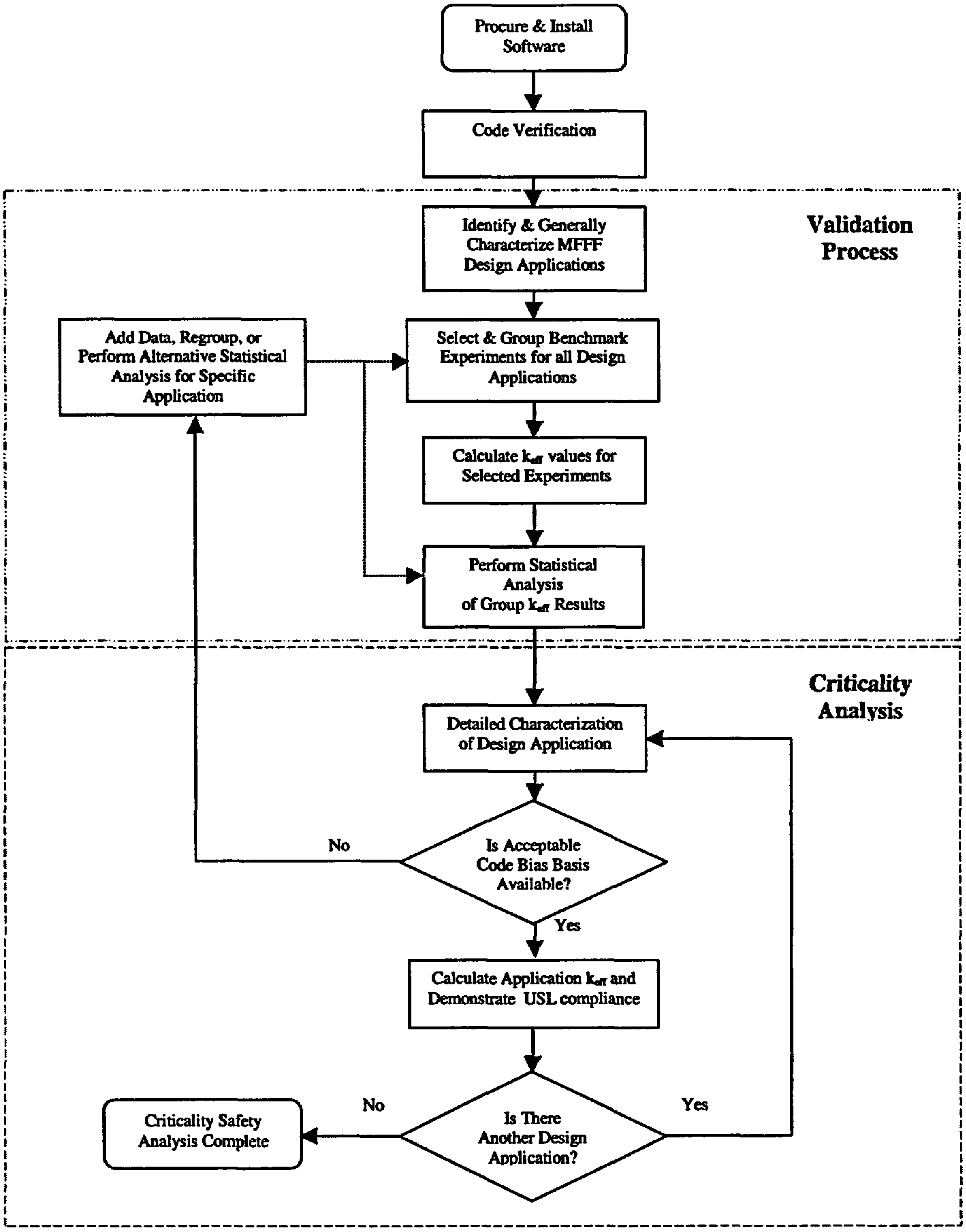


Figure 3-1 Overview of the Criticality Analysis Process of the MFFF

Table 3-2 Characteristics of the MFFF Application Areas*

Parameter	**Pu-nitrate solution**	**MOX pellets, fuel rods, FAs**	**PuO_2 powder/water mixtures**	**MOX powder/water mixtures**	**Aqueous solutions of Pu compounds**
Fissile Material Physical/Chemical Form	Pu-nitrate	MOX green and sintered pellets, MOX Rods and FAs	PuO_2 powder	MOX powder	(a) Pu-oxalate (b) PuO_2F_2
Isotopic composition of fissile material **	96% ^{239}Pu 4% ^{240}Pu	96% ^{239}Pu 4% ^{240}Pu depleted U	96% ^{239}Pu 4% ^{240}Pu	96% ^{239}Pu 4% ^{240}Pu depleted U	96% ^{239}Pu 4% ^{240}Pu
$PuO_2/(UO_2+PuO_2)$	100 %	≤ 6.3 %	100 %	6.3% – 22%	100 %
Maximum oxide density [g/cm^3]	–	7.0, 11.0	3.5, 7.0, 11.46	4.1, 5.5	–
Pu concentration [g/liter]	125 – 237	–	–	–	(a) 242 (b) 696
Type of moderation	Homogeneous	Heterogeneous	Homogeneous	Homogeneous	Homogeneous
Optimum moderation ***	H/Pu=100–200	v^m/v^f = 1.9 – 9	H/Pu= 0.3 – 6 and 700 – 1900	H/Pu=1.6 – 291	(a) H/Pu=100 (b) H/Pu=30
Low density moderation [wt.% H_2O]	–	≤ 5 ****	≤ 5	≤ 5	–
Anticipated absorber/reflector materials	Water Cd/water Concrete Borated concrete	Water Concrete Borated concrete	Water Borated concrete	Water	Water Cd/water Concrete
Typical geometry	Annular cylinders Cylinders Slabs	Cylinders Arrays Cuboids	Various configurations	Various configurations	Annular cylinders Cylinders Slabs

* Characteristics presented typically refer to optimal or bounding values or ranges associated with respective AOAs

** Bounding design isotopic composition from Aqueous Polishing System basis of design

*** Per calculation

**** Green Pellets (i.e., unsintered pellets) < 5; sintered pellets < 1

3.6 IDENTIFICATION OF BENCHMARK EXPERIMENTS

Benchmark experiments applicable to the validation of SCALE 4.4a for the areas of applicability covered in this report are identified using the sensitivity and uncertainty analysis technique developed by Oak Ridge National Laboratory [25]. This technique provides a quantitative means of identifying applicable experiments which exhibit a high degree of correlation with the design application with respect to both computed sensitivities and known uncertainties in the underlying cross-section data.

The S/U analytical tools include the SEN1 and SEN3 sensitivity analysis sequences, which will be available with the next release of the Standardized Computer Analyses for Licensing Evaluation (SCALE) code system. These analysis sequences compute the relative change in the system neutron multiplication factor, k_{eff}, which would be observed for perturbations in the group-wise neutron cross-section data for each reaction of each nuclide in the system. The CANDE code uses sensitivity data determined separately for the design system applications and the individual experiments, along with the cross-section-covariance data, to calculate integral parameters which give a measure of the similarity between a particular design system and an experimental benchmark. A high-valued integral parameter for an experiment application pair indicates that the experiment demonstrates similar properties to the application. Thus, the experiment is applicable for the criticality code validation of the design system. A theoretical basis for the S/U techniques applied in this report is given in Sect. 2 of [25].

The experiments identified in the ORNL report [25] are included here for use in the validation of SCALE 4.4a for AOA(3) and AOA(4).

3.6.1 Sensitivity and Uncertainty Analysis

A detailed description of the theory supporting the S/U technique is provided in [25] and in the references cited therein. For the purposes of this report, the end result of the S/U technique applied to a candidate benchmark experiment with respect to a particular design application is a parameter c_k which represents the correlation coefficient between uncertainties in the two systems.

These correlations arise due to the fact that the uncertainties in the k_{eff} values for two different systems are related, since they contain the same materials. Cross-section uncertainties will propagate to all systems containing these materials. Systems with the same materials and similar spectra would be correlated, while systems with different materials or differing spectra would not be correlated. The interpretation of the correlation coefficient is the following: a value of 0 represents no correlation between the systems, a value of 1 represents full correlation between the systems, and a value of -1 represents a full anti-correlation.

In [21], the criterion for the acceptance of a benchmark for the validation of a design system was established such that experiments exhibiting a c_k value of 0.8 or higher could be used for the validation of the design system. This criterion was chosen based on two methods of evaluation. The first was objectively viewing the sensitivity profiles to determine which systems appear to exhibit similar properties. The systems that exhibited the most similarities were those with a ck value of 0.8 or higher. The second method for establishing the criterion was the divergence of the computational bias predicted by the Generalized Linear Least Squares Methodology (GLLSM) procedure. Through this procedure, the GLLSM code was used to predict the computational bias of a system based on differing sets of experimental benchmarks. First, a large number of critical systems, with a wide range of c_k values, were included in the evaluation, and a bias was computed. Next, systems with ck values of 0.9 or greater were removed from the experimental set, thus the experiment set included only those experiments with ck values of 0.89 or lower. No change in the computational bias calculated by GLLSM was observed. A third GLLSM evaluation was performed using only experiments exhibiting a c_k value of 0.79 or lower. In this case, the computational bias computed by GLLSM varied from the previous two calculations by approximately 0.5%. A similarly skewed bias was found when only including systems with a c_k of 0.69 or lower. Thus, it is concluded in [21], there is a clear break in the behavior of systems at a c_k value of 0.8, and this should be used as the criterion for applicability.

3.6.2 Benchmark Experiments Identified for AOA(3)

In order to identify experiments applicable to AOA(3), three typical PuO_2 powder systems are first identified and the S/U methodology is applied to determine the sensitivity of k_{eff} for these design applications to cross section data. The three design applications characterizing AOA(3) are described in Table 3-3.

Table 3-3 Characteristics of Design Systems for AOA(3)

Application	H/Pu	EALF (eV)	keff
AOA 3-1	1.58	1019	0.9984
AOA 3-2	5.99	94.37	1.001
AOA 3-3	3.04	884.3	1.006

Table 3-4 Experimental configurations with c_k coefficients ≥ 0.8 for AOA 3-1

Experiment	ck	H/Pu	H/(Pu + U)	Wt % ^{240}Pu	Wt % Pu	EALF (eV)	keff	σ	NSK	GEN	NPG
PMF016-05	0.87	0.00	0.00	5.99%	100.0%	7.96E+03	0.9986	0.0006	11	503	5000
PMF016-01	0.87	0.00	0.00	5.99%	100.0%	1.17E+04	1.0128	0.0006	20	503	5000
PMF037-16	0.86	0.00	0.00	5.98%	100.0%	2.84E+04	1.0007	0.0005	8	503	5000
PMF037-15	0.86	0.00	0.00	5.98%	100.0%	1.83E+04	0.9992	0.0006	26	503	5000
PMF003-02	0.86	0.00	0.00	5.97%	100.0%	6.94E+05	0.9930	0.0006	3	503	5000
PMF003-01	0.86	0.00	0.00	5.97%	100.0%	1.24E+06	0.9946	0.0006	5	503	5000
PMF037-07	0.86	0.00	0.00	5.98%	100.0%	3.32E+04	0.9978	0.0006	21	503	5000
PMF003-03	0.86	0.00	0.00	5.97%	100.0%	1.24E+06	0.9876	0.0006	4	503	5000
PMF001-01	0.86	0.00	0.00	4.52%	100.0%	1.24E+06	0.9957	0.0006	11	503	5000
PMF016-03	0.86	0.00	0.00	5.99%	100.0%	8.23E+03	0.9994	0.0006	3	503	5000
PMF037-12	0.86	0.00	0.00	5.98%	100.0%	2.36E+04	0.9996	0.0006	11	503	5000
PMF003-04	0.86	0.00	0.00	5.97%	100.0%	6.28E+05	0.9922	0.0006	30	503	5000
PMF016-04	0.86	0.00	0.00	5.99%	100.0%	8.08E+03	0.9983	0.0006	16	503	5000
PMF017-01	0.86	0.00	0.00	5.97%	100.0%	7.83E+05	0.9896	0.0006	63	503	5000
PMF037-01	0.86	0.00	0.00	5.98%	100.0%	1.46E+05	0.9977	0.0006	15	503	5000
PMF003-05	0.86	0.00	0.00	5.97%	100.0%	1.25E+06	0.9914	0.0006	24	503	5000
PMF037-10	0.86	0.00	0.00	5.98%	100.0%	2.58E+04	0.9985	0.0006	6	503	5000
PMF016-02	0.86	0.00	0.00	5.99%	100.0%	8.56E+03	1.0008	0.0006	13	503	5000
PMF017-02	0.86	0.00	0.00	5.97%	100.0%	4.07E+05	0.9912	0.0007	6	503	5000
PMF017-03	0.85	0.00	0.00	5.97%	100.0%	2.31E+05	0.9951	0.0006	4	503	5000
PMF017-04	0.85	0.00	0.00	5.97%	100.0%	4.57E+05	0.9903	0.0007	5	503	5000
PMF037-05	0.85	0.00	0.00	5.98%	100.0%	5.12E+04	0.9969	0.0006	5	503	5000
PMF002-01	0.85	0.00	0.00	20.16%	100.0%	1.26E+06	0.9973	0.0006	19	503	5000
PMF016-06	0.84	0.00	0.00	5.99%	100.0%	7.80E+03	1.0003	0.0006	20	503	5000
PMF017-05	0.84	0.00	0.00	5.97%	100.0%	9.38E+04	1.0004	0.0006	26	503	5000
PCM002-02	0.83	0.04	0.04	18.35%	100.0%	4.24E+03	1.0306	0.0006	19	503	5000
PMF033-01	0.83	0.00	0.00	5.85%	52.5%	4.00E+05	1.0072	0.0005	30	503	5000
PCM002-01	0.82	0.04	0.04	18.35%	100.0%	4.92E+03	1.0329	0.0006	8	503	5000
PCM002-03	0.81	0.04	0.04	18.35%	100.0%	3.49E+03	1.0275	0.0005	3	503	5000
PCM002-04	0.81	0.04	0.04	18.35%	100.0%	2.58E+03	1.0204	0.0006	7	503	5000

Table 3-5 Experimental configurations with c_k coefficients ≥ 0.8 for AOA 3-2

Experiment	ck	H/Pu	H/(Pu + U)	Wt % ^{240}Pu	Wt % Pu	EALF (eV)	keff	σ	NSK	GEN	NPG
PCM002-06	0.99	5.05	5.05	11.46%	100.0%	9.26E+01	1.0230	0.0005	15	503	5000
PCM002-07	0.99	5.05	5.05	11.46%	100.0%	8.43E+01	1.0219	0.0006	9	503	5000
PCM002-08	0.99	5.05	5.05	11.46%	100.0%	6.79E+01	1.0210	0.0006	3	503	5000
PCM002-09	0.98	5.05	5.05	11.46%	100.0%	5.73E+01	1.0223	0.0006	63	503	5000
PCM001-02	0.98	5.05	5.05	11.46%	100.0%	1.74E+03	1.0203	0.0007	29	503	5000
PCM001-04	0.97	14.95	14.95	8.06%	100.0%	3.95E+01	0.9881	0.0006	10	503	5000
PCM001-03	0.97	15.10	15.10	2.20%	100.0%	3.26E+01	1.0164	0.0006	10	503	5000
PCM002-21	0.95	14.95	14.95	8.06%	100.0%	6.66E+00	1.0092	0.0005	5	503	5000
PCM002-22	0.95	14.95	14.95	8.06%	100.0%	6.41E+00	1.0145	0.0006	6	503	5000
PCM002-20	0.95	14.95	14.95	8.06%	100.0%	6.68E+00	1.0090	0.0005	4	503	5000
PCM002-19	0.95	14.95	14.95	8.06%	100.0%	6.46E+00	1.0091	0.0005	8	503	5000
PCM002-18	0.95	14.95	14.95	8.06%	100.0%	6.17E+00	1.0101	0.0005	5	503	5000
NSE55T5-07	0.95	9.55	2.79	11.53%	29.3%	4.35E+01	1.0045	0.0005	8	503	5000
PCM002-14	0.95	15.10	15.10	2.20%	100.0%	5.59E+00	1.0297	0.0006	8	503	5000
PU-29-1	0.95	9.47	2.77	11.52%	29.3%	4.16E+01	0.9934	0.0003	52	1503	5000
NSE55T5-01	0.95	9.55	2.79	11.53%	29.3%	4.02E+01	1.0044	0.0005	3	503	5000
PU-29-4	0.95	9.47	2.77	11.52%	29.3%	3.80E+01	0.9928	0.0005	4	503	5000
NSE55T5-10	0.95	9.55	2.79	11.53%	29.3%	3.86E+01	1.0038	0.0005	29	503	5000
PU-29-3	0.95	9.47	2.77	11.52%	29.3%	4.10E+01	1.0029	0.0005	50	503	5000
PU-29-2	0.95	9.47	2.77	11.52%	29.3%	4.07E+01	0.9931	0.0005	6	503	5000
PU-29-7	0.94	9.47	2.77	11.52%	29.3%	3.52E+01	0.9938	0.0005	3	503	5000
PCM002-15	0.94	15.10	15.10	2.20%	100.0%	5.56E+00	1.0279	0.0006	7	503	5000
NSE55T5-08	0.94	9.55	2.79	11.53%	29.3%	3.94E+01	1.0015	0.0005	17	503	5000
PCM002-16	0.94	15.10	15.10	2.20%	100.0%	5.14E+00	1.0250	0.0006	57	503	5000
PU-29-5	0.94	9.47	2.77	11.52%	29.3%	3.78E+01	0.9935	0.0005	17	503	5000
NSE55T5-05	0.94	9.55	2.79	11.53%	29.3%	4.07E+01	1.0021	0.0005	17	503	5000
NSE55T5-02	0.94	9.55	2.79	11.53%	29.3%	3.97E+01	1.0023	0.0005	20	503	5000
PU-29-8	0.94	9.47	2.77	11.52%	29.3%	3.45E+01	0.9926	0.0005	7	503	5000
PU-29-6	0.94	9.47	2.77	11.52%	29.3%	3.67E+01	0.9924	0.0005	12	503	5000
PU-29-9	0.94	9.47	2.77	11.52%	29.3%	3.46E+01	0.9968	0.0005	9	503	5000
PCM002-17	0.94	14.95	14.95	8.06%	100.0%	4.90E+00	1.0080	0.0006	41	503	5000
NSE55T5-03	0.94	9.55	2.79	11.53%	29.3%	4.02E+01	1.0043	0.0006	12	503	5000
NSE55T5-04	0.94	9.55	2.79	11.53%	29.3%	4.08E+01	1.0037	0.0005	9	503	5000
NSE55T5-06	0.94	9.55	2.79	11.53%	29.3%	4.17E+01	1.0024	0.0005	10	503	5000
PCM002-12	0.94	15.10	15.10	2.20%	100.0%	5.15E+00	1.0284	0.0006	10	503	5000
PCM002-11	0.94	15.10	15.10	2.20%	100.0%	4.55E+00	1.0286	0.0005	3	503	5000
PCM002-10	0.94	15.10	15.10	2.20%	100.0%	4.14E+00	1.0325	0.0006	22	503	5000
NSE55T5-09	0.94	9.55	2.79	11.53%	29.3%	3.92E+01	1.0029	0.0005	12	503	5000
BNWL2129T4-01	0.90	209.96	30.56	8.00%	14.6%	6.14E+00	1.0166	0.0005	12	503	5000
BNWL2129T4-02	0.89	209.96	30.56	8.00%	14.6%	4.50E+00	1.0181	0.0005	13	503	5000
BNWL2129T4-04	0.89	209.96	30.56	8.00%	14.6%	5.00E+00	1.0180	0.0005	4	503	5000
BNWL2129T4-16	0.89	209.96	30.56	8.00%	14.6%	5.21E+00	1.0168	0.0005	12	503	5000
BNWL2129T4-15	0.89	209.96	30.56	8.00%	14.6%	5.00E+00	1.0155	0.0005	17	503	5000
BNWL2129T4-07	0.89	209.96	30.56	8.00%	14.6%	4.90E+00	1.0165	0.0005	4	503	5000
BNWL2129T4-09	0.89	209.96	30.56	8.00%	14.6%	5.76E+00	1.0178	0.0005	21	503	5000
BNWL2129T4-17	0.88	209.96	30.56	8.00%	14.6%	4.24E+00	1.0188	0.0005	19	503	5000
PCM002-13	0.88	15.10	15.10	2.20%	100.0%	5.44E+00	1.0261	0.0006	5	503	5000
BNWL2129T4-19	0.87	209.96	30.56	8.00%	14.6%	4.03E+00	1.0186	0.0005	4	503	5000
BNWL2129T4-12	0.87	209.96	30.56	8.00%	14.6%	3.71E+00	1.0210	0.0006	4	503	5000
BNWL2129T4-10	0.86	209.96	30.56	8.00%	14.6%	5.23E+00	1.0165	0.0005	12	503	5000
BNWL2129T4-03	0.86	209.96	30.56	8.00%	14.6%	3.38E+00	1.0190	0.0006	8	503	5000
BNWL2129T4-18	0.86	209.96	30.56	8.00%	14.6%	3.56E+00	1.0180	0.0006	12	503	5000
BNWL2129T4-05	0.85	209.96	30.56	8.00%	14.6%	3.21E+00	1.0186	0.0005	4	503	5000
BNWL2129T4-08	0.83	209.96	30.56	8.00%	14.6%	2.38E+00	1.0177	0.0006	5	503	5000
BNWL2129T4-11	0.82	209.96	30.56	8.00%	14.6%	3.50E+00	1.0171	0.0005	6	503	5000
BNWL2129T4-13	0.82	209.96	30.56	8.00%	14.6%	2.52E+00	1.0220	0.0006	4	503	5000
PCM001-05	0.82	49.63	49.63	18.50%	100.0%	1.54E+00	1.0105	0.0006	13	503	5000
PCM002-05	0.82	0.04	0.04	18.35%	100.0%	1.87E+03	1.0167	0.0005	23	503	5000
PCI001-01	0.82	0.37	0.37	5.36%	100.0%	3.08E+02	0.9988	0.0001	15	503	5000
BNWL2129T4-06	0.81	209.96	30.56	8.00%	14.6%	2.21E+00	1.0193	0.0005	9	503	5000

Table 3-6 Experimental configurations with c_k coefficients ≥ 0.8 for AOA 3-3

Experiment	ck	H/Pu	H/(Pu + U)	Wt % ^{240}Pu	Wt % Pu	EALF (eV)	keff	σ	NSK	GEN	NPG
PCM001-02	0.96	5.05	5.05	11.46%	100.0%	1.74E+03	1.0203	0.0007	29	503	5000
PCM002-06	0.95	5.05	5.05	11.46%	100.0%	9.26E+01	1.0230	0.0005	15	503	5000
PCM002-09	0.95	5.05	5.05	11.46%	100.0%	5.73E+01	1.0223	0.0006	63	503	5000
PCM002-08	0.95	5.05	5.05	11.46%	100.0%	6.79E+01	1.0210	0.0006	3	503	5000
PCM002-07	0.93	5.05	5.05	11.46%	100.0%	8.43E+01	1.0219	0.0006	9	503	5000
PCM002-05	0.93	0.04	0.04	18.35%	100.0%	1.87E+03	1.0167	0.0005	23	503	5000
PCM002-03	0.92	0.04	0.04	18.35%	100.0%	3.49E+03	1.0275	0.0005	3	503	5000
PCM002-04	0.91	0.04	0.04	18.35%	100.0%	2.58E+03	1.0204	0.0006	7	503	5000
PCM002-01	0.91	0.04	0.04	18.35%	100.0%	4.92E+03	1.0329	0.0006	8	503	5000
PCM002-02	0.90	0.04	0.04	18.35%	100.0%	4.24E+03	1.0306	0.0006	19	503	5000
PMF016-06	0.89	0.00	0.00	5.99%	100.0%	7.80E+03	1.0003	0.0006	20	503	5000
PCM001-04	0.88	14.95	14.95	8.06%	100.0%	3.95E+01	0.9881	0.0006	10	503	5000
PMF016-01	0.88	0.00	0.00	5.99%	100.0%	1.17E+04	1.0128	0.0006	20	503	5000
PMF016-02	0.88	0.00	0.00	5.99%	100.0%	8.56E+03	1.0008	0.0006	13	503	5000
PMF016-04	0.88	0.00	0.00	5.99%	100.0%	8.08E+03	0.9983	0.0006	16	503	5000
PU-29-1	0.88	9.47	2.77	11.52%	29.3%	4.16E+01	0.9934	0.0003	52	1503	5000
PU-29-2	0.88	9.47	2.77	11.52%	29.3%	4.07E+01	0.9931	0.0005	6	503	5000
PU-29-3	0.87	9.47	2.77	11.52%	29.3%	4.10E+01	1.0029	0.0005	50	503	5000
NSE55T5-01	0.87	9.55	2.79	11.53%	29.3%	4.02E+01	1.0044	0.0005	3	503	5000
PU-29-4	0.87	9.47	2.77	11.52%	29.3%	3.80E+01	0.9928	0.0005	4	503	5000
PU-29-5	0.87	9.47	2.77	11.52%	29.3%	3.78E+01	0.9935	0.0005	17	503	5000
NSE55T5-05	0.87	9.55	2.79	11.53%	29.3%	4.07E+01	1.0021	0.0005	17	503	5000
NSE55T5-07	0.87	9.55	2.79	11.53%	29.3%	4.35E+01	1.0045	0.0005	8	503	5000
NSE55T5-08	0.87	9.55	2.79	11.53%	29.3%	3.94E+01	1.0015	0.0005	17	503	5000
PCM001-03	0.87	15.10	15.10	2.20%	100.0%	3.26E+01	1.0164	0.0006	10	503	5000
PMF037-15	0.87	0.00	0.00	5.98%	100.0%	1.83E+04	0.9992	0.0006	26	503	5000
NSE55T5-02	0.87	9.55	2.79	11.53%	29.3%	3.97E+01	1.0023	0.0005	20	503	5000
NSE55T5-10	0.87	9.55	2.79	11.53%	29.3%	3.86E+01	1.0038	0.0005	29	503	5000
PU-29-8	0.87	9.47	2.77	11.52%	29.3%	3.45E+01	0.9926	0.0005	7	503	5000
PU-29-7	0.87	9.47	2.77	11.52%	29.3%	3.52E+01	0.9938	0.0005	3	503	5000
NSE55T5-06	0.87	9.55	2.79	11.53%	29.3%	4.17E+01	1.0024	0.0005	10	503	5000
PU-29-6	0.87	9.47	2.77	11.52%	29.3%	3.67E+01	0.9924	0.0005	12	503	5000
NSE55T5-04	0.87	9.55	2.79	11.53%	29.3%	4.08E+01	1.0037	0.0005	9	503	5000
NSE55T5-03	0.87	9.55	2.79	11.53%	29.3%	4.02E+01	1.0043	0.0006	12	503	5000
PU-29-9	0.87	9.47	2.77	11.52%	29.3%	3.46E+01	0.9968	0.0005	9	503	5000
PMF016-05	0.87	0.00	0.00	5.99%	100.0%	7.96E+03	0.9986	0.0006	11	503	5000
NSE55T5-09	0.87	9.55	2.79	11.53%	29.3%	3.92E+01	1.0029	0.0005	12	503	5000
PMF037-07	0.87	0.00	0.00	5.98%	100.0%	3.32E+04	0.9978	0.0006	21	503	5000
PMF037-12	0.87	0.00	0.00	5.98%	100.0%	2.36E+04	0.9996	0.0006	11	503	5000
PMF016-03	0.87	0.00	0.00	5.99%	100.0%	8.23E+03	0.9994	0.0006	3	503	5000
PMF037-05	0.87	0.00	0.00	5.98%	100.0%	5.12E+04	0.9969	0.0006	5	503	5000
PMF017-05	0.86	0.00	0.00	5.97%	100.0%	9.38E+04	1.0004	0.0006	26	503	5000
PMF037-16	0.86	0.00	0.00	5.98%	100.0%	2.84E+04	1.0007	0.0005	8	503	5000
PMF037-10	0.86	0.00	0.00	5.98%	100.0%	2.58E+04	0.9985	0.0006	6	503	5000
PCM002-21	0.85	14.95	14.95	8.06%	100.0%	6.66E+00	1.0092	0.0005	5	503	5000
PCM002-20	0.85	14.95	14.95	8.06%	100.0%	6.68E+00	1.0090	0.0005	4	503	5000
PCM002-22	0.85	14.95	14.95	8.06%	100.0%	6.41E+00	1.0145	0.0006	6	503	5000
PCM002-18	0.85	14.95	14.95	8.06%	100.0%	6.17E+00	1.0101	0.0005	5	503	5000
PCM002-19	0.85	14.95	14.95	8.06%	100.0%	6.46E+00	1.0091	0.0005	8	503	5000
PCM002-17	0.84	14.95	14.95	8.06%	100.0%	4.90E+00	1.0080	0.0006	41	503	5000
PMF037-01	0.84	0.00	0.00	5.98%	100.0%	1.46E+05	0.9977	0.0006	15	503	5000
PCM002-14	0.84	15.10	15.10	2.20%	100.0%	5.59E+00	1.0297	0.0006	8	503	5000
PCM002-15	0.84	15.10	15.10	2.20%	100.0%	5.56E+00	1.0279	0.0006	7	503	5000
PCM002-16	0.84	15.10	15.10	2.20%	100.0%	5.14E+00	1.0250	0.0006	57	503	5000
PCM002-12	0.83	15.10	15.10	2.20%	100.0%	5.15E+00	1.0284	0.0006	10	503	5000
PMF017-03	0.83	0.00	0.00	5.97%	100.0%	2.31E+05	0.9951	0.0006	4	503	5000
PCM002-11	0.83	15.10	15.10	2.20%	100.0%	4.55E+00	1.0286	0.0005	3	503	5000
PCM002-10	0.83	15.10	15.10	2.20%	100.0%	4.14E+00	1.0325	0.0006	22	503	5000
PMF017-04	0.82	0.00	0.00	5.97%	100.0%	4.57E+05	0.9903	0.0007	5	503	5000
PMF017-02	0.82	0.00	0.00	5.97%	100.0%	4.07E+05	0.9912	0.0007	6	503	5000
BNWL2129T4-01	0.81	209.96	30.56	8.00%	14.6%	6.14E+00	1.0166	0.0005	12	503	5000

3.6.3 Benchmark Experiments Identified for AOA(4)

Typical design applications for AOA(4) MOX powders are characterized in Table 3-7. Design application 4-4 is based on nearly dry MOX powder systems for which the critical mass is significantly larger than any anticipated application in the MFFF. Hence, in addition to the design application corresponding to a critical mass of plutonium (4-4-Critical), three additional masses of powder are analyzed with the S/U technique, corresponding to 163, 40, and 8 kg of Pu, which more closely correspond to the masses of material which will be analyzed in the MFFF.

The resulting experiments identified as applicable to AOA(4) by the S/U analysis are shown in Table 3-8 through Table 3-14. Note that for the AOA 4-4-Critical and AOA4-4-P163 cases, the c_k acceptance criteria is reduced to 0.7. The inclusion of these additional experiments is conservative because the USL for this AOA is determined using the nonparametric technique described in Section 3.2.3 which is based on the overall observed minimum k_{eff} value in the benchmark set. Also, no unique experiments are introduced for these design applications. That is, all experiments listed in Table 3-11 (4-4-Critical) and Table 3-12 (4-4-P163) appear in some other result set for which a c_k value greater than 0.8 is computed.

Furthermore, the 4-4-Critical and 4-4-P163 design applications correspond to plutonium masses of 454 and 163 kg Pu, respectively. These masses are far in excess of anticipated analyzed conditions in the MFFF, even under worst case credible accident conditions. Hence, these design applications might well have been omitted altogether without affecting the USL analysis for this AOA. However, they have been retained for consistency with the results presented in [25].

Table 3-7 Characteristics of Design Systems for AOA(4)

Application	H/(U+Pu)	EALF (eV)	K_{eff}
AOA 4-1	1.58	127	1.0020
AOA 4-2	1.58	3751	0.9989
AOA 4-3	1.58	27.8	1.0000
AOA 4-4-Critical	0.30	2355	0.9993
AOA 4-4-P163	0.30	1214	0.9350
AOA 4-4-P40	0.30	368	0.8120
AOA 4-4-P8	0.30	86.4	0.6430

Table 3-8 Experimental configurations with c_k coefficients ≥ 0.8 for AOA 4-1

Experiment	ck	H/Pu	H/(Pu + U)	Wt % ^{240}Pu	Wt % Pu	EALF (eV)	keff	σ	NSK	GEN	NPG
PU-29-2	0.98	9.47	2.77	11.52%	29.3%	4.07E+01	0.9931	0.0005	6	503	5000
PU-29-1	0.98	9.47	2.77	11.52%	29.3%	4.16E+01	0.9934	0.0003	52	1503	5000
NSE55T5-07	0.98	9.55	2.79	11.53%	29.3%	4.35E+01	1.0045	0.0005	8	503	5000
PU-29-3	0.98	9.47	2.77	11.52%	29.3%	4.10E+01	1.0029	0.0005	50	503	5000
PU-29-4	0.98	9.47	2.77	11.52%	29.3%	3.80E+01	0.9928	0.0005	4	503	5000
NSE55T5-10	0.98	9.55	2.79	11.53%	29.3%	3.86E+01	1.0038	0.0005	29	503	5000
PU-29-5	0.98	9.47	2.77	11.52%	29.3%	3.78E+01	0.9935	0.0005	17	503	5000
NSE55T5-06	0.98	9.55	2.79	11.53%	29.3%	4.17E+01	1.0024	0.0005	10	503	5000
NSE55T5-01	0.98	9.55	2.79	11.53%	29.3%	4.02E+01	1.0044	0.0005	3	503	5000
NSE55T5-05	0.98	9.55	2.79	11.53%	29.3%	4.07E+01	1.0021	0.0005	17	503	5000
NSE55T5-02	0.98	9.55	2.79	11.53%	29.3%	3.97E+01	1.0023	0.0005	20	503	5000
NSE55T5-08	0.98	9.55	2.79	11.53%	29.3%	3.94E+01	1.0015	0.0005	17	503	5000
PU-29-7	0.98	9.47	2.77	11.52%	29.3%	3.52E+01	0.9938	0.0005	3	503	5000
NSE55T5-04	0.98	9.55	2.79	11.53%	29.3%	4.08E+01	1.0037	0.0005	9	503	5000
PU-29-8	0.98	9.47	2.77	11.52%	29.3%	3.45E+01	0.9926	0.0005	7	503	5000
NSE55T5-03	0.98	9.55	2.79	11.53%	29.3%	4.02E+01	1.0043	0.0006	12	503	5000
PU-29-6	0.98	9.47	2.77	11.52%	29.3%	3.67E+01	0.9924	0.0005	12	503	5000
PU-29-9	0.98	9.47	2.77	11.52%	29.3%	3.46E+01	0.9968	0.0005	9	503	5000
NSE55T5-09	0.98	9.55	2.79	11.53%	29.3%	3.92E+01	1.0029	0.0005	12	503	5000
PCM002-06	0.95	5.05	5.05	11.46%	100.0%	9.26E+01	1.0230	0.0005	15	503	5000
PCM002-07	0.95	5.05	5.05	11.46%	100.0%	8.43E+01	1.0219	0.0006	9	503	5000
PCM002-09	0.95	5.05	5.05	11.46%	100.0%	5.73E+01	1.0223	0.0006	63	503	5000
PCM002-08	0.94	5.05	5.05	11.46%	100.0%	6.79E+01	1.0210	0.0006	3	503	5000
BNWL2129T4-01	0.94	209.96	30.56	8.00%	14.6%	6.14E+00	1.0166	0.0005	12	503	5000
PCM001-04	0.94	14.95	14.95	8.06%	100.0%	3.95E+01	0.9881	0.0006	10	503	5000
PCM001-02	0.93	5.05	5.05	11.46%	100.0%	1.74E+03	1.0203	0.0007	29	503	5000
BNWL2129T4-02	0.93	209.96	30.56	8.00%	14.6%	4.50E+00	1.0181	0.0005	13	503	5000
BNWL2129T4-09	0.93	209.96	30.56	8.00%	14.6%	5.76E+00	1.0178	0.0005	21	503	5000
BNWL2129T4-04	0.93	209.96	30.56	8.00%	14.6%	5.00E+00	1.0180	0.0005	4	503	5000
PCM001-03	0.92	15.10	15.10	2.20%	100.0%	3.26E+01	1.0164	0.0006	10	503	5000
BNWL2129T4-16	0.92	209.96	30.56	8.00%	14.6%	5.21E+00	1.0168	0.0005	12	503	5000
BNWL2129T4-07	0.92	209.96	30.56	8.00%	14.6%	4.90E+00	1.0165	0.0005	4	503	5000
BNWL2129T4-15	0.92	209.96	30.56	8.00%	14.6%	5.00E+00	1.0155	0.0005	17	503	5000
PCM002-21	0.92	14.95	14.95	8.06%	100.0%	6.66E+00	1.0092	0.0005	5	503	5000
BNWL2129T4-17	0.92	209.96	30.56	8.00%	14.6%	4.24E+00	1.0188	0.0005	19	503	5000
PCM002-22	0.92	14.95	14.95	8.06%	100.0%	6.41E+00	1.0145	0.0006	6	503	5000
PCM002-20	0.92	14.95	14.95	8.06%	100.0%	6.68E+00	1.0090	0.0005	4	503	5000
PCM002-18	0.92	14.95	14.95	8.06%	100.0%	6.17E+00	1.0101	0.0005	5	503	5000
PCM002-19	0.91	14.95	14.95	8.06%	100.0%	6.46E+00	1.0091	0.0005	8	503	5000
PCM002-17	0.91	14.95	14.95	8.06%	100.0%	4.90E+00	1.0080	0.0006	41	503	5000
BNWL2129T4-19	0.91	209.96	30.56	8.00%	14.6%	4.03E+00	1.0186	0.0005	4	503	5000
BNWL2129T4-12	0.91	209.96	30.56	8.00%	14.6%	3.71E+00	1.0210	0.0006	4	503	5000
PCM002-15	0.91	15.10	15.10	2.20%	100.0%	5.56E+00	1.0279	0.0006	7	503	5000
PCM002-14	0.90	15.10	15.10	2.20%	100.0%	5.59E+00	1.0297	0.0006	8	503	5000
BNWL2129T4-10	0.90	209.96	30.56	8.00%	14.6%	5.23E+00	1.0165	0.0005	12	503	5000
PCM002-16	0.90	15.10	15.10	2.20%	100.0%	5.14E+00	1.0250	0.0006	57	503	5000
PCM002-12	0.90	15.10	15.10	2.20%	100.0%	5.15E+00	1.0284	0.0006	10	503	5000
PCM002-10	0.90	15.10	15.10	2.20%	100.0%	4.14E+00	1.0325	0.0006	22	503	5000
PCM002-11	0.90	15.10	15.10	2.20%	100.0%	4.55E+00	1.0286	0.0005	3	503	5000
BNWL2129T4-03	0.89	209.96	30.56	8.00%	14.6%	3.38E+00	1.0190	0.0006	8	503	5000
BNWL2129T4-18	0.89	209.96	30.56	8.00%	14.6%	3.56E+00	1.0180	0.0006	12	503	5000
BNWL2129T4-05	0.88	209.96	30.56	8.00%	14.6%	3.21E+00	1.0186	0.0005	4	503	5000
BNWL2129T4-11	0.86	209.96	30.56	8.00%	14.6%	3.50E+00	1.0171	0.0005	6	503	5000
BNWL2129T4-08	0.86	209.96	30.56	8.00%	14.6%	2.38E+00	1.0177	0.0006	5	503	5000
BNWL2129T4-13	0.85	209.96	30.56	8.00%	14.6%	2.52E+00	1.0220	0.0006	4	503	5000
PCI001-01	0.85	0.37	0.37	5.36%	100.0%	3.08E+02	0.9988	0.0001	15	503	5000
PCM002-13	0.85	15.10	15.10	2.20%	100.0%	5.44E+00	1.0261	0.0006	5	503	5000
BNWL2129T4-06	0.84	209.96	30.56	8.00%	14.6%	2.21E+00	1.0193	0.0005	9	503	5000
MCT001-01	0.81	0.00	0.00	11.54%	22.4%	9.69E-01	1.0023	0.0005	5	503	5000

Table 3-9 Experimental configurations with c_k coefficients ≥ 0.8 for AOA 4-2

Experiment	ck	H/Pu	H/(Pu + U)	Wt % ^{240}Pu	Wt % Pu	EALF (eV)	keff	σ	NSK	GEN	NPG
NSE55T5-07	0.94	9.55	2.79	11.53%	29.3%	4.35E+01	1.0045	0.0005	8	503	5000
NSE55T5-04	0.94	9.55	2.79	11.53%	29.3%	4.08E+01	1.0037	0.0005	9	503	5000
NSE55T5-06	0.94	9.55	2.79	11.53%	29.3%	4.17E+01	1.0024	0.0005	10	503	5000
NSE55T5-05	0.94	9.55	2.79	11.53%	29.3%	4.07E+01	1.0021	0.0005	17	503	5000
NSE55T5-01	0.93	9.55	2.79	11.53%	29.3%	4.02E+01	1.0044	0.0005	3	503	5000
PU-29-3	0.93	9.47	2.77	11.52%	29.3%	4.10E+01	1.0029	0.0005	50	503	5000
NSE55T5-03	0.93	9.55	2.79	11.53%	29.3%	4.02E+01	1.0043	0.0006	12	503	5000
PU-29-1	0.93	9.47	2.77	11.52%	29.3%	4.16E+01	0.9934	0.0003	52	1503	5000
PU-29-2	0.93	9.47	2.77	11.52%	29.3%	4.07E+01	0.9931	0.0005	6	503	5000
NSE55T5-10	0.93	9.55	2.79	11.53%	29.3%	3.86E+01	1.0038	0.0005	29	503	5000
NSE55T5-02	0.93	9.55	2.79	11.53%	29.3%	3.97E+01	1.0023	0.0005	20	503	5000
NSE55T5-08	0.93	9.55	2.79	11.53%	29.3%	3.94E+01	1.0015	0.0005	17	503	5000
PU-29-4	0.93	9.47	2.77	11.52%	29.3%	3.80E+01	0.9928	0.0005	4	503	5000
PU-29-5	0.93	9.47	2.77	11.52%	29.3%	3.78E+01	0.9935	0.0005	17	503	5000
PU-29-8	0.93	9.47	2.77	11.52%	29.3%	3.45E+01	0.9926	0.0005	7	503	5000
NSE55T5-09	0.93	9.55	2.79	11.53%	29.3%	3.92E+01	1.0029	0.0005	12	503	5000
PU-29-7	0.93	9.47	2.77	11.52%	29.3%	3.52E+01	0.9938	0.0005	3	503	5000
PU-29-6	0.93	9.47	2.77	11.52%	29.3%	3.67E+01	0.9924	0.0005	12	503	5000
PU-29-9	0.93	9.47	2.77	11.52%	29.3%	3.46E+01	0.9968	0.0005	9	503	5000
PCM001-02	0.90	5.05	5.05	11.46%	100.0%	1.74E+03	1.0203	0.0007	29	503	5000
PCM002-07	0.90	5.05	5.05	11.46%	100.0%	8.43E+01	1.0219	0.0006	9	503	5000
PCM002-06	0.89	5.05	5.05	11.46%	100.0%	9.26E+01	1.0230	0.0005	15	503	5000
PCM002-09	0.88	5.05	5.05	11.46%	100.0%	5.73E+01	1.0223	0.0006	63	503	5000
PCM002-08	0.88	5.05	5.05	11.46%	100.0%	6.79E+01	1.0210	0.0006	3	503	5000
PCM001-04	0.88	14.95	14.95	8.06%	100.0%	3.95E+01	0.9881	0.0006	10	503	5000
BNWL2129T4-01	0.87	209.96	30.56	8.00%	14.6%	6.14E+00	1.0166	0.0005	12	503	5000
PCM001-03	0.86	15.10	15.10	2.20%	100.0%	3.26E+01	1.0164	0.0006	10	503	5000
BNWL2129T4-02	0.86	209.96	30.56	8.00%	14.6%	4.50E+00	1.0181	0.0005	13	503	5000
BNWL2129T4-09	0.85	209.96	30.56	8.00%	14.6%	5.76E+00	1.0178	0.0005	21	503	5000
BNWL2129T4-04	0.85	209.96	30.56	8.00%	14.6%	5.00E+00	1.0180	0.0005	4	503	5000
BNWL2129T4-07	0.85	209.96	30.56	8.00%	14.6%	4.90E+00	1.0165	0.0005	4	503	5000
BNWL2129T4-16	0.85	209.96	30.56	8.00%	14.6%	5.21E+00	1.0168	0.0005	12	503	5000
BNWL2129T4-15	0.85	209.96	30.56	8.00%	14.6%	5.00E+00	1.0155	0.0005	17	503	5000
BNWL2129T4-17	0.85	209.96	30.56	8.00%	14.6%	4.24E+00	1.0188	0.0005	19	503	5000
PCM002-21	0.85	14.95	14.95	8.06%	100.0%	6.66E+00	1.0092	0.0005	5	503	5000
PCM002-22	0.84	14.95	14.95	8.06%	100.0%	6.41E+00	1.0145	0.0006	6	503	5000
PCM002-20	0.84	14.95	14.95	8.06%	100.0%	6.68E+00	1.0090	0.0005	4	503	5000
PCI001-01	0.84	0.37	0.37	5.36%	100.0%	3.08E+02	0.9988	0.0001	15	503	5000
PCM002-18	0.84	14.95	14.95	8.06%	100.0%	6.17E+00	1.0101	0.0005	5	503	5000
PCM002-19	0.84	14.95	14.95	8.06%	100.0%	6.46E+00	1.0091	0.0005	8	503	5000
BNWL2129T4-10	0.84	209.96	30.56	8.00%	14.6%	5.23E+00	1.0165	0.0005	12	503	5000
PCM002-17	0.83	14.95	14.95	8.06%	100.0%	4.90E+00	1.0080	0.0006	41	503	5000
BNWL2129T4-19	0.83	209.96	30.56	8.00%	14.6%	4.03E+00	1.0186	0.0005	4	503	5000
BNWL2129T4-12	0.83	209.96	30.56	8.00%	14.6%	3.71E+00	1.0210	0.0006	4	503	5000
PCM002-14	0.83	15.10	15.10	2.20%	100.0%	5.59E+00	1.0297	0.0006	8	503	5000
PCM002-15	0.83	15.10	15.10	2.20%	100.0%	5.56E+00	1.0279	0.0006	7	503	5000
PCM002-16	0.82	15.10	15.10	2.20%	100.0%	5.14E+00	1.0250	0.0006	57	503	5000
PCM002-12	0.82	15.10	15.10	2.20%	100.0%	5.15E+00	1.0284	0.0006	10	503	5000
BNWL2129T4-03	0.82	209.96	30.56	8.00%	14.6%	3.38E+00	1.0190	0.0006	8	503	5000
PCM002-10	0.82	15.10	15.10	2.20%	100.0%	4.14E+00	1.0325	0.0006	22	503	5000
PCM002-11	0.82	15.10	15.10	2.20%	100.0%	4.55E+00	1.0286	0.0005	3	503	5000
BNWL2129T4-18	0.81	209.96	30.56	8.00%	14.6%	3.56E+00	1.0180	0.0006	12	503	5000
BNWL2129T4-05	0.80	209.96	30.56	8.00%	14.6%	3.21E+00	1.0186	0.0005	4	503	5000

Table 3-10 Experimental configurations with c_k coefficients ≥ 0.8 for AOA 4-3

Experiment	ck	H/Pu	H/(Pu + U)	Wt % ^{240}Pu	Wt % Pu	EALF (eV)	keff	σ	NSK	GEN	NPG
BNWL2129T4-10	0.85	209.96	30.56	8.00%	14.6%	5.23E+00	1.0165	0.0005	12	503	5000
BNWL2129T4-09	0.85	209.96	30.56	8.00%	14.6%	5.76E+00	1.0178	0.0005	21	503	5000
NSE55T5-07	0.84	9.55	2.79	11.53%	29.3%	4.35E+01	1.0045	0.0005	8	503	5000
BNWL2129T4-01	0.84	209.96	30.56	8.00%	14.6%	6.14E+00	1.0166	0.0005	12	503	5000
NSE55T5-10	0.84	9.55	2.79	11.53%	29.3%	3.86E+01	1.0038	0.0005	29	503	5000
PU-29-7	0.84	9.47	2.77	11.52%	29.3%	3.52E+01	0.9938	0.0005	3	503	5000
NSE55T5-01	0.84	9.55	2.79	11.53%	29.3%	4.02E+01	1.0044	0.0005	3	503	5000
NSE55T5-02	0.84	9.55	2.79	11.53%	29.3%	3.97E+01	1.0023	0.0005	20	503	5000
NSE55T5-04	0.84	9.55	2.79	11.53%	29.3%	4.08E+01	1.0037	0.0005	9	503	5000
NSE55T5-05	0.84	9.55	2.79	11.53%	29.3%	4.07E+01	1.0021	0.0005	17	503	5000
NSE55T5-03	0.84	9.55	2.79	11.53%	29.3%	4.02E+01	1.0043	0.0006	12	503	5000
PU-29-3	0.84	9.47	2.77	11.52%	29.3%	4.10E+01	1.0029	0.0005	50	503	5000
PU-29-4	0.84	9.47	2.77	11.52%	29.3%	3.80E+01	0.9928	0.0005	4	503	5000
BNWL2129T4-02	0.84	209.96	30.56	8.00%	14.6%	4.50E+00	1.0181	0.0005	13	503	5000
PU-29-8	0.84	9.47	2.77	11.52%	29.3%	3.45E+01	0.9926	0.0005	7	503	5000
PU-29-9	0.84	9.47	2.77	11.52%	29.3%	3.46E+01	0.9968	0.0005	9	503	5000
PU-29-1	0.84	9.47	2.77	11.52%	29.3%	4.16E+01	0.9934	0.0003	52	1503	5000
BNWL2129T4-11	0.84	209.96	30.56	8.00%	14.6%	3.50E+00	1.0171	0.0005	6	503	5000
BNWL2129T4-16	0.84	209.96	30.56	8.00%	14.6%	5.21E+00	1.0168	0.0005	12	503	5000
NSE55T5-06	0.84	9.55	2.79	11.53%	29.3%	4.17E+01	1.0024	0.0005	10	503	5000
PU-29-5	0.84	9.47	2.77	11.52%	29.3%	3.78E+01	0.9935	0.0005	17	503	5000
PU-29-6	0.84	9.47	2.77	11.52%	29.3%	3.67E+01	0.9924	0.0005	12	503	5000
PU-29-2	0.84	9.47	2.77	11.52%	29.3%	4.07E+01	0.9931	0.0005	6	503	5000
BNWL2129T4-04	0.84	209.96	30.56	8.00%	14.6%	5.00E+00	1.0180	0.0005	4	503	5000
BNWL2129T4-15	0.84	209.96	30.56	8.00%	14.6%	5.00E+00	1.0155	0.0005	17	503	5000
NSE55T5-08	0.84	9.55	2.79	11.53%	29.3%	3.94E+01	1.0015	0.0005	17	503	5000
BNWL2129T4-07	0.84	209.96	30.56	8.00%	14.6%	4.90E+00	1.0165	0.0005	4	503	5000
BNWL2129T4-17	0.84	209.96	30.56	8.00%	14.6%	4.24E+00	1.0188	0.0005	19	503	5000
NSE55T5-09	0.84	9.55	2.79	11.53%	29.3%	3.92E+01	1.0029	0.0005	12	503	5000
BNWL2129T4-19	0.83	209.96	30.56	8.00%	14.6%	4.03E+00	1.0186	0.0005	4	503	5000
BNWL2129T4-12	0.83	209.96	30.56	8.00%	14.6%	3.71E+00	1.0210	0.0006	4	503	5000
BNWL2129T4-03	0.83	209.96	30.56	8.00%	14.6%	3.38E+00	1.0190	0.0006	8	503	5000
BNWL2129T4-18	0.83	209.96	30.56	8.00%	14.6%	3.56E+00	1.0180	0.0006	12	503	5000
BNWL2129T4-05	0.82	209.96	30.56	8.00%	14.6%	3.21E+00	1.0186	0.0005	4	503	5000
MCT002-02	0.82	0.00	0.00	7.76%	2.0%	7.72E-01	0.9967	0.0005	23	503	5000
MCT009-01	0.82	0.00	0.00	7.87%	1.5%	5.53E-01	0.9944	0.0005	4	503	5000
BNWL2129T4-08	0.82	209.96	30.56	8.00%	14.6%	2.38E+00	1.0177	0.0006	5	503	5000
PU-8-3	0.82	90.86	7.33	11.59%	8.1%	6.37E-01	1.0061	0.0005	10	503	5000
PU-8-4	0.82	90.86	7.33	11.59%	8.1%	6.32E-01	1.0051	0.0005	6	503	5000
PU-8-2	0.82	90.86	7.33	11.59%	8.1%	6.42E-01	1.0040	0.0005	12	503	5000
PU-8-1	0.82	90.86	7.33	11.59%	8.1%	6.43E-01	1.0046	0.0006	8	503	5000
BNWL2129T4-13	0.81	209.96	30.56	8.00%	14.6%	2.52E+00	1.0220	0.0006	4	503	5000
BNWL2129T4-06	0.81	209.96	30.56	8.00%	14.6%	2.21E+00	1.0193	0.0005	9	503	5000
MCT002-01	0.80	0.00	0.00	7.76%	2.0%	5.80E-01	0.9939	0.0005	13	503	5000

Table 3-11 Experimental configurations with c_k coefficients ≥ 0.7 for AOA 4-4 (critical)

Experiment	ck	H/Pu	H/(Pu + U)	Wt % ^{240}Pu	Wt % Pu	EALF (eV)	keff	σ	NSK	GEN	NPG
NSE55T5-04	0.74	9.55	2.79	11.53%	29.3%	4.08E+01	1.0037	0.0005	9	503	5000
NSE55T5-03	0.74	9.55	2.79	11.53%	29.3%	4.02E+01	1.0043	0.0006	12	503	5000
NSE55T5-05	0.74	9.55	2.79	11.53%	29.3%	4.07E+01	1.0021	0.0005	17	503	5000
NSE55T5-07	0.74	9.55	2.79	11.53%	29.3%	4.35E+01	1.0045	0.0005	8	503	5000
NSE55T5-01	0.74	9.55	2.79	11.53%	29.3%	4.02E+01	1.0044	0.0005	3	503	5000
NSE55T5-08	0.74	9.55	2.79	11.53%	29.3%	3.94E+01	1.0015	0.0005	17	503	5000
NSE55T5-06	0.74	9.55	2.79	11.53%	29.3%	4.17E+01	1.0024	0.0005	10	503	5000
NSE55T5-02	0.73	9.55	2.79	11.53%	29.3%	3.97E+01	1.0023	0.0005	20	503	5000
NSE55T5-09	0.73	9.55	2.79	11.53%	29.3%	3.92E+01	1.0029	0.0005	12	503	5000
PU-29-3	0.73	9.47	2.77	11.52%	29.3%	4.10E+01	1.0029	0.0005	50	503	5000
PU-29-8	0.73	9.47	2.77	11.52%	29.3%	3.45E+01	0.9926	0.0005	7	503	5000
PU-29-9	0.73	9.47	2.77	11.52%	29.3%	3.46E+01	0.9968	0.0005	9	503	5000
NSE55T5-10	0.73	9.55	2.79	11.53%	29.3%	3.86E+01	1.0038	0.0005	29	503	5000
PU-29-6	0.73	9.47	2.77	11.52%	29.3%	3.67E+01	0.9924	0.0005	12	503	5000
PU-29-4	0.73	9.47	2.77	11.52%	29.3%	3.80E+01	0.9928	0.0005	4	503	5000
PU-29-5	0.73	9.47	2.77	11.52%	29.3%	3.78E+01	0.9935	0.0005	17	503	5000
PU-29-7	0.73	9.47	2.77	11.52%	29.3%	3.52E+01	0.9938	0.0005	3	503	5000
PU-29-1	0.73	9.47	2.77	11.52%	29.3%	4.16E+01	0.9934	0.0003	52	1503	5000
PU-29-2	0.73	9.47	2.77	11.52%	29.3%	4.07E+01	0.9931	0.0005	6	503	5000

Table 3-12 Experimental configurations with c_k coefficients ≥ 0.7 for AOA 4-4-P163

Experiment	ck	H/Pu	H/(Pu + U)	Wt % ^{240}Pu	Wt % Pu	EALF (eV)	keff	σ	NSK	GEN	NPG
NSE55T5-04	0.77	9.55	2.79	11.53%	29.3%	4.08E+01	1.0037	0.0005	9	503	5000
NSE55T5-03	0.77	9.55	2.79	11.53%	29.3%	4.02E+01	1.0043	0.0006	12	503	5000
NSE55T5-05	0.77	9.55	2.79	11.53%	29.3%	4.07E+01	1.0021	0.0005	17	503	5000
NSE55T5-07	0.77	9.55	2.79	11.53%	29.3%	4.35E+01	1.0045	0.0005	8	503	5000
NSE55T5-01	0.77	9.55	2.79	11.53%	29.3%	4.02E+01	1.0044	0.0005	3	503	5000
NSE55T5-08	0.77	9.55	2.79	11.53%	29.3%	3.94E+01	1.0015	0.0005	17	503	5000
NSE55T5-06	0.77	9.55	2.79	11.53%	29.3%	4.17E+01	1.0024	0.0005	10	503	5000
NSE55T5-02	0.77	9.55	2.79	11.53%	29.3%	3.97E+01	1.0023	0.0005	20	503	5000
NSE55T5-09	0.76	9.55	2.79	11.53%	29.3%	3.92E+01	1.0029	0.0005	12	503	5000
PU-29-3	0.76	9.47	2.77	11.52%	29.3%	4.10E+01	1.0029	0.0005	50	503	5000
PU-29-8	0.76	9.47	2.77	11.52%	29.3%	3.45E+01	0.9926	0.0005	7	503	5000
PU-29-9	0.76	9.47	2.77	11.52%	29.3%	3.46E+01	0.9968	0.0005	9	503	5000
NSE55T5-10	0.76	9.55	2.79	11.53%	29.3%	3.86E+01	1.0038	0.0005	29	503	5000
PU-29-6	0.76	9.47	2.77	11.52%	29.3%	3.67E+01	0.9924	0.0005	12	503	5000
PU-29-5	0.76	9.47	2.77	11.52%	29.3%	3.78E+01	0.9935	0.0005	17	503	5000
PU-29-4	0.76	9.47	2.77	11.52%	29.3%	3.80E+01	0.9928	0.0005	4	503	5000
PU-29-1	0.76	9.47	2.77	11.52%	29.3%	4.16E+01	0.9934	0.0003	52	1503	5000
PU-29-7	0.76	9.47	2.77	11.52%	29.3%	3.52E+01	0.9938	0.0005	3	503	5000
PU-29-2	0.76	9.47	2.77	11.52%	29.3%	4.07E+01	0.9931	0.0005	6	503	5000
PCM002-09	0.71	5.05	5.05	11.46%	100.0%	5.73E+01	1.0223	0.0006	63	503	5000
PCM001-02	0.71	5.05	5.05	11.46%	100.0%	1.74E+03	1.0203	0.0007	29	503	5000
PCM002-06	0.71	5.05	5.05	11.46%	100.0%	9.26E+01	1.0230	0.0005	15	503	5000
BNWL2129T4-01	0.70	209.96	30.56	8.00%	14.6%	6.14E+00	1.0166	0.0005	12	503	5000
PCM002-07	0.70	5.05	5.05	11.46%	100.0%	8.43E+01	1.0219	0.0006	9	503	5000
PCM002-08	0.70	5.05	5.05	11.46%	100.0%	6.79E+01	1.0210	0.0006	3	503	5000
BNWL2129T4-02	0.70	209.96	30.56	8.00%	14.6%	4.50E+00	1.0181	0.0005	13	503	5000
PCI001-01	0.70	0.37	0.37	5.36%	100.0%	3.08E+02	0.9988	0.0001	15	503	5000

Table 3-13 Experimental configurations with c_k coefficients ≥ 0.8 for AOA 4-4-P40

Experiment	ck	H/Pu	H/(Pu + U)	Wt % ^{240}Pu	Wt % Pu	EALF (eV)	keff	σ	NSK	GEN	NPG
NSE55T5-04	0.83	9.55	2.79	11.53%	29.3%	4.08E+01	1.0037	0.0005	9	503	5000
NSE55T5-03	0.83	9.55	2.79	11.53%	29.3%	4.02E+01	1.0043	0.0006	12	503	5000
NSE55T5-05	0.83	9.55	2.79	11.53%	29.3%	4.07E+01	1.0021	0.0005	17	503	5000
NSE55T5-01	0.83	9.55	2.79	11.53%	29.3%	4.02E+01	1.0044	0.0005	3	503	5000
NSE55T5-08	0.83	9.55	2.79	11.53%	29.3%	3.94E+01	1.0015	0.0005	17	503	5000
NSE55T5-02	0.83	9.55	2.79	11.53%	29.3%	3.97E+01	1.0023	0.0005	20	503	5000
NSE55T5-09	0.83	9.55	2.79	11.53%	29.3%	3.92E+01	1.0029	0.0005	12	503	5000
NSE55T5-06	0.83	9.55	2.79	11.53%	29.3%	4.17E+01	1.0024	0.0005	10	503	5000
PU-29-8	0.83	9.47	2.77	11.52%	29.3%	3.45E+01	0.9926	0.0005	7	503	5000
NSE55T5-07	0.83	9.55	2.79	11.53%	29.3%	4.35E+01	1.0045	0.0005	8	503	5000
PU-29-3	0.83	9.47	2.77	11.52%	29.3%	4.10E+01	1.0029	0.0005	50	503	5000
PU-29-9	0.83	9.47	2.77	11.52%	29.3%	3.46E+01	0.9968	0.0005	9	503	5000
PU-29-6	0.83	9.47	2.77	11.52%	29.3%	3.67E+01	0.9924	0.0005	12	503	5000
PU-29-5	0.83	9.47	2.77	11.52%	29.3%	3.78E+01	0.9935	0.0005	17	503	5000
PU-29-4	0.83	9.47	2.77	11.52%	29.3%	3.80E+01	0.9928	0.0005	4	503	5000
PU-29-7	0.83	9.47	2.77	11.52%	29.3%	3.52E+01	0.9938	0.0005	3	503	5000
PU-29-1	0.82	9.47	2.77	11.52%	29.3%	4.16E+01	0.9934	0.0003	52	1503	5000
NSE55T5-10	0.82	9.55	2.79	11.53%	29.3%	3.86E+01	1.0038	0.0005	29	503	5000
PU-29-2	0.82	9.47	2.77	11.52%	29.3%	4.07E+01	0.9931	0.0005	6	503	5000

Table 3-14 Experimental configurations with c_k coefficients ≥ 0.8 for AOA 4-4-P8

Experiment	ck	H/Pu	H/(Pu + U)	Wt % ^{240}Pu	Wt % Pu	EALF (eV)	keff	σ	NSK	GEN	NPG
PU-29-6	0.89	9.47	2.77	11.52%	29.3%	3.67E+01	0.9924	0.0005	12	503	5000
PU-29-8	0.89	9.47	2.77	11.52%	29.3%	3.45E+01	0.9926	0.0005	7	503	5000
PU-29-9	0.89	9.47	2.77	11.52%	29.3%	3.46E+01	0.9968	0.0005	9	503	5000
NSE55T5-09	0.89	9.55	2.79	11.53%	29.3%	3.92E+01	1.0029	0.0005	12	503	5000
PU-29-5	0.89	9.47	2.77	11.52%	29.3%	3.78E+01	0.9935	0.0005	17	503	5000
PU-29-7	0.89	9.47	2.77	11.52%	29.3%	3.52E+01	0.9938	0.0005	3	503	5000
NSE55T5-04	0.89	9.55	2.79	11.53%	29.3%	4.08E+01	1.0037	0.0005	9	503	5000
NSE55T5-03	0.89	9.55	2.79	11.53%	29.3%	4.02E+01	1.0043	0.0006	12	503	5000
NSE55T5-02	0.89	9.55	2.79	11.53%	29.3%	3.97E+01	1.0023	0.0005	20	503	5000
NSE55T5-05	0.89	9.55	2.79	11.53%	29.3%	4.07E+01	1.0021	0.0005	17	503	5000
PU-29-4	0.89	9.47	2.77	11.52%	29.3%	3.80E+01	0.9928	0.0005	4	503	5000
PU-29-3	0.89	9.47	2.77	11.52%	29.3%	4.10E+01	1.0029	0.0005	50	503	5000
PU-29-1	0.89	9.47	2.77	11.52%	29.3%	4.16E+01	0.9934	0.0003	52	1503	5000
NSE55T5-08	0.89	9.55	2.79	11.53%	29.3%	3.94E+01	1.0015	0.0005	17	503	5000
PU-29-2	0.89	9.47	2.77	11.52%	29.3%	4.07E+01	0.9931	0.0005	6	503	5000
NSE55T5-01	0.89	9.55	2.79	11.53%	29.3%	4.02E+01	1.0044	0.0005	3	503	5000
NSE55T5-06	0.88	9.55	2.79	11.53%	29.3%	4.17E+01	1.0024	0.0005	10	503	5000
NSE55T5-10	0.88	9.55	2.79	11.53%	29.3%	3.86E+01	1.0038	0.0005	29	503	5000
NSE55T5-07	0.88	9.55	2.79	11.53%	29.3%	4.35E+01	1.0045	0.0005	8	503	5000
BNWL2129T4-10	0.88	209.96	30.56	8.00%	14.6%	5.23E+00	1.0165	0.0005	12	503	5000
BNWL2129T4-09	0.88	209.96	30.56	8.00%	14.6%	5.76E+00	1.0178	0.0005	21	503	5000
BNWL2129T4-01	0.88	209.96	30.56	8.00%	14.6%	6.14E+00	1.0166	0.0005	12	503	5000
BNWL2129T4-07	0.87	209.96	30.56	8.00%	14.6%	4.90E+00	1.0165	0.0005	4	503	5000
BNWL2129T4-15	0.87	209.96	30.56	8.00%	14.6%	5.00E+00	1.0155	0.0005	17	503	5000
BNWL2129T4-02	0.87	209.96	30.56	8.00%	14.6%	4.50E+00	1.0181	0.0005	13	503	5000
BNWL2129T4-04	0.87	209.96	30.56	8.00%	14.6%	5.00E+00	1.0180	0.0005	4	503	5000
BNWL2129T4-16	0.87	209.96	30.56	8.00%	14.6%	5.21E+00	1.0168	0.0005	12	503	5000
BNWL2129T4-17	0.87	209.96	30.56	8.00%	14.6%	4.24E+00	1.0188	0.0005	19	503	5000
BNWL2129T4-12	0.86	209.96	30.56	8.00%	14.6%	3.71E+00	1.0210	0.0006	4	503	5000
BNWL2129T4-11	0.86	209.96	30.56	8.00%	14.6%	3.50E+00	1.0171	0.0005	6	503	5000
BNWL2129T4-19	0.86	209.96	30.56	8.00%	14.6%	4.03E+00	1.0186	0.0005	4	503	5000
BNWL2129T4-03	0.86	209.96	30.56	8.00%	14.6%	3.38E+00	1.0190	0.0006	8	503	5000
BNWL2129T4-18	0.86	209.96	30.56	8.00%	14.6%	3.56E+00	1.0180	0.0006	12	503	5000
BNWL2129T4-05	0.85	209.96	30.56	8.00%	14.6%	3.21E+00	1.0186	0.0005	4	503	5000
BNWL2129T4-08	0.85	209.96	30.56	8.00%	14.6%	2.38E+00	1.0177	0.0006	5	503	5000
BNWL2129T4-13	0.84	209.96	30.56	8.00%	14.6%	2.52E+00	1.0220	0.0006	4	503	5000
PCM002-09	0.84	5.05	5.05	11.46%	100.0%	5.73E+01	1.0223	0.0006	63	503	5000
BNWL2129T4-06	0.83	209.96	30.56	8.00%	14.6%	2.21E+00	1.0193	0.0005	9	503	5000
PCM002-06	0.82	5.05	5.05	11.46%	100.0%	9.26E+01	1.0230	0.0005	15	503	5000
PCM002-08	0.82	5.05	5.05	11.46%	100.0%	6.79E+01	1.0210	0.0006	3	503	5000
PCM002-13	0.80	15.10	15.10	2.20%	100.0%	5.44E+00	1.0261	0.0006	5	503	5000
PCM002-20	0.80	14.95	14.95	8.06%	100.0%	6.68E+00	1.0090	0.0005	4	503	5000
PCM002-18	0.80	14.95	14.95	8.06%	100.0%	6.17E+00	1.0101	0.0005	5	503	5000
PCM002-17	0.80	14.95	14.95	8.06%	100.0%	4.90E+00	1.0080	0.0006	41	503	5000
PCM002-22	0.80	14.95	14.95	8.06%	100.0%	6.41E+00	1.0145	0.0006	6	503	5000

4. MFFF DESIGN APPLICATION CLASSIFICATION

This section describes the characteristics of the established AOAs based on the various fuel configurations encountered in the MFFF. AOAs covering Pu and MOX applications are as follows (see Table 3-2):

- Pu-nitrate aqueous solution
- MOX pellets, fuel rods, and fuel assemblies (FA)
- PuO_2 powders
- MOX powders
- Aqueous solutions of Pu compounds (e.g., Pu-oxalate solution).

4.1 DESIGN APPLICATION (3) – PuO_2 POWDER

Table 4-1 summarizes the anticipated criticality calculations to be performed for the design of the MFFF in which PuO_2 will be processed. The table provides the relevant parameters (i.e., chemical form, isotopic vector, moderator to fuel atomic ratio (H/Pu), and EALF) for each criticality design application.

For some applications, geometry control is used and the calculations are performed at optimum moderation taking into account full water reflection. In these cases a thermal neutron spectrum will be found. In other applications (e.g., jar store and the can receiving and emptying unit) where mass and moderation control are used and the fissile materials are reflected by borated concrete materials, or the concrete reflector is far from the fuel, the neutron spectrum will be intermediate to fast.

4.2 DESIGN APPLICATION (4) – MOX POWDER

Table 4-2 summarizes the anticipated criticality calculations to be performed for the design of the MOX powder process. In addition, the table provides the relevant parameters (i.e., chemical form, moderator to fuel atomic ratio (H/Pu), and EALF) for each criticality design application.

Table 4-1 Anticipated Criticality Calculation Derived Characteristics for Design Applications Involving PuO_2 Powder

Fuel Configuration	Reflector Conditions	Chemical Form	Pu-Isotopic Composition	Max $\rho(PuO_2)$ $[g/cm^3]$	H/Pu	EALF[4] [eV]
AP: Decanning						
PuO_2 dosing hopper	Water	PuO_2 powder	4% ^{240}Pu	7.0	1.67	13,090
AP: Dissolution						
Electrolyzer	Water[1]/Cd[2]	PuO_2 powder	4% ^{240}Pu	7.0	1.67	18,048
Filter glove box	Water[1]	PuO_2 powder	4% ^{240}Pu	7.0	1.67	654
Tanks in cell	Water[1]/Cd[2]	PuO_2 powder	4% ^{240}Pu	7.0	1.67	18,700
AP: Oxalic Precipitation Conversion						
Furnace GB	Water[1]	PuO_2 powder	4% ^{240}Pu	3.5	5.97	67
AP: Homogenization						
Separating hopper	Water	PuO_2 powder	4% ^{240}Pu	3.5	5.97	3.76
PuO_2 powder sampling GB	Water	PuO_2 powder	4% ^{240}Pu	3.5	5.97	77
Sampling GB	Water	PuO_2 powder	4% ^{240}Pu	3.5	5.97	95
Sample storage GB	Water	PuO_2 powder	4% ^{240}Pu	3.5	5.97	95
Cylindrical condenser	Water[1]	PuO_2 powder	4% ^{240}Pu	3.5	5.97	21
MP: Powder Area						
PuO_2 3013 can store	Concrete reflected array	PuO_2 powder	4% ^{240}Pu	7.0, 11.46	1.67	65000
PuO_2 can buffer store	Concrete[3] reflected array	PuO_2 powder	4% ^{240}Pu	3.5	5.97	3.1
Primary dosing unit	Water[1]	PuO_2 powder	4% ^{240}Pu	3.5	1.16	525
PuO_2 decanning unit	Water[1]	PuO_2 powder	4% ^{240}Pu	3.5	5.97	493
Range of Design Application	**Various**	**PuO_2 powder**	**4% ^{240}Pu**	**3.5 – 11.46**	**1.16 to 5.97**	**3.1 to 65000**

[1] The concrete walls are conservatively modeled. However, the presence of a close fitting water reflector effectively eliminates its effect.

[2] Cadmium sheet of 0.05 cm thickness (clad in 0.1 cm stainless steel).

[3] Boron is actually present in the concrete, but no credit is required in the safety analysis of the unit.

[4] Bounding safety analysis case at bounding moderation.

Table 4-2 Anticipated Criticality Calculation Derived Characteristics for Design Applications Involving MOX Powder

Fuel Configuration	Reflector Condition	Chemical Form	$PuO_2/(UO_2+PuO_2)$	Pu-isotopic Composition	Max ρ(MOX) [g/cm^3]	H/(U+Pu)	EALF[2] [eV]
MP: Powder area							
Ball milling units	Water	MOX powder	6.3%, 22%	4% ^{240}Pu	5.5	1.15	175
Jar store unit	Water[1]	MOX powder	6.3%, 22%	4% ^{240}Pu	5.5	1.58	0.8
Final dosing unit	Water	MOX powder	6.3%, 22%	4% ^{240}Pu	5.5	1.15	175
Final mix homogenization and press station unit	Water	MOX powder	6.3%, 22%	4% ^{240}Pu	5.5	1.58	44.9
Scrap processing unit	Water	MOX powder	6.3%	4% ^{240}Pu	5.5	1.15	175
Auxiliary powder unit	Water	MOX powder	6.3%, 22%	4% ^{240}Pu	5.5	1.15	175
Expected Range of Application	**Water**	**MOX powder**	**6.3%, 22 %**	**4% ^{240}Pu**	**5.5**	**1.15-1.58**	**0.8 – 175**

[1] The concrete walls are conservatively modeled. However, the presence of a close fitting water reflector effectively eliminates its effect.

[2] Bounding safety analysis case at bounding moderation.

5. BENCHMARK EXPERIMENTS

Descriptions of the critical experiments comprising the candidate experiment database to which the S/U technique is applied are presented below. The discussion is adapted from Section 5 of [25].

Resulting comparisons of the selected benchmark experiments and the design applications with respect to key design parameters are shown in Table 5-1 and Table 5-2 for AOA(3) and AOA(4), respectively.

The validated area of applicability in each case is defined by the range of key parameters of the design applications used as input to the sensitivity and uncertainty analysis.

5.1 PLUTONIUM SYSTEMS

Sixty-one plutonium benchmarks are included in the database. These include metal systems and oxide systems.

5.1.1 Plutonium Metal Systems

Twenty-six plutonium metal experiments are included in this set of benchmarks. Two bare metal spheres are included: one with a low ^{240}Pu content (4.5 at. %), designated ^{239}Pu Jezebel (PU-MET-FAST-001), and another with a higher ^{240}Pu content (20.1 at. %) designated as ^{240}Pu Jezebel (PU-MET-FAST-002). A set of three experiments using arrays of unmoderated plutonium metal buttons, and either bare or with one side reflected by polyethylene, were included (PU-MET-FAST-003). A group of thirteen experiments using plutonium metal in cans, and placed in 3 x 3 x 3 or 2 x 2 x N arrays with water moderation and reflection are taken from PU-MET-FAST-016 and PU-MET-FAST-037. Five experiments using moderated arrays of plutonium metal cylinders are included from PU-MET-FAST-017. The final plutonium metal experiment is from PU-MET-FAST-033, and is part of the ZPPR-21 series of experiments, which also include MIX-MET-FAST-011 and HEU-MET-FAST-061. The ZPPR-21 series began with a fissile core containing only plutonium, and gradually substituted highly-enriched uranium metal for some of the plutonium metal until the final configuration contained only uranium.

5.1.2 Plutonium Oxide Systems

A set of thirty-four experiments involve plutonium oxide that has been mixed with various quantities of polystyrene, and then compacted into cubes. These cubes are stacked in arrays to form critical configurations with or without Plexiglas reflection. Five unreflected experiments are taken from PU-COMP-MIXED-001, and twenty-nine experiments from PU-COMP-MIXED-002. The H/Pu ratios in these compacts range from 0.04 to 49.6, giving a range of fission neutron spectra from fast to thermal.

One benchmark using plutonium oxide, graphite, and boron was included from PU-COMP-INTER-001. This benchmark describes a system with a k_{inf} of one, and is interpolated from measured reactivity worths for a number of fuel samples with varied boron content. With an energy of average lethargy causing fission (EALF) of approximately 300 eV, this benchmark was chosen to represent the dry plutonium oxide powders in applications AOA(3)–1 through AOA(3)–3.

5.2 MIXED PLUTONIUM AND URANIUM SYSTEMS

Two hundred and thirty-seven mixed plutonium and uranium systems are included in this set of benchmarks. These experiments involve solution systems, fuel pin lattices, solid mixed-oxide systems moderated by polystyrene, and mixed metal systems.

5.2.1 Mixed Plutonium and Uranium Solution Systems

Thirteen experiments with mixed plutonium and uranium solution in annular cylinder geometry are taken from MIX-SOL-THERM-001. The ratio of Pu/(U+Pu) is 0.22 or 0.97, and the concentration of the solution in the annular region is varied from 61 to 489 g (U+Pu)/liter. All experiments use a water reflector.

Three experiments with similar solution in large cylindrical geometry are from MIX-SOL-THERM-002. The objective of these experiments was to obtain data on the minimum fissile concentration for criticality in an effectively infinite cylindrical geometry. The reaction vessel has an inside diameter of 68.68 cm. The concentrations of the solution are 23 and 53 g (U+Pu)/liter with a ratio of Pu/(Pu + U) of 0.52 and 0.23, respectively. All three experiments are water reflected.

Nine experiments from this same series that use small cylindrical geometry are also included from MIX-SOL-THERM-004. The reaction tank has an inside diameter of 35.39 cm and inside height of 106.60 cm. The concentrations of the solution are 105, 293, and 435 g (U+Pu)/liter with a ratio of Pu/(U+Pu) of 0.4 for all nine experiments. Three measurements have a water reflector, three have a concrete reflector, and three have no reflector.

Seven experiments with mixed plutonium and uranium solution in slab geometry are taken from MIX-SOL-THERM-005. The solution concentration ranged from 105 to 435 g (U+Pu)/liter with a ratio of Pu/(U+Pu) of 0.4. Four experiments were water-reflected, and four were bare.

5.2.2 Mixed Plutonium and Uranium Fuel Pin Lattices

Four experiments using natural UO_2–20 wt. % PuO_2 (11.5 wt. % ^{240}Pu) fuel pins in a square lattice were analyzed (MIX-COMP-THERM-001). These experiments used water reflection, and incorporated polypropylene grid plates to minimize the effect of the grids on the reactivity of the core. The pitch was varied from 0.95 to 1.9 cm.

Six experiments with natural UO_2-2 wt. % PuO_2 (8% ^{240}Pu) fuel include square-pitched lattices, with 0.70-inch, 0.87-inch, or 0.99-inch pitch, in borated or pure water moderator (MIX-COMP-THERM-002). These experiments are also referred to as PNL 30-35 in NUREG/CR-0210 in the CSEWG Thermal Reactor Benchmarks (BNL-19302).

Six more experiments with natural UO_2-6.6 wt. % PuO_2 fuel include square-pitched, partial-moderator-height lattices with five lattice pitches of 0.52 inch, 0.56 inch, 0.735 inch, 0.792 inch, and 1.04 inch (MIX-COMP-THERM-003). The purpose of these experiments was to verify the nuclear design of the Saxton partial plutonium core, which consisted of MOX assemblies in the central region with peripheral enriched UO2 assemblies. The experiments with 0.56-inch-pitched lattices were performed with borated or pure water moderator, but the other pitched-lattice experiments were performed only with pure water moderator.

Eleven experiments conducted at the Tokai Research Establishment of JAERI in Japan used natural UO_2 – 3.01 wt. % PuO_2 rods in square arrays of varying pitch (MIX-COMP-THERM-004). The plutonium in the fuel pins contained 24 wt. % ^{240}Pu.

Forty-one experiments from the Plutonium Utilization Program at Pacific Northwest Laboratories are included (MIX-COMP-THERM-005, MIX-COMP-THERM-008, and MIX-COMP-THERM-009). These experiments were performed using MOX fuel with PuO_2 enrichments varying from 1.5 to 4 wt. % PuO_2, and the ^{240}Pu isotopic composition of the plutonium was varied from 8% to 24%. The fuel pins are arranged in hexagonal lattices with varying pitches with the rods uniformly arrayed in such a manner that the core is a right circular cylinder.

Six benchmark experiments using MOX fuel designed for the RAPSODIE fast breeder reactor in Cadarache, France are included from MIX-COMP-THERM-011. The uranium was enriched to 60 wt. % ^{235}U, and the plutonium content of the MOX fuel was 25.8 wt. %, with 9.72 wt. % of the plutonium being ^{240}Pu. The pitch was triangular, and measured either 1.9 cm or 2.5 cm.

5.2.3 Mixed Plutonium and Uranium Solid Systems

Several experiments using various combinations of plutonium oxide, depleted uranium oxide and polystyrene, which had been pressed into compacts and stacked into arrays, are included in this database. They are included in MIX-COMP-THERM-012 and three other published references that have not yet been included in the IHECSBE. The configurations are similar to those in PU-COMP-THERM-001 and -002, but with MOX instead of plutonium oxide. There are both reflected and unreflected arrays, and some of the stacked arrays contain neutron poison plates.

There are thirty-three experiments included from MIX-COMP-THERM-012. These configurations contain mixtures of plutonium and DU oxides containing between 7.6 and 30 wt. % plutonium, with H/X ratios from 19.5 to 51.8. Six experiments with 7.6 wt. % plutonium used plutonium that contains 23 wt. % ^{240}Pu. The other experiments use plutonium with 8 wt. % ^{240}Pu. Twenty-seven experiments are Plexiglas-reflected, while six are bare.

Fourteen other experiments were done with a similar range of plutonium oxide concentrations, but with much lower moderation levels [23]. These experiments also utilize compacts with between 7.6 and 30 wt. % plutonium, and H/X ratios ranging from 3 to 7. The plutonium contained 11.5 wt % ^{240}Pu. Only the Plexiglas-reflected configurations from this reference are included. In the attached tables, these experiments are labeled PU-8-1 through PU-8-4, PU-15-1, and PU-29-1 through PU-29-9. However, the result for case PU-15-1 is not included as a candidate benchmark experiment since it is based on only a single experiment with this fuel configuration, and the indicated experimental uncertainty in the result suggests that the resulting benchmark is unreliable.

Thirty-two experiments were performed with MOX-polystyrene compacts in arrays that contained either one or two copper, copper/cadmium, or aluminum plates of varying thickness within the stack [22]. All of these experiments were fully reflected with Plexiglas. Two types of fuel were used in these experiments. The first contained MOX with a plutonium content of

14.6 wt. %, of which 7.97 wt. % was ^{240}Pu, and with an H/X of 30.6. The second type of fuel contained MOX with a plutonium content of 30.3 wt. %, of which 11.5 wt. % was ^{240}Pu, and with an H/X of 2.8. Twenty-two experiments contained the fuel with an H/X of 30.6, and ten experiments used the fuel with an H/X of 2.8. These experiments are labeled NSE55Tx-xx in subsequent sections of this report.

Fifty experiments were performed using these same two fuel compositions, but with other types of neutron poison plates contained with the array stacks. All of these experiments were also fully reflected with Plexiglas [24]. The poison plate materials included Type 304 stainless steel, steel with 1.1 wt. % boron, steel with 1.6 wt. % boron, boral, lead, depleted uranium, cadmium, and aluminum. Thirty-one independent experiments were performed with the fuel with an H/X of 30.6. In the case of the fuel with an H/X of 2.8, the nineteen configurations used some of the fuel with an H/X of 30.6 as a driver. An 8 × 8 × 2 array of the lower moderated fuel was used above and below the neutron poison plate, and on top of this was placed at least two layers of the higher moderated fuel. The thickness of driver fuel was varied to achieve criticality with the various neutron poison plate materials and thicknesses. The reference states that the neutron flux in the region containing the poison plate was characteristic of the lower-moderated fuel, and that less than 30% of the fissions occurred in the higher-moderated fuel. However, when using these experiments as critical benchmarks, the importance of the more moderated fuel is significant, and the overall flux is more thermal than the experiments using only the lower-moderated fuel. These experiments are labeled BNWL2129Tx-xx in subsequent sections of this report.

5.2.4 Mixed Plutonium and Uranium Metal System

A set of four mixed plutonium and uranium metal systems was analyzed as a means of including homogeneous uranium/plutonium systems with a fast energy spectrum. These experiments are documented in MIX-MET-FAST-011, and are part of the ZPPR-21 series of experiments that also include PU-MET-FAST-033 and HEU-MET-FAST-061. As described previously, the ZPPR-21 series began with a fissile core containing only plutonium, and gradually substituted highly enriched uranium metal for some of the plutonium metal until the final configuration contained only uranium. (The last configuration is described in HEU-MET-FAST-061, and was not included in this database since it did not pertain to any of the applications of interest.) The four experiments in MIX-MET-FAST-011 contain between 41.4 and 7.7 wt. % plutonium metal, which included between 6.16 and 11.6 wt. % ^{240}Pu. The bulk of the neutron spectrum is in the 100-keV to 4-MeV energy range and the peak is at about 600 keV. Thus, the spectrum is in the fast range, although not as hard as the spectrum in many other fast metal assemblies.

5.3 LOW-ENRICHED URANIUM OXIDE SYSTEMS

In order to include experiments with low-enriched uranium oxide at low moderation levels, eighteen experiments from LEU-COMP-THERM-049 were placed in the database. These models primarily assist in validating ^{238}U capture and fission cross-sections in the higher neutron energy region. The experiments were performed under the MARACAS program at the Valduc facility in France. The uranium dioxide was enriched to 5 wt. % ^{235}U, and was moderated to an H/X of between 2 and 3. Uranium dioxide powder was moistened and contained in metal boxes, which were placed in various sized arrays on a split table, and the overall configuration was reflected with polyethylene. The overall neutron spectrum is thermal but has a significant intermediate energy component.

5.4 ESTABLISHING VALIDATED AREA OF APPLICABILITY

The benchmark experiments identified by the S/U technique have widely varying ranges of key parameters. This variation suggests that traditional characterization of the validated AOA based on parameter ranges of benchmark experiments may not be appropriate. Instead, a much more restrictive definition of the AOA is adopted based on key parameter ranges of the design applications used as *input* to the S/U analysis. A description of the key parameters of these design applications is presented in Table 5-1 (for PuO_2 powders) and Table 5-2 (for MOX powders).

One qualitative parameter defining the AOA requires special attention. The geometric form of the material is characterized simply based on whether the fissile material is a single contiguous mass or an array of such masses. Since the Monte Carlo technique treats geometry exactly, no bias is associated with the specific geometry of the system. Instead, due to the multigroup energy treatment employed in KENO-VI, the potential for code bias exists as a result of the resonance processing performed in the Material Information Processor (MIP) of SCALE. In the case of arrays of, for example, pellets, the LATTICECELL option is typically employed, and this resonance treatment model includes approximations such as Dancoff corrections and simplified geometric models which may contribute to code bias. For single contiguous units or for arrays of large units such as jars or cans of powder which are typically 10-50 cm in diameter, the INFHOMMEDIUM treatment is used. While this approach itself may contribute a bias, the important distinction is that the validated geometric forms use the same INFHOMMEDIUM model as the design application models input to the S/U analysis, and hence the potential bias has been accounted for in the S/U analysis. With respect to the validated AOAs defined in Table 5-1 and Table 5-2, the input design applications consist of spherical geometry, but the validated AOA is considered to cover other forms of contiguous units including general parallelepipeds and arrays of large cylinders, which are the subject of this validation report also. Observe that these particular geometric forms are also represented in the benchmark experiment set.

Generally, the resulting validated AOA contain the corresponding key parameters of the anticipated design applications for which the code system will be used to determine reactivity. In some cases, parameter values for design applications may fall outside the validated area of applicability. In these cases, DCS commits to identifying additional margin, referred to as AOA margin, in the associated calculations or NCSEs, consistent with the approach described in NUREG-6698. The required margin is typically quantified by extrapolating observed trends in the bias as a function of the parameter.

Table 5-1 AOA(3) Comparison of Key Parameters and Definition of Validated AOA

Parameter	Design Application (cf. Table 4-1)	Benchmarks	Validated AOA (cf. Table 3-3)
Geometric shape	Parallelepipeds Arrays of cylinders Spheres	Parallelepipeds Arrays of cylinders Spheres	Parallelepipeds Arrays of cylinders Spheres
Absorber/reflector	Water, Cd, Concrete	Plexiglas, air, water	Water
Chemical form	PuO_2 powder	PuO_2 in polystyrene (C_8H_8) Pu-metal in air/water	PuO_2 powder
Isotopic composition	4 wt. % ^{240}Pu	2.2 wt. % to 20.2 wt. % ^{240}Pu	4 wt. % ^{240}Pu
H/Pu	1.16 to 5.97	0 to 210	1.58 to 5.99
EALF [eV]	3.1 to 65000	1 to 10^6	94 to 1019[1]

[1] The range of EALF used in the "typical design applications" used in the S/U determination of benchmarks as shown in Table 3-3, 94-1019 eV, does not encompass the full anticipated range in the design applications, 3.1-65000 eV, as shown above. However, as shown above, the range of EALF of the benchmarks actually used (1-10^6 eV) clearly encompasses the range of the design applications. Additionally, as shown in Figure 6-2, the trend of k_{eff} as a function of EALF shows that between 94-1019 eV and the anticipated range of the calculations, 3-1-65000 eV, the changes in keff are small (less than about 0.004). Further, the full range of the benchmarks (1-10^6 eV) is well represented by data points throughout the range. Thus the use of extrapolation, as discussed in Section 5.4, is applicable.

Table 5-2 AOA(4) Comparison of Key Parameters and Definition of Validated AOA

Parameter	Design Application (cf. Table 4-2)	Benchmark	Validated AOA (cf. Table 3-7)
Geometrical shape	Parallelepipeds Spheres	Parallelepipeds Arrays of pins	Parallelepipeds Spheres
Absorber/reflector	Water	Plexiglas	Water Depleted Uranium
Chemical form	MOX powder	MOX and PuO_2 powder in polystyrene Water moderated MOX fuel pins	MOX powder
Pu/(U+Pu) composition	6.3 or 22 wt. %	1.5 to 100 wt.%	6.3 or 22 wt. %
Isotopic composition	4 wt. % ^{240}Pu	2.2 to 11.6 wt. % ^{240}Pu	4 wt. % ^{240}Pu
H/(U+Pu)	1.15 to 1.58	0[1] to 31	0.3 to 1.58
EALF [eV]	0.8 to 175	0.6 to 1740	28 to 3751

[1] Moderated arrays of fuel pins

6. ANALYSIS OF VALIDATION RESULTS

6.1 DESIGN APPLICATION (3) – PuO_2 POWDER

The benchmark experiments identified using the S/U technique are modeled with CSAS26/KENO VI using the 238 group library 238GROUPNDF5. The calculated k_{eff} values for selected benchmark experiments are presented in Table 3-4 through Table 3-6.

Figure 6-1 shows the distribution of calculated k_{eff} values for the experiments as calculated with SCALE 4.4a (KENO-VI Update 3) on the PC platform. The k_{eff} values are first analyzed statistically using the USLSTATS computer code[2]. However, the data fails the test for normality employed in that analysis. Hence, the nonparametric technique described in Section 3.2.3 is employed.

With a total of 90 unique experiments for this AOA, the degree of confidence, β, obtained from Equation 3.3 is 99.0%. Hence, the required nonparametric margin obtained from Table 3-1 is 0.0. The minimum computed benchmark k_{eff} is 0.9876 ± 0.0006 obtained for case PMF003-03 [5]. The experimental uncertainty determined for this case in the Handbook evaluation [5] is 0.0030. The resulting combined uncertainty associated with this benchmark calculation is

$$\sqrt{0.0030^2 + 0.0006^2} = 0.0031$$

The resulting USL for AOA(3) is then determined from Equation 3.1 as

USL = Smallest k_{eff} value – Uncertainty for smallest k_{eff} – Nonparametric margin – Δk_m

$$\text{USL AOA(3)} = 0.9876 - 0.0031 - 0.0 - 0.05 = 0.9345$$

This USL is applicable for design applications falling within the validated range of key parameters shown in Table 5-1. For design applications outside the AOA, ANSI/ANS 8.1-1998 [2] permits extension of the AOA based on observed trends in the bias as a function of the extended parameter. In order to establish these trends, computed k_{eff} results are plotted as a function of trending parameter in Figure 6-2 through Figure 6-4. To facilitate trending analysis, the plotted data is fitted linearly, and the resulting regression formula is shown in each figure. Data for EALF is fitted logarithmically due to the extended range of the parameter.

The USL for AOA(3) is 0.9345. This value includes a 0.05 administrative margin and consideration for calculational bias and allowance for uncertainties. Justification for an administrative margin of 0.05 is provided in Section 7.1.

---

[2] Many of the benchmark experiments in the International Handbook of Evaluated Criticality Safety Benchmark Experiments (Nuclear Energy Agency 1999) are considered to be critical (i.e., $k_{eff} = 1.000$), while other experiments are not considered critical (i.e., $k_{eff} \neq 1.000$). Therefore, all calculated k_{eff} values are normalized to the handbook values.

6.2 DESIGN APPLICATION (4) – MOX POWDER

The benchmark experiments identified using the S/U technique for AOA(4) are modeled with CSAS26/KENO VI using the 238 group library 238GROUPNDF5. The calculated k_{eff} values for selected benchmark experiments are presented in Table 3-8 through Table 3-14.

Figure 6-5 shows the distribution of calculated k_{eff} values for the experiments as calculated with SCALE 4.4a (KENO-VI Update 3) on the PC platform. The k_{eff} values are first analyzed statistically using the USLSTATS computer code. Although the data passes the test for normality employed in that analysis, visual inspection of the double-peaked histogram shown in Figure 6-5 suggests that an assumption of normality for this data is inappropriate. Hence, the nonparametric technique described in Section 3.2.3 is employed.

With a total of 66 unique experiments for this AOA, the degree of confidence, β, obtained from Equation 3.3 is 96.6%. Hence, the required nonparametric margin obtained from Table 3-1 is 0.0. The minimum computed benchmark k_{eff} is 0.9881 ± 0.0006 obtained for case PCM001-004 [5]. The experimental uncertainty determined for this case in the Handbook evaluation [5] is 0.0058. The resulting combined uncertainty associated with this benchmark calculation is

$$\sqrt{0.0058^2 + 0.0006^2} = 0.0058$$

The resulting USL for AOA(4) is then determined from Equation 3.1 as

USL = Smallest k_{eff} value – Uncertainty for smallest k_{eff} – Nonparametric margin – Δk_m

$$\text{USL AOA(4)} = 0.9881 - 0.0058 - 0.0 - 0.05 = 0.9323$$

This USL is applicable for design applications falling within the range of key parameters shown in Table 5-2. For design applications outside the AOA, ANSI/ANS 8.1-1998 [2] permits extension of the AOA based on observed trends in the bias as a function of the extended parameter. In order to establish these trends, computed k_{eff} results are plotted as a function of trending parameter in Figure 6-6 through Figure 6-10. To facilitate trending analysis, the plotted data is fitted linearly, and the resulting regression formula is shown in each figure. Data for EALF is fitted logarithmically due to the extended range of the parameter.

The USL for AOA(4) is 0.9323. This value includes a 0.05 administrative margin and consideration for calculational bias and allowance for uncertainties. Justification for an administrative margin of 0.05 is provided in Section 7.1.

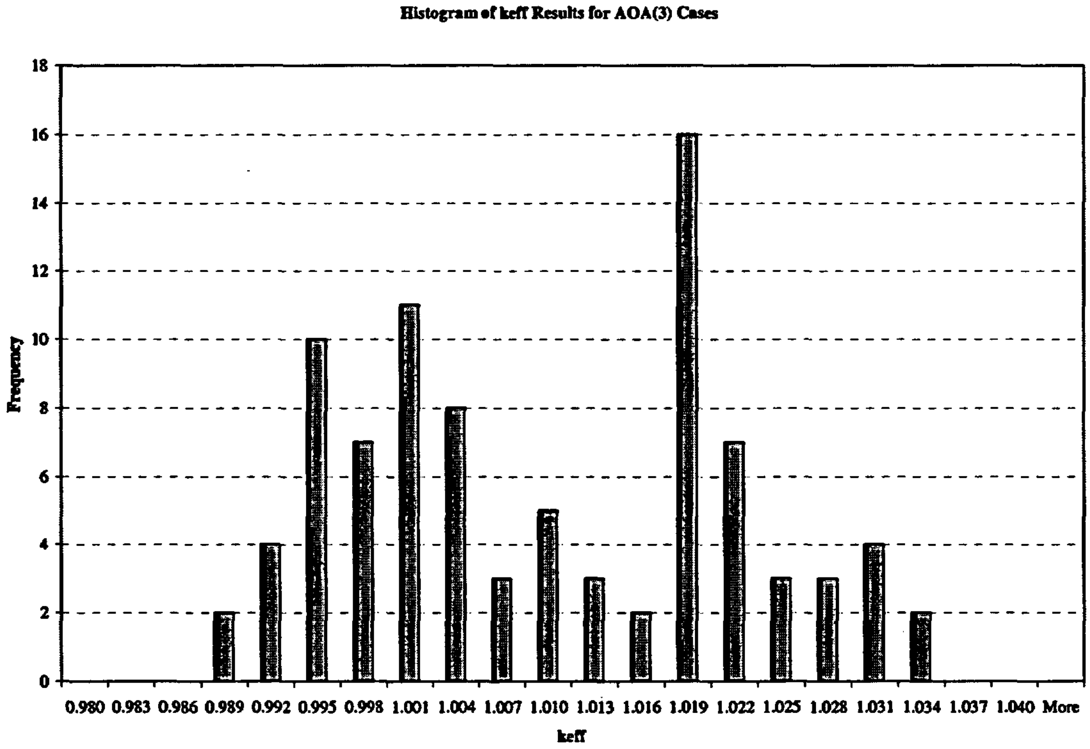


Figure 6-1 Histogram of k_{eff} occurrences for AOA(3)

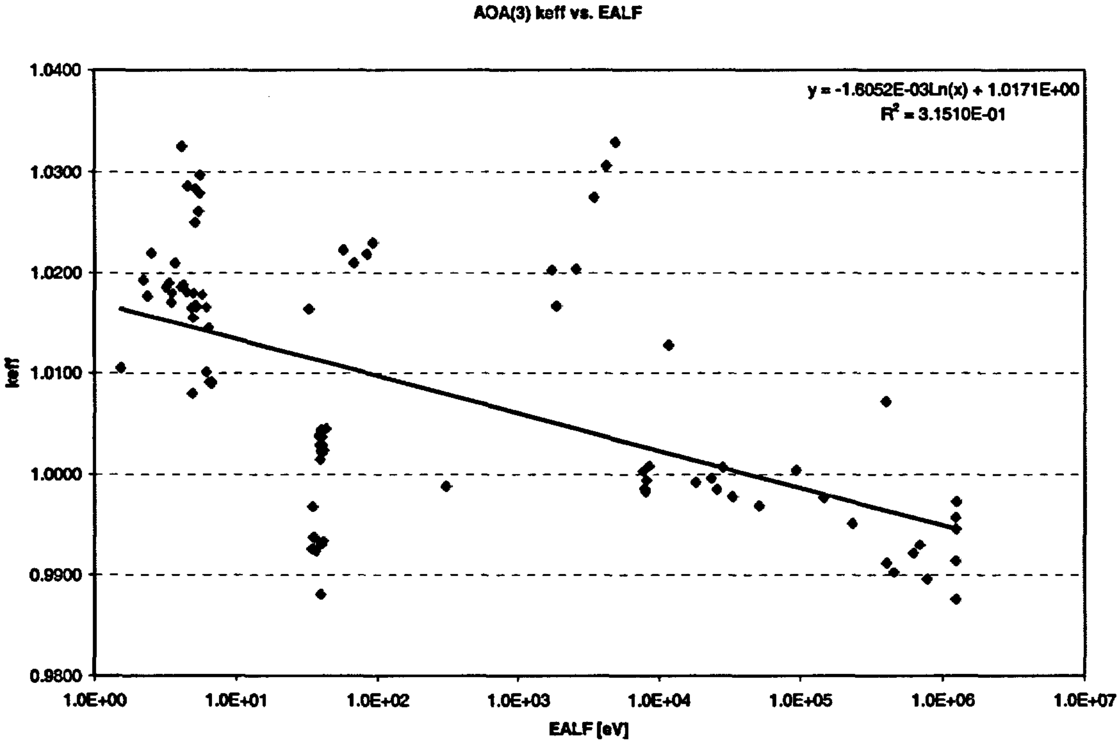


Figure 6-2 AOA(3) k_{eff} as a function of EALF

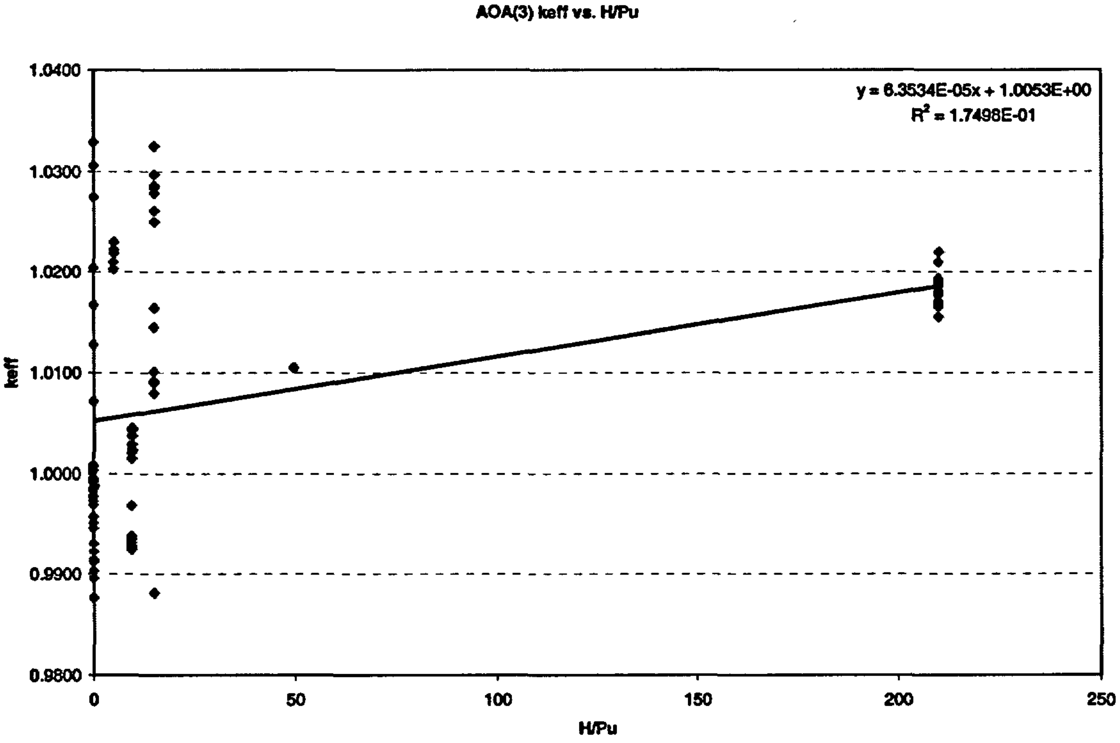


Figure 6-3 AOA(3) k_{eff} as a function of H/Pu

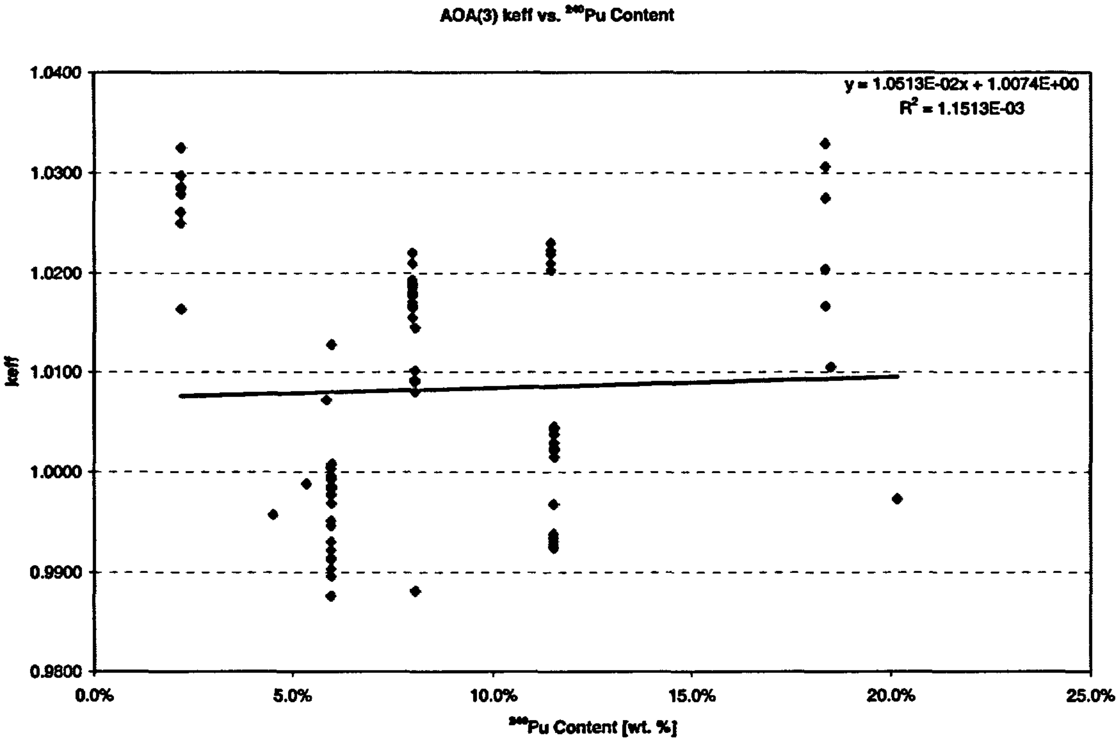


Figure 6-4 AOA(3) k_{eff} as a function of ^{240}Pu content

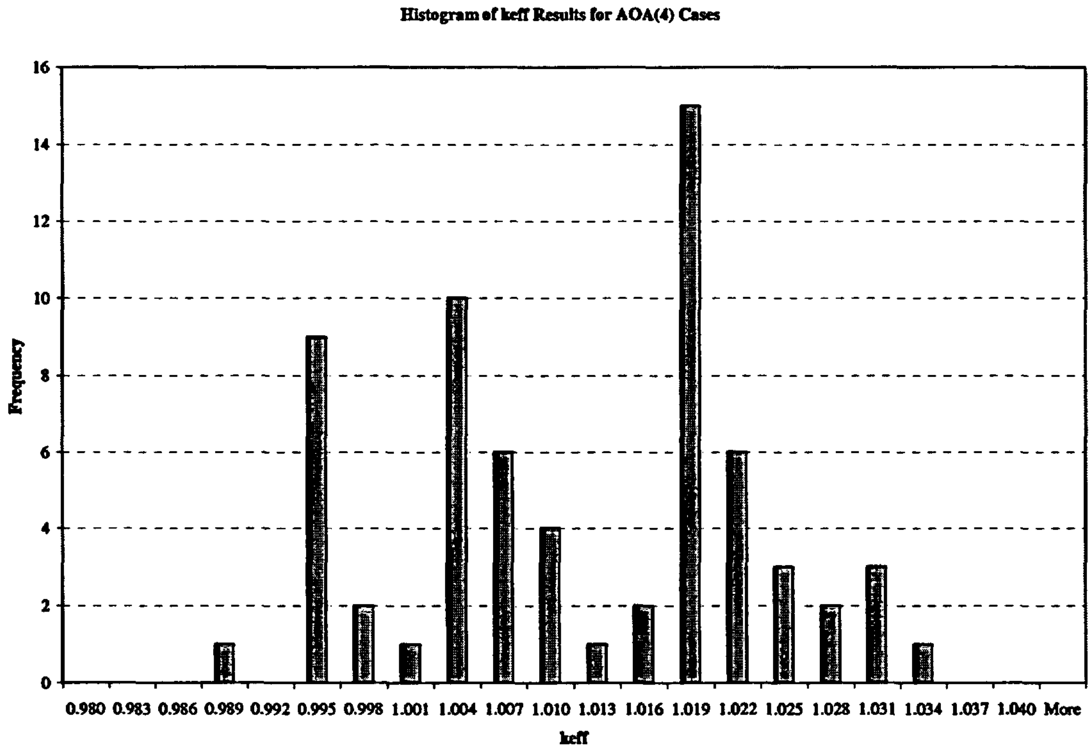


Figure 6-5 Histogram of k_{eff} occurrences for AOA(4)

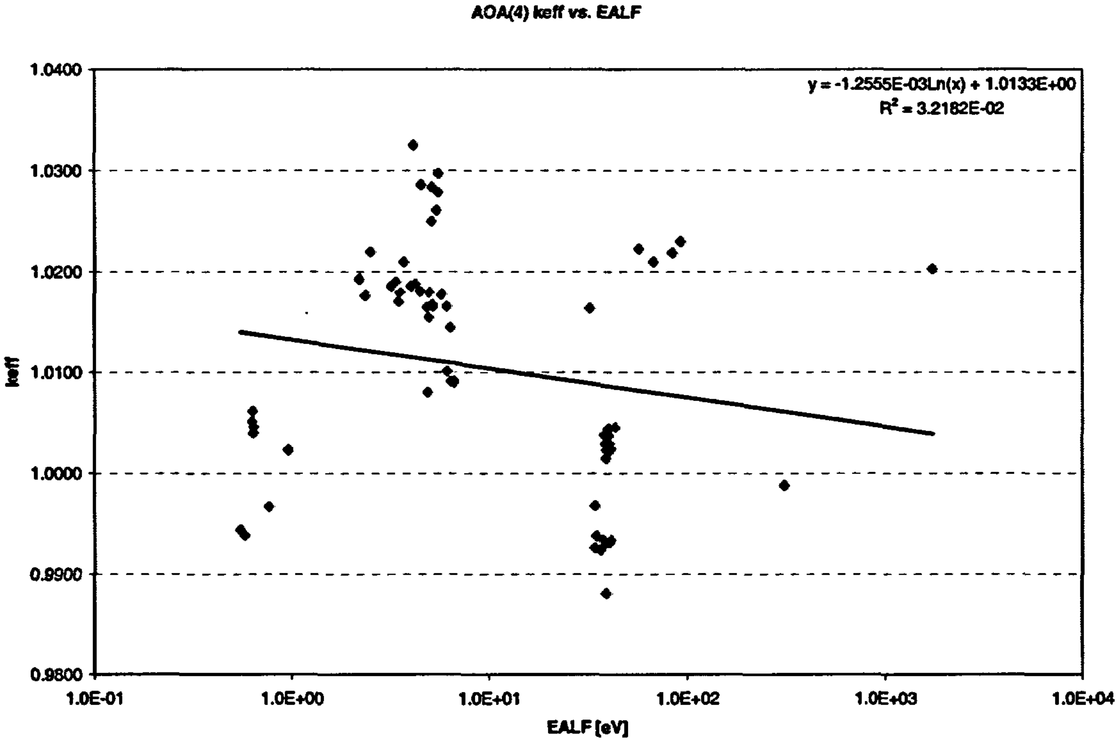


Figure 6-6 AOA(4) k_{eff} as a function of EALF

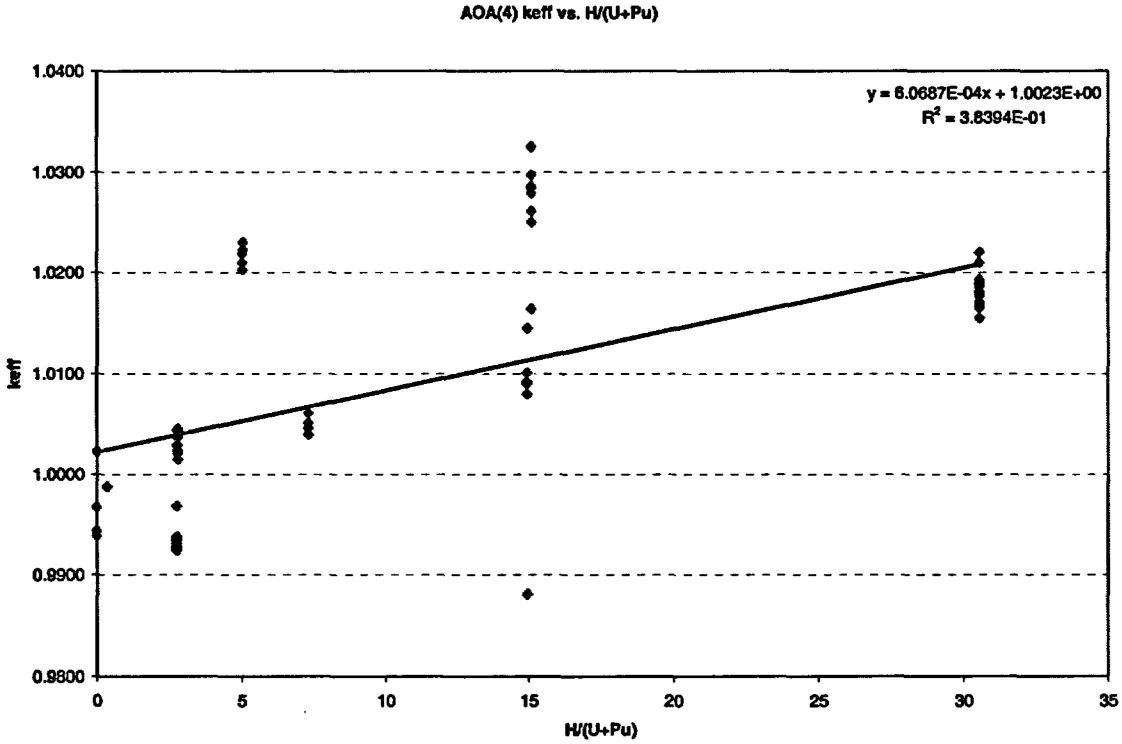


Figure 6-7 AOA(4) k_{eff} as a function of H/(U+Pu)

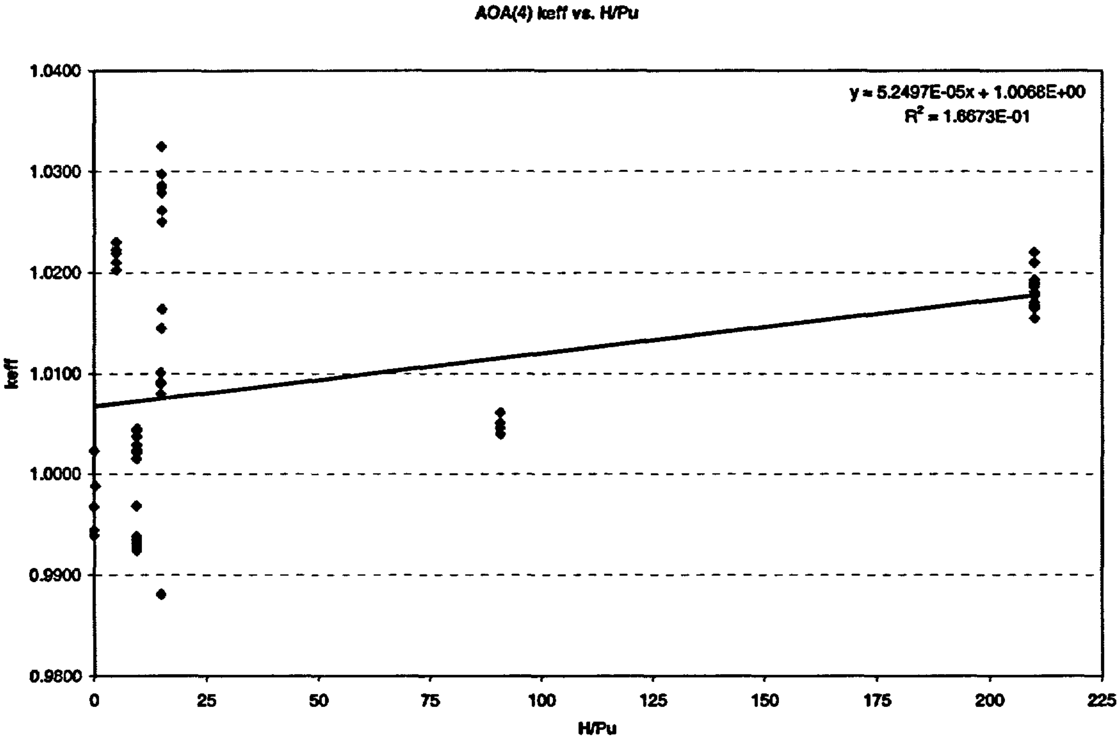


Figure 6-8 AOA(4) k_{eff} as a function of H/Pu

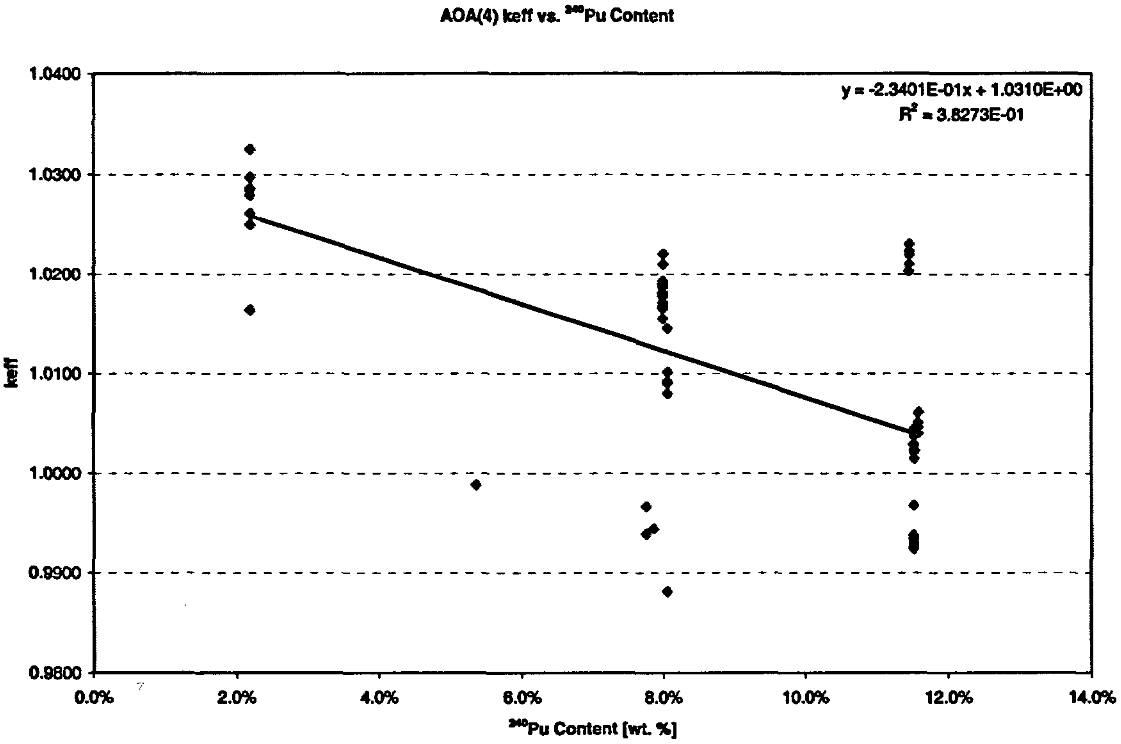


Figure 6-9 AOA(4) k_{eff} as a function of ^{240}Pu content

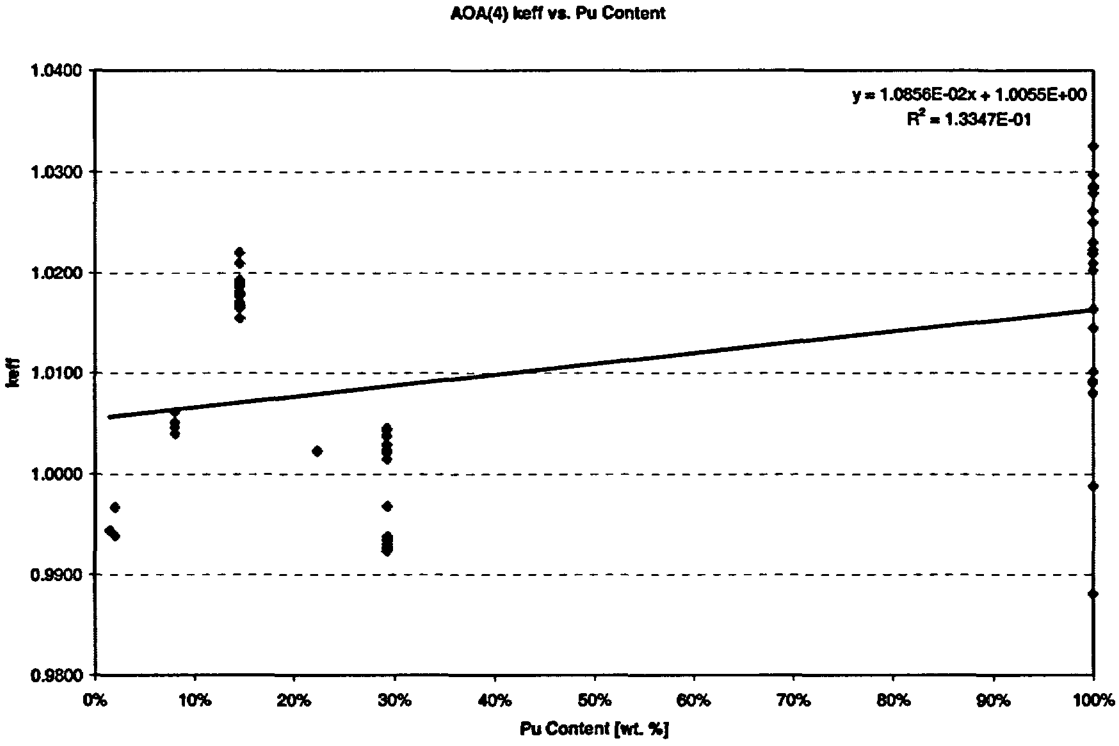


Figure 6-10 AOA(4) k_{eff} as a function of Pu content

7. CONCLUSIONS

The SCALE 4.4a code package using the CSAS26 (KENOVI) sequence and the 238 energy group cross section library 238GROUPDF5 has been validated to perform criticality calculations for the MFFF on the PC platform. It has been validated for two of the design applications: AOA(3) PuO_2 powder and AOA(4) MOX powder.

The USL for the two design application areas is as follows:

- Design application (3) PuO_2 powder USL AOA(3) = 0.9345
- Design application (4) MOX powder USL AOA(4) = 0.9323

The USL accounts for the computational bias, uncertainties, and an administrative margin. The administrative margin is established at 0.05 such that $k_{eff} + 2\sigma - bias \leq 0.95$ for all normal and credible abnormal conditions. Section 7.1 contains a detailed justification of the administrative margin.

Where extrapolation outside the range of applicability for AOA(3) or AOA(4) is necessary, ANSI/ANS-8.1 [2] allows extrapolating the trends established for the bias and USL. Results presented here provide the required trending regressions for determining adjusted USL values. If extrapolation is necessary, it will be discussed on a case-by-case basis in the respective calculation.

7.1 JUSTIFICATION FOR ADMINISTRATIVE MARGIN

The administrative margin applied in the determination of the USL is intended as an added level of conservatism. The code validation effort accounts for all code bias and the effects of both code and experimental benchmark uncertainties. The administrative margin is applied *in addition* to the code bias and bias uncertainty in determining the USL.

The USL values determined here are based on an administrative margin of 0.05. Based on actual process conditions, including 1) the degree to which application parameters fall within the validated Area of Applicability (AOA) of the calculational method and 2) the results of sensitivity analyses demonstrating the sensitivity of k_{eff} values to variations in controlled parameters, the USL may be adjusted. Each NCSE and criticality calculation will include a discussion of the appropriateness of the USL applied for each specific design application.

Typically, the NCSEs and criticality calculations will present k_{eff} results for various scenarios, including normal operation and credible abnormal situations. The results of these analyses permit a quantitative assessment of the degree of subcriticality of the system measured in terms of variation of one or more controlled parameters. Hence, the NCSEs/criticality calculations for specific design applications will verify the conformance with the AOA used in the validation reports.

In general, based on the discussion below, the administrative margin used in criticality analyses is 0.05. This assessment is based on a comparison against administrative margin practices at both NRC and DOE facilities, and past NRC guidance and practice, and is further substantiated by a statistical analysis of the benchmark validation results.

7.1.1 Fuel Cycle and Industry Practice

A review of NRC materials licensees and analogous DOE facilities (including plutonium facilities) indicates that administrative margins for accident analysis conditions range from 0.02 to 0.05 as shown in Table 7-1. These values apply to applications within the validated AOAs; adjustments to the administrative margin are typically made for application outside the validated region.

These values are consistent with precedent information provided by the NRC Staff [20], which indicates administrative margins with a similar range to those indicated in Table 7-1.

An administrative margin of 0.05 is greater than or equal to the most conservative margins identified in Table 7-1 and other NRC precedent [20] for analysis of credible abnormal conditions.

This margin is consistent with guidance provided in NUREG-1718 [3], which supports an administrative margin of 0.05 for the MFFF. It is also consistent with past NRC-accepted practice in reactor operations (10 CFR 50) [19], and transportation (10 CFR 71) and on-site storage (10 CFR 72) of spent nuclear fuel. Examination of various precedents indicates 0.05 is a conservative administrative margin for activities falling within the validated AOA. For criticality analyses applied outside the validated AOA, specific guidance is provided in ANSI/ANS-8.1–1998 which indicates that the administrative margin may be adjusted based on established trends in the bias, if necessary.

7.1.2 Summary of Administrative Margin Practice

This effort involves the validation of the code to applications within one or more specific areas of applicability. There is no intent to account for or to address the uncertainties and unknowns involved in the actual design applications. This approach is consistent with NUREG/CR-6698 which states "*the subcritical margin is not intended to account for process upset conditions or for uncertainties associated with a process.*" These issues are properly addressed in the nuclear criticality safety evaluations (NCSEs). These evaluations will demonstrate that the design application falls within the required AOA, that design uncertainties and unknowns are properly and conservatively addressed, that sensitivity to controlled parameters is adequately addressed, and that the criticality models themselves are suitably conservative representations of the actual physical phenomena. In cases where calculated k_{eff} values are shown to be sensitive to controlled parameters, the NCSE will demonstrate the adequacy of the control.

In conclusion, an administrative margin of 0.05, selected on the basis of NRC guidance and conservative comparison with applicable precedent is justified, and is sufficiently conservative to provide for an adequate margin of subcriticality.

Table 7-1 Fuel Cycle and Industry Practice

Facility	Process/Application	Material	Administrative Margin
Framatome Cogema Fuels	Fuel assembly manufacture	Low enriched U	0.05
Westinghouse Columbia Site	Fuel assembly manufacture	Low enriched U	0.02
Nuclear Fuel Services	Fuel processing (solutions, powder, pellets, etc.)	Various U enrichments	0.03 LEU 0.05 HEU
Paducah Uranium Enrichment Plant	Uranium enrichment	Low enriched U	0.02
Rocky Flats	Weapons material processing	Plutonium	0.03
BWXT	Fuel assembly manufacture	Low to High Enriched U	0.03 LEU 0.05 HEU
Savannah River Site	a) MTR fuel assemblies b) Pipe overpack material storage c) Mark 42 tube dissolution d) Ion exchange columns with fissile solutions e) DDF-1 package	a) High enriched U b) ^{239}Pu c) ^{239}Pu d) ^{239}Pu solution e) Pu metal and oxide	a) 0.02 b) 0.02 c) 0.05 d) 0.04 e) 0.05
Y-12	Weapons material processing	High enriched U	0.02 – 0.05[1]
Idaho National Engineering and Environmental Lab	Solutions/spent fuel/powders/pieces	Low to High Enriched U, including ^{233}U;some Pu	0.02 – 0.05 0.05 typical
Hanford Site	Waste tanks Packaging and transportation	Various	0.05

[1] Pending final approval of validation document.

8. REFERENCES

[1] SCALE 4.4 : A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation, NUREG/CR-0200 (ORNL/NUREG/CSD-2/R6), Volumes I, II and III. Available from Radiation Shielding Information Center as CCC-545.

[2] ANSI/ANS (American National Standards Institute/American Nuclear Society), 1998. American National Standard for Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors, ANSI/ANS–8.1–1998, La Grange Park, IL.

[3] NRC (U.S. Nuclear Regulatory Commission), 2000. Standard Review Plan for the Review of an Application for a Mixed Oxide (MOX) Fuel Fabrication Facility, NUREG-1718, U.S. Nuclear Regulatory Commission, Washington, DC.

[4] Verification of the SCALE 4.4a Code Package on SGN Pentium PCs, SGN Document NT 12046 00 028 A.

[5] Nuclear Energy Agency, 1999. International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC(95)03, Nuclear Energy Agency, Organization for Economic Co-operation and Development.

[6] Emmett, M.B., and W.C. Jordan, 1996, Guide to Verification and Validation of the SCALE-4 Criticality Safety Software, NUREG/CR-6483 (ORNL/TM-12834), Lockheed Martin Energy Research Corp., Oak Ridge National Laboratory, Oak Ridge, TN.

[7] Neutronics Benchmarks for the Utilization of Mixed-Oxide Fuel: Joint U.S./Russian Progress Report for Fiscal Year 1997, Prepared by the Staffs of the Oak Ridge National Laboratory and the Amarillo National Research Center for Plutonium, Coordinated in the U.S. by R.T. Primm III, ORNL/TM-13603/V2, March 1999.

[8] ANSI/ANS (American National Standards Institute/American Nuclear Society), 1984. Criticality Safety Criteria for Handling Storage, and Transportation of LWR Fuel Outside Reactors, ANSI/ANS-8.17, La Grange Park, IL.

[9] Lichtenwalter, J.J., S.M. Bowman, M.D. DeHart, and C.M. Hopper, 1997. Criticality Benchmark Guide for Light-Water-Reactor Fuel in Transportation and Storage Packages, NUREG/CR-6361 (ORNL/TM-13211), Lockheed Martin Energy Research Corp., Oak Ridge National Laboratory, Oak Ridge, TN.

[10] Dyer, H.R., W.C. Jordan, and V.R. Cain, 1991. A Technique for Code Validation for Criticality Safety Calculations, Trans. Am. Nucl. Soc. 63, 238 (June 1991).

[11] Easter, M.E., 1985. Validation of KENO V.a and Two Cross-Section Libraries for Criticality Calculations of Low-Enriched Uranium Systems, ORNL/CSD/TM-223, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., July 1985.

[12] Bowden D.C. and F.A. Graybill, 1966. Confidence Bands of Uniform and Proportional Width for Linear Models, Am. Stat. Assoc. J. 61, 182 (March 1966).

[13] Johnson, N.L.,1968. Ed., Query, Technometrics 10, 207-209 (February 1968).

[14] Cain, V.R., 1995. A Computer Code to Perform Analyses of Criticality Validation Results, Y/DD-574, Martin Marietta Energy Systems, Inc., Oak Ridge Y-12 Plant, September 1995.

[15] Comparison of original and patched versions of Scale4.4a, Document in preparation.

[16] DCS01 ZJJ CG CAL H 04023 A, Validation of SCALE4.4 and SCALE4.4a for Application to the MOX Fuel Fabrication Facility using the 238 group ENDF/B-V Cross Section Library, Part I: AOA(1) Pu-nitrate solution, AOA(2): MOX Fuel rod lattices

[17] Validation of SCALE4.4 and SCALE 4.4a for Application to the MOX Fuel Fabrication Facility Using the 238 Group ENDF/B-V Cross Section Library Part III: AOA(5) Aqueous solution of Pu compounds, Document in preparation.

[18] J.C. Dean, R.W. Tayloe, Jr., "Guide for Validation of Nuclear Criticality Safety Calculational Methodology," NUREG/CR-6698, Science Applications International Corporation, Oak Ridge, TN, January 2001.

[19] NRC Memorandum, L. Kopp to T. Collins, "Guidance on the regulatory requirements for criticality analysis of fuel storage at light-water reactor power plants," August, 1998.

[20] NRC Letter, A. Persinko to P.S. Hastings, "Nuclear Criticality Safety Staff Qualifications and Administrative Margins for Fuel Fabrication Facilities," 09 November 2001.

[21] B. L. Broadhead, C. M. Hopper, R. L. Childs, and C. V. Parks, Sensitivity and Uncertainty Analyses Applied to Criticality Safety Validation, NUREG/CR-6655, Vols. 1 and 2 (ORNL/TM-13692/V1 and V2), U.S. Nuclear Regulatory Commission, Oak Ridge National Laboratory, November 1999.

[22] S. R. Bierman, and E. D. Clayton, "Critical Experiments to Measure the Neutron Poisoning Effect of Copper and Copper-Cadmium Plates," *Nucl. Sci. Eng.*, 55, pp. 58–66 (1974).

[23] S. R. Bierman and E. D. Clayton, "Critical Experiments with Low-Moderated Homogeneous Mixtures of Plutonium and Uranium Oxides Containing 8, 15, and 30 wt % Plutonium," *Nucl. Sci. Eng.*, 61, pp. 370–376 (1976).

[24] S. R. Bierman, B. M. Durst, and E. D. Clayton, *Critical Experiments Measuring the Reactivity Worths of Materials Commonly Encountered as Fixed Neutron Poisons*, BNWL-2129, Battelle Pacific Northwest Laboratories, October 1976.

[25] B. T. Rearden and K. R. Elam, *Investigations and Recommendations on the Use of Existing Experiments in Criticality Safety Analysis of Nuclear Fuel Cycle Facilities for Weapons-Grade Plutonium*, ORNL/TM-2001/262, Oak Ridge National Laboratory, 2002.

ATTACHMENT NUMBER 1

INPUT AND OUTPUT FILES

The files listed in Figure A7–1 are included on the attached compact disc media.

Figure A7–1 Listing of Files on Attached Media

```
 Volume in drive D is Local Disk
 Volume Serial Number is B177-FD81

 Directory of D:\MFFF

01/02/2003  09:51p      <DIR>          .
01/02/2003  09:51p      <DIR>          ..
01/02/2003  09:51p      <DIR>          Validation
               0 File(s)              0 bytes

 Directory of D:\MFFF\Validation

01/02/2003  09:51p      <DIR>          .
01/02/2003  09:51p      <DIR>          ..
01/02/2003  09:51p      <DIR>          Part2
               0 File(s)              0 bytes

 Directory of D:\MFFF\Validation\Part2

01/02/2003  09:51p      <DIR>          .
01/02/2003  09:51p      <DIR>          ..
01/02/2003  09:51p      <DIR>          Cases
               0 File(s)              0 bytes

 Directory of D:\MFFF\Validation\Part2\Cases

01/02/2003  09:51p      <DIR>          .
01/02/2003  09:51p      <DIR>          ..
01/02/2003  09:51p      <DIR>          PC
               0 File(s)              0 bytes

 Directory of D:\MFFF\Validation\Part2\Cases\PC

01/02/2003  09:51p      <DIR>          .
01/02/2003  09:51p      <DIR>          ..
01/02/2003  09:53p      <DIR>          ornl_HTC
               0 File(s)              0 bytes

 Directory of D:\MFFF\Validation\Part2\Cases\PC\ornl_HTC

01/02/2003  09:53p      <DIR>          .
01/02/2003  09:53p      <DIR>          ..
01/02/2003  10:14p      <DIR>          bnwl-2129
06/19/2002  04:18p                 579 ChangeLog
01/02/2003  10:14p      <DIR>          mct-001
01/02/2003  10:14p      <DIR>          mct-002
01/02/2003  10:14p      <DIR>          mct-009
01/02/2003  10:14p      <DIR>          nse-55
01/02/2003  10:14p      <DIR>          nse-61
01/02/2003  10:14p      <DIR>          pci-001
01/02/2003  10:14p      <DIR>          pcm-001
01/02/2003  10:14p      <DIR>          pcm-002
01/02/2003  10:14p      <DIR>          pmf-001
01/02/2003  10:14p      <DIR>          pmf-002
01/02/2003  10:15p      <DIR>          pmf-003
01/02/2003  10:15p      <DIR>          pmf-016
01/02/2003  10:15p      <DIR>          pmf-017
01/02/2003  10:15p      <DIR>          pmf-033
01/02/2003  10:15p      <DIR>          pmf-037
               1 File(s)            579 bytes

 Directory of D:\MFFF\Validation\Part2\Cases\PC\ornl_HTC\bnwl-2129

01/02/2003  10:14p      <DIR>          .
01/02/2003  10:14p      <DIR>          ..
05/10/2002  03:23p              13,167 bnwl2129t4-01.inp
06/19/2002  03:20p             692,379 bnwl2129t4-01.out
05/10/2002  03:23p              14,807 bnwl2129t4-02.inp
06/19/2002  04:26p             711,993 bnwl2129t4-02.out
05/10/2002  03:24p              14,807 bnwl2129t4-03.inp
06/19/2002  05:31p             712,187 bnwl2129t4-03.out
05/10/2002  03:25p              14,889 bnwl2129t4-04.inp
06/19/2002  06:34p             713,731 bnwl2129t4-04.out
05/10/2002  03:25p              14,889 bnwl2129t4-05.inp
06/19/2002  07:35p             714,723 bnwl2129t4-05.out
05/10/2002  03:41p              14,889 bnwl2129t4-06.inp
06/20/2002  11:37a             715,011 bnwl2129t4-06.out
05/10/2002  03:26p              14,889 bnwl2129t4-07.inp
06/20/2002  12:40p             714,705 bnwl2129t4-07.out
05/10/2002  03:26p              14,889 bnwl2129t4-08.inp
06/20/2002  01:43p             715,396 bnwl2129t4-08.out
05/10/2002  03:27p              15,709 bnwl2129t4-09.inp
06/20/2002  02:47p             764,758 bnwl2129t4-09.out
05/10/2002  03:28p              15,709 bnwl2129t4-10.inp
```

```
06/20/2002  03:51p             765,612 bnwl12129t4-10.out
05/10/2002  03:30p              15,709 bnwl12129t4-11.inp
06/20/2002  04:53p             766,026 bnwl12129t4-11.out
05/10/2002  03:31p              16,611 bnwl12129t4-12.inp
06/20/2002  08:42p             763,147 bnwl12129t4-12.out
05/10/2002  03:32p              17,267 bnwl12129t4-13.inp
06/20/2002  09:43p             765,081 bnwl12129t4-13.out
05/10/2002  03:33p              14,151 bnwl12129t4-15.inp
06/20/2002  10:45p             697,461 bnwl12129t4-15.out
05/10/2002  03:34p              14,233 bnwl12129t4-16.inp
06/20/2002  11:47p             697,777 bnwl12129t4-16.out
05/10/2002  03:35p              14,233 bnwl12129t4-17.inp
06/21/2002  12:50a             698,393 bnwl12129t4-17.out
05/10/2002  03:36p              14,233 bnwl12129t4-18.inp
06/21/2002  01:53a             698,413 bnwl12129t4-18.out
05/10/2002  03:36p              15,217 bnwl12129t4-19.inp
06/21/2002  02:56a             722,402 bnwl12129t4-19.out
              36 File(s)     13,299,493 bytes

 Directory of D:\MFFF\Validation\Part2\Cases\PC\ornl_HTC\mct-001

01/02/2003  10:14p      <DIR>          .
01/02/2003  10:14p      <DIR>          ..
05/14/2002  06:23a              55,397 mct001-01.inp
06/19/2002  07:28p             933,867 mct001-01.out
               2 File(s)        989,264 bytes

 Directory of D:\MFFF\Validation\Part2\Cases\PC\ornl_HTC\mct-002

01/02/2003  10:14p      <DIR>          .
01/02/2003  10:14p      <DIR>          ..
05/14/2002  06:23a              16,611 mct002-01.inp
06/19/2002  08:14p             605,829 mct002-01.out
05/14/2002  06:23a              16,611 mct002-02.inp
06/19/2002  08:46p             614,529 mct002-02.out
               4 File(s)      1,253,580 bytes

 Directory of D:\MFFF\Validation\Part2\Cases\PC\ornl_HTC\mct-009

01/02/2003  10:14p      <DIR>          .
01/02/2003  10:14p      <DIR>          ..
05/21/2002  12:20p             143,908 mct009-01.inp
06/19/2002  10:26p           1,344,732 mct009-01.out
               2 File(s)      1,488,640 bytes

 Directory of D:\MFFF\Validation\Part2\Cases\PC\ornl_HTC\nse-55

01/02/2003  10:14p      <DIR>          .
01/02/2003  10:14p      <DIR>          ..
05/14/2002  06:24a               8,575 nse55t5-01.inp
06/19/2002  11:43p             596,596 nse55t5-01.out
05/14/2002  06:24a              11,281 nse55t5-02.inp
06/20/2002  12:59a             626,092 nse55t5-02.out
05/14/2002  06:24a              11,281 nse55t5-03.inp
06/20/2002  02:15a             626,382 nse55t5-03.out
05/14/2002  06:24a              11,281 nse55t5-04.inp
06/20/2002  03:30a             627,482 nse55t5-04.out
05/14/2002  06:24a              11,609 nse55t5-05.inp
06/20/2002  04:46a             668,740 nse55t5-05.out
05/14/2002  06:24a              11,609 nse55t5-06.inp
06/20/2002  06:01a             669,105 nse55t5-06.out
05/14/2002  06:24a              11,609 nse55t5-07.inp
06/20/2002  07:15a             669,453 nse55t5-07.out
05/14/2002  06:24a              11,445 nse55t5-08.inp
06/20/2002  08:32a             635,555 nse55t5-08.out
05/14/2002  06:24a              11,445 nse55t5-09.inp
06/20/2002  09:49a             635,881 nse55t5-09.out
05/14/2002  06:24a              11,445 nse55t5-10.inp
06/20/2002  11:05a             636,276 nse55t5-10.out
              20 File(s)      6,503,142 bytes

 Directory of D:\MFFF\Validation\Part2\Cases\PC\ornl_HTC\nse-61

01/02/2003  10:14p      <DIR>          .
01/02/2003  10:14p      <DIR>          ..
05/14/2002  06:24a               9,723 pu-29-1.inp
06/20/2002  07:31p             932,891 pu-29-1.out
05/14/2002  06:25a               9,723 pu-29-2.inp
06/20/2002  09:07p             591,248 pu-29-2.out
05/14/2002  06:25a               9,723 pu-29-3.inp
06/20/2002  10:41p             591,847 pu-29-3.out
05/14/2002  06:25a               9,723 pu-29-4.inp
06/21/2002  12:17a             590,913 pu-29-4.out
05/14/2002  06:25a               9,723 pu-29-5.inp
06/21/2002  01:53a             590,908 pu-29-5.out
05/14/2002  06:25a               9,723 pu-29-6.inp
06/21/2002  03:30a             590,799 pu-29-6.out
05/14/2002  06:25a               9,723 pu-29-7.inp
06/21/2002  05:09a             591,435 pu-29-7.out
05/14/2002  06:25a               9,723 pu-29-8.inp
06/21/2002  06:47a             591,791 pu-29-8.out
05/14/2002  06:25a               9,723 pu-29-9.inp
```

```
06/21/2002  08:23a            591,900 pu-29-9.out
05/14/2002  06:25a              9,231 pu-8-1.inp
06/22/2002  02:02a            591,832 pu-8-1.out
05/14/2002  06:25a              9,231 pu-8-2.inp
06/22/2002  03:02a            592,513 pu-8-2.out
05/14/2002  06:25a              9,149 pu-8-3.inp
06/22/2002  04:01a            591,550 pu-8-3.out
05/14/2002  06:25a              9,231 pu-8-4.inp
06/22/2002  05:00a            592,576 pu-8-4.out
              26 File(s)      8,156,552 bytes

 Directory of D:\MFFF\Validation\Part2\Cases\PC\ornl_HTC\pci-001

01/02/2003  10:14p      <DIR>          .
01/02/2003  10:14p      <DIR>          ..
05/14/2002  06:25a              2,179 pci001-01.inp
06/21/2002  01:35p            383,519 pci001-01.out
               2 File(s)        385,698 bytes

 Directory of D:\MFFF\Validation\Part2\Cases\PC\ornl_HTC\pcm-001

01/02/2003  10:14p      <DIR>          .
01/02/2003  10:14p      <DIR>          ..
05/14/2002  06:26a              4,393 pcm001-02.inp
06/21/2002  10:20a            433,357 pcm001-02.out
05/14/2002  06:26a              4,311 pcm001-03.inp
06/21/2002  11:10a            418,321 pcm001-03.out
05/14/2002  06:26a              4,393 pcm001-04.inp
06/21/2002  11:56a            427,072 pcm001-04.out
05/18/2002  10:35p              4,885 pcm001-05.inp
06/21/2002  12:38p            454,026 pcm001-05.out
               8 File(s)      1,750,758 bytes

 Directory of D:\MFFF\Validation\Part2\Cases\PC\ornl_HTC\pcm-002

01/02/2003  10:14p      <DIR>          .
01/02/2003  10:14p      <DIR>          ..
05/18/2002  10:34p              4,475 pcm002-01.inp
06/21/2002  10:55a            419,081 pcm002-01.out
05/18/2002  10:34p              4,475 pcm002-02.inp
06/21/2002  01:10p            419,088 pcm002-02.out
05/18/2002  10:34p              4,475 pcm002-03.inp
06/21/2002  03:24p            418,924 pcm002-03.out
05/18/2002  10:34p              4,475 pcm002-04.inp
06/21/2002  05:38p            419,078 pcm002-04.out
05/18/2002  10:34p              4,475 pcm002-05.inp
06/21/2002  07:51p            419,158 pcm002-05.out
05/14/2002  06:26a              4,475 pcm002-06.inp
06/21/2002  09:38p            422,659 pcm002-06.out
05/14/2002  06:26a              4,475 pcm002-07.inp
06/21/2002  11:25p            422,430 pcm002-07.out
05/14/2002  06:26a              4,475 pcm002-08.inp
06/22/2002  01:12a            422,241 pcm002-08.out
05/14/2002  06:26a              4,475 pcm002-09.inp
06/22/2002  02:58a            423,119 pcm002-09.out
05/14/2002  06:26a              4,393 pcm002-10.inp
06/22/2002  04:39a            407,188 pcm002-10.out
05/14/2002  06:26a              4,393 pcm002-11.inp
06/22/2002  06:20a            407,089 pcm002-11.out
05/14/2002  06:26a              4,393 pcm002-12.inp
06/22/2002  08:02a            407,398 pcm002-12.out
05/14/2002  06:26a              4,393 pcm002-13.inp
06/22/2002  09:44a            407,527 pcm002-13.out
05/14/2002  06:26a              4,393 pcm002-14.inp
06/22/2002  11:25a            407,039 pcm002-14.out
05/14/2002  06:26a              4,393 pcm002-15.inp
06/22/2002  01:07p            407,086 pcm002-15.out
05/14/2002  06:26a              4,393 pcm002-16.inp
06/22/2002  02:49p            406,954 pcm002-16.out
05/14/2002  06:27a              4,393 pcm002-17.inp
06/22/2002  04:26p            416,481 pcm002-17.out
05/14/2002  06:27a              4,393 pcm002-18.inp
06/22/2002  06:02p            415,738 pcm002-18.out
05/14/2002  06:27a              4,393 pcm002-19.inp
06/22/2002  07:38p            416,514 pcm002-19.out
05/14/2002  06:27a              4,393 pcm002-20.inp
06/22/2002  09:14p            416,017 pcm002-20.out
05/14/2002  06:27a              4,393 pcm002-21.inp
06/22/2002  10:50p            416,105 pcm002-21.out
05/14/2002  06:27a              4,393 pcm002-22.inp
06/23/2002  12:26a            415,960 pcm002-22.out
              44 File(s)      9,230,258 bytes

 Directory of D:\MFFF\Validation\Part2\Cases\PC\ornl_HTC\pmf-001

01/02/2003  10:14p      <DIR>          .
01/02/2003  10:14p      <DIR>          ..
05/18/2002  10:33p              3,573 pmf001-01.inp
06/23/2002  12:27a            366,262 pmf001-01.out
               2 File(s)        369,835 bytes

 Directory of D:\MFFF\Validation\Part2\Cases\PC\ornl_HTC\pmf-002
```

```
01/02/2003  10:14p      <DIR>          .
01/02/2003  10:14p      <DIR>          ..
05/18/2002  10:33p               3,655 pmf002-01.inp
06/23/2002  12:28a             377,703 pmf002-01.out
               2 File(s)        381,358 bytes

 Directory of D:\MFFF\Validation\Part2\Cases\PC\ornl_HTC\pmf-003

01/02/2003  10:15p      <DIR>          .
01/02/2003  10:15p      <DIR>          ..
06/12/2002  03:13p              20,553 pmf003-01.inp
06/23/2002  12:35a             566,536 pmf003-01.out
05/18/2002  10:32p              24,483 pmf003-02.inp
06/23/2002  12:55a             579,298 pmf003-02.out
05/18/2002  10:32p              20,875 pmf003-03.inp
06/23/2002  01:03a              65,749 pmf003-03.out.gz
06/12/2002  03:14p              24,653 pmf003-04.inp
06/23/2002  01:20a             580,600 pmf003-04.out
06/12/2002  03:15p              20,307 pmf003-05.inp
06/23/2002  01:27a             565,924 pmf003-05.out
              10 File(s)      2,468,978 bytes

 Directory of D:\MFFF\Validation\Part2\Cases\PC\ornl_HTC\pmf-016

01/02/2003  10:15p      <DIR>          .
01/02/2003  10:15p      <DIR>          ..
05/18/2002  10:31p              17,513 pmf016-01.inp
06/23/2002  01:59a             647,089 pmf016-01.out
05/18/2002  10:31p              15,955 pmf016-02.inp
06/23/2002  03:26a             642,198 pmf016-02.out
05/18/2002  10:31p              15,955 pmf016-03.inp
06/23/2002  04:55a             642,447 pmf016-03.out
05/18/2002  10:31p              15,955 pmf016-04.inp
06/23/2002  06:26a             642,543 pmf016-04.out
05/18/2002  10:31p              15,955 pmf016-05.inp
06/23/2002  07:59a             642,506 pmf016-05.out
05/18/2002  10:31p              15,955 pmf016-06.inp
06/23/2002  09:31a             642,619 pmf016-06.out
              12 File(s)      3,956,690 bytes

 Directory of D:\MFFF\Validation\Part2\Cases\PC\ornl_HTC\pmf-017

01/02/2003  10:15p      <DIR>          .
01/02/2003  10:15p      <DIR>          ..
05/18/2002  10:30p              46,131 pmf017-01.inp
06/22/2002  02:20p             840,918 pmf017-01.out
05/18/2002  10:30p              46,131 pmf017-02.inp
06/22/2002  03:35p             840,749 pmf017-02.out
05/18/2002  10:30p              46,131 pmf017-03.inp
06/22/2002  04:49p             841,121 pmf017-03.out
06/14/2002  09:45a              10,412 pmf017-04.inp
06/22/2002  05:08p             809,757 pmf017-04.out
05/18/2002  10:30p              42,933 pmf017-05.inp
06/22/2002  06:20p             818,667 pmf017-05.out
              10 File(s)      4,342,950 bytes

 Directory of D:\MFFF\Validation\Part2\Cases\PC\ornl_HTC\pmf-033

01/02/2003  10:15p      <DIR>          .
01/02/2003  10:15p      <DIR>          ..
06/12/2002  03:28p              17,923 pmf033-01.inp
06/22/2002  11:03a             996,700 pmf033-01.out
               2 File(s)      1,014,623 bytes

 Directory of D:\MFFF\Validation\Part2\Cases\PC\ornl_HTC\pmf-037

01/02/2003  10:15p      <DIR>          .
01/02/2003  10:15p      <DIR>          ..
05/18/2002  10:24p              26,451 pmf037-01.inp
06/21/2002  06:02p             637,666 pmf037-01.out
05/18/2002  10:24p              66,385 pmf037-05.inp
06/21/2002  06:45p             752,654 pmf037-05.out
05/18/2002  10:24p              62,449 pmf037-07.inp
06/21/2002  07:31p             741,330 pmf037-07.out
05/18/2002  10:24p              33,831 pmf037-10.inp
06/21/2002  08:23p             659,222 pmf037-10.out
05/18/2002  10:24p              34,159 pmf037-12.inp
06/21/2002  09:31p             661,053 pmf037-12.out
06/12/2002  12:24p              16,538 pmf037-15.inp
06/21/2002  10:31p             753,301 pmf037-15.out
06/12/2002  12:26p              17,850 pmf037-16.inp
06/21/2002  11:35p             758,717 pmf037-16.out
              14 File(s)      5,221,606 bytes

     Total Files Listed:
             197 File(s)     60,814,004 bytes
              65 Dir(s)   3,221,131,264 bytes free
```

DUKE COGEMA
STONE & WEBSTER

Mixed Oxide Fuel Fabrication Facility

Criticality Code Validation

Part III

Revision 1

Docket Number 070-03098

Prepared by
Duke Cogema Stone & Webster

June 2003

Under
U.S. Department of Energy
Contract DE-AC02-99-CH10888

REVISION DESCRIPTION SHEET

REVISION NUMBER	DESCRIPTION
0	Initial Issue December 2002
1	Clarify applicability of validation for design application with H/Pu < 30. Affected pages: 24-25, 43, 46, 48. Editorial and typographical corrections: various pages.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

AIVM	Addition of individual volume and masses
ANS	American Nuclear Society
ANSI	American National Standards Institute
AOA	area of applicability
AP	aqueous polishing
CFR	Code of Federal Regulations
DCS	Duke Cogema Stone & Webster
DOE	U.S. Department of Energy
EALF	energy of average lethargy causing fission
FA	fuel assembly
LTB	lower tolerance band
MFFF	Mixed Oxide Fuel Fabrication Facility
MOX	mixed oxide
NRC	U.S. Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
RSICC	Radiation Safety Information Computational Center
USL	upper safety limit

ABSTRACT

This report documents the validation of the nuclear criticality safety codes to be used in the design of the Mixed Oxide (MOX) Fuel Fabrication Facility (MFFF), to be owned by the U.S. Department of Energy (DOE) and operated by the licensee, Duke Cogema Stone & Webster (DCS). This report is applicable to the validation of the SCALE 4.4a code package [1] using the CSAS26 (KENOVI) sequence and the 238 energy group cross section library 238GROUPNDF5.

Title 10 Code of Federal Regulations (CFR) §70.61(d) requires that all nuclear processes remain subcritical under all normal and credible abnormal conditions. In order to establish that a system or process will be subcritical under all normal and credible abnormal conditions, it is necessary to establish acceptable subcritical limits for the operation and then show that the proposed operation will not exceed those values. In order to comply with this requirement, the *American National Standard for Nuclear Criticality in Operations with Fissionable Material Outside Reactors* [2] and the U.S. Nuclear Regulatory Commission (NRC) *Standard Review Plan for the Review of an Application for a Mixed Oxide (MOX) Fuel Fabrication Facility* [3], require that a validation be performed that (1) demonstrates the adequacy of the margin of subcriticality for safety by assuring that the margin is large compared to the uncertainty in the calculated value of k_{eff} and (2) determines the area(s) of applicability (AOA) and use of the code within the AOA, including justification for extending the AOA by using trends in the bias.

A number of design AOAs are established to cover the range of processes and fissile materials in the MFFF. AOAs covering Pu and MOX applications are as follows (1) Pu-nitrate aqueous solutions, (2) MOX pellets, fuel rods, and fuel assemblies, (3) PuO_2 powders, (4) MOX powders, and (5) Aqueous solutions of Pu compounds and Pu precipitates. The first four AOAs are addressed in the validation reports Part I [15] and Part II [16]. This report addresses the fifth AOA: (5) Aqueous solutions of Pu compounds and Pu precipitates.

The report concludes that the upper safety limit (USL) for the fifth design AOA is 0.9411 for Pu-nitrate solutions (H/Pu>50) and 0.9328 for PuO_2 powder-polystyrene mixtures (H/Pu<50). The USL accounts for the computational bias, uncertainties, and a 0.05 administrative margin.

The validation report concludes further that the MFFF application: Aqueous solutions of Pu compounds and Pu precipitates are in the range of the AOA (5). Therefore, the USL of AOA (5) is relevant for these MFFF applications.

The report further demonstrates that the PuO_2F_2 "standard salt" introduced in the criticality safety analysis to cover these aqueous solutions of Pu compounds and Pu precipitates is also in the range of the AOA (5) and represents bounding medium for criticality analysis of these aqueous solutions.

1. Introduction

1.1 Purpose

The purpose of this report is to validate the criticality codes and determine the upper safety limit (USL) to be used for performing nuclear criticality safety calculations and analyses of the Mixed Oxide (MOX) Fuel Fabrication Facility (MFFF), to be owned by the U.S. Department of Energy (DOE) and operated by the licensee, Duke Cogema Stone & Webster (DCS).

1.2 Scope

The scope of this report is limited to the validation of the CSAS26 sequence of the SCALE 4.4a code package [1] with the 238 energy group cross-section library 238GROUPNDF5 for nuclear criticality safety calculations of the MFFF.

1.3 Applicability

The following areas of applicability (AOAs) are identified to cover a range of processes in the MFFF involving Pu and MOX materials:

MFFF Design Application	AOA of Experiments	
(1) Pu-nitrate solutions	AOA(1)	Pu-nitrate solution
(2) MOX pellets, fuel rods, and FA	AOA(2)	MOX pellet lattices in water
(3) PuO_2 powders-H_2O systems	AOA(3)	PuO_2 powder-polystyrene mixture and Pu metal systems
(4) MOX powders-H_2O systems	AOA(4)	MOX powder-polystyrene mixture
(5) Aqueous solutions of Pu compounds and Pu precipitates and Pu-nitrate solutions	AOA(5)	PuO_2 powder-polystyrene mixture

The first four AOAs are addressed in the code validation reports Part I [15] and Part II [16]. The following sections address AOA(5): PuO_2 powder-polystyrene mixtures and Pu-nitrate solutions (see Section 5.1). Section 4 demonstrates that the AOA(5) covers the design application aqueous solution of Pu compounds and Pu precipitated oxalates.

In order to cover the chemical compounds of Pu-oxalates in the AP process (precipitation of Pu-oxalates), a criticality bounding medium, PuO_2F_2 "standard salt," is defined and shown to be a bounding computational proxy for design applications within AOA(5).

1.4 Background

1.4.1 Overall MFFF Design

The MFFF is designed to produce MOX fuel assemblies on an industrial scale from a mixture of depleted uranium and plutonium oxides for use in mission light-water reactors. The MFFF will be constructed on a DOE site and will be licensed by the U.S. Nuclear Regulatory Commission (NRC) under Title 10 Code of Federal Regulations (CFR) Part 70. The facility is designed to applicable U.S. codes and standards and operated by DCS, a private consortium under contract to DOE. The goal of the contract is to design, construct, and operate a facility to fabricate MOX fuel based on existing technology from the COGEMA MELOX and La Hague plants in France. To maximize the benefit of the existing technology, process and equipment designs from the MELOX and La Hague plants are duplicated, to the maximum extent possible, in the design of the new plant.

The feed material is depleted uranium dioxide and surplus plutonium dioxide supplied by DOE. The impurities in the plutonium dioxide feed are extracted by the Aqueous Polishing process. The MOX fuel fabrication process blends this "polished" plutonium dioxide with depleted uranium dioxide to form mixed oxide pellets. These pellets are loaded into the fuel rods, which are integrated into fuel assemblies. The nuclear fuel assemblies are transported for use in specific U.S. commercial reactors as nuclear fuel. The MFFF is designed to process 3.5 metric tons annually, for a total disposition of 33 metric tons of plutonium (as dioxide).

1.4.2 Regulatory Requirements, Guidance, and Industrial Standards

Title 10 CFR §70.61(d) requires that "under normal and credible abnormal conditions, all nuclear processes are subcritical, including use of an approved safety margin of subcriticality for safety". In order to comply with this requirement, NUREG 1718 [3] and ANSI/ANS-8.1-1998 [2] require a validation report that (1) demonstrates the adequacy of the margin of subcriticality for safety by assuring that the margin is large compared to the uncertainty in the calculated value of k_{eff} and (2) determines the AOAs and use of the code within the AOA, including justification for extending the AOA by using trends in the bias.

NUREG 1718 [3] further states that the validation report should contain:

> A description of the AOA that identifies the range of values for which valid results have been obtained for the parameters used in the methodology. As defined in ANSI/ANS 8.1–1983, the AOA is the range of material compositions and geometric arrangements within which the bias of a calculational method is established. Other variables that may affect the neutronic behavior of the calculational method should also be specified in the definition of the AOA. Particular attention should be given to validating the code for calculations involving mixed oxides of differing isotopics and defining the isotopic ranges covered by the available benchmark experiments. In accordance with the provisions in ANSI/ANS 8.1–1983 (applicable section is Section 4.3.2), any extrapolation of the AOA beyond the physical range of the data should be supported by an established mathematical methodology.

2. Calculational Method

The SCALE 4.4a code package [1] is the computational system used for MFFF criticality analyses. The code package is available from the Radiation Safety Information Computational Center (RSICC). The SCALE 4.4a code package is installed and verified on the SGN PC hardware platform under the operating system "Windows NT 4.0", as documented in [4].

A recent KENO-VI update published in SCALE Newsletter number 24 (July 2001), available at the SCALE web site, has not been applied to the version of SCALE 4.4a used for calculations. Comparison between patched and unpatched SCALE 4.4a versions do not present significant differences [17].

SCALE 4.4a is a collection of modules designed to perform criticality, shielding, and thermal calculations. The CSAS26 sequence is validated in this report. Functional modules may be run individually or sequentially in a module designated as a criticality safety control sequence (CSAS). A control sequence is also referred to as a control module. The CSAS26 (KENO VI) sequence is used for MFFF criticality analyses using the 238 group cross-section library 238GROUPNDF5 based on the ENDF/B-V data file. The CSAS sequences process the cross sections via the BONAMI and NITAWL-II modules within SCALE. The calculation of k_{eff} is performed with the Monte Carlo code KENO VI.

3. Criticality Code Validation Methodology

In order to establish that a system or process will be subcritical under all normal and credible abnormal conditions, it is necessary to establish acceptable subcritical limits for the operation and then show that the proposed operation will not exceed those values.

Figure 3–1 shows how the validation process fits within the overall MFFF nuclear criticality analysis process. The first step involves the procurement, installation, and verification of the criticality software on a specific computer platform. For the MFFF, the SCALE 4.4a code package has been procured, installed, and verified on the PC [4] hardware platform. This step is followed by the validation of the criticality software, which is the purpose of this report. The final step involves the criticality safety design analysis calculations, which are performed and presented in separate reports.

The criticality code validation methodology can be divided into four steps:

- Identify general MFFF design applications,
- Select applicable benchmark experiments and group them into AOAs,
- Model and calculate k_{eff} values of selected critical benchmark experiments,
- Perform statistical analysis of results to determine computational bias and upper safety limit (USL).

The first step is to identify the MFFF design applications and key parameters associated with the normal and upset design conditions. Table 3–1 lists the key parameters for the MFFF.

The second step involves several substeps. First, based on the key parameters, the AOA and expected range of each key parameter are identified. ANSI/ANS-8.1 [2] defines the AOA as "the limiting range of material composition, geometric arrangements, neutron energy spectra, and other relevant parameters (such as heterogeneity, leakage interaction, absorption, etc.) within which the bias of a computational method is established." AOAs covering Pu and MOX applications are as follows: (1) Pu-nitrate solutions; (2) MOX pellets, fuel rods, and fuel assemblies; (3) PuO_2 powders; (4) MOX powders; and (5) PuO_2-polystyrene mixture and Pu-nitrate solutions. These AOAs are defined and presented in Section 4. After identifying the AOAs, a set of critical benchmark experiments is selected. Benchmark experiments for the fifth AOA are selected from the references listed in the International Handbook of Evaluated Criticality Safety Benchmark Experiments [5]. A description of all relevant experiments used for each AOA considered here is provided in Section 5.

The third step involves modeling the critical experiments and calculating the k_{eff} values of the selected critical benchmark experiments[1]. Attachment 4 presents calculated results.

The final step involves the statistical analysis of the results in order to calculate the computational bias and USL. Section 6 presents the computational bias and USL results.

---

[1] Note that these models contain simplifications of critical experiments geometry. These simplifications lead to additional uncertainties which are included in the statistical analysis of the results.

3.1 Determination of Bias

ANSI/ANS–8.1–1998 [2] requires a determination of the calculational bias by "*correlating the results of critical and exponential experiments with results obtained for these same systems by the calculational method being validated.*" The correlation must be sufficient to determine if major changes in the bias can occur over the range of variables in the operation being analyzed. The standard permits the use of trends in the bias to justify extension of the area of applicability of the method outside the range of experimental conditions.

Calculational bias is the systematic difference between experimental data and calculated results. The simplest technique is to find the difference between the average value of the calculated results of critical benchmark experiments and 1.0. This technique gives a constant bias over a defined range of applicability.

Another technique is to find the difference between a regression fit of the calculated results of critical benchmark experiments and 1.0, as a function of an independent variable (e.g., enrichment, moderator-to-fuel ratio, etc.). As a rule, the bias is not a constant, but is dependent upon an independent variable, usually the degree of moderation of the neutrons. For example, the bias for an unmoderated system in which fission occurs with fast neutrons would not be expected to be the same as for a moderated system in which fission occurs with thermal neutrons. The AOA for the bias is the limiting range of material composition, geometric arrangement, etc., over which the bias is collectively established.

The recommended approach for establishing subcriticality based on numerical calculations of the neutron multiplication factor is prescribed in Section 5.1 of ANSI/ANS-8.17 [8]. The criteria to establish subcriticality requires that for a design application (system) to be considered as subcritical, the calculated multiplication factor for the system, k_s, must be less than or equal to an established maximum allowed multiplication factor based on benchmark calculations and uncertainty terms that is:

$$k_s \leq k_c - \Delta k_s - \Delta k_c - \Delta k_m \qquad \text{(Eq. 3.1)}$$

where:

k_s = the calculated allowable maximum multiplication factor, (k_{eff}) of the design application (system)

k_c = the mean k_{eff} value resulting from the calculation of benchmark critical experiments using a specific calculation method and data

Δk_s = the uncertainty in the value of k_s

Δk_c = the uncertainty in the value of k_c

Δk_m = the administrative margin to ensure subcriticality.

Sources of uncertainty that determine Δk_s include:

- Statistical and/or convergence uncertainties
- Material and fabrication tolerances
- Limitations in the geometric and/or material representations used.

Sources of uncertainty that determine Δk_c include:

- Uncertainties in critical experiments
- Statistical and/or convergence uncertainties in the computation
- Extrapolation outside of the range of experimental data
- Limitations in the geometric and/or material representations used.

An assurance of subcriticality requires the determination of an acceptable margin based on known biases and uncertainties. The USL is defined as the upper bound for an acceptable calculation.

Critical benchmark experiments used to determine calculational bias (β) should be similar in composition, configuration, and nuclear characteristics to the system under examination. The range of applicability may be extended beyond the range of conditions represented by the benchmark experiments by extrapolating the trends established for the bias. β is related to k_c as follows:

$$\beta = k_c - 1 \qquad \text{(Eq. 3.2)}$$

$$\Delta\beta = \Delta k_c \qquad \text{(Eq. 3.3)}$$

Using this definition of bias, the condition for subcriticality in Eq. 3.1 is rewritten as:

$$k_s + \Delta k_s \leq 1 - \Delta k_m + \beta - \Delta\beta \qquad \text{(Eq. 3.4)}$$

A system is acceptably subcritical if a calculated k_{eff} plus calculational uncertainties lies at or below the USL.

$$k_s + \Delta k_s \leq USL \qquad \text{(Eq. 3.5)}$$

The USL can be written as:

$$USL = 1 - \Delta k_m + \beta - \Delta\beta \qquad \text{(Eq. 3.6)}$$

Bias is negative if $k_c < 1$ and positive if $k_c > 1$. For conservatism, a positive bias is set equal to zero for the purpose of defining the USL. $\Delta\beta$ is typically determined at the 95% confidence level.

The USL takes into account bias, uncertainties, and administrative and/or statistical margins such that the calculated configuration will be subcritical with a high degree of confidence.

β is related to system parameters and may not be constant over the range of a parameter of interest. If k_{eff} values for benchmark experiments vary as a function of a system parameter, such as enrichment or degree of moderation, then β can be determined from a best fit as a function of the parameter upon which it is dependent. Extrapolation outside the range of validation must take into account trends in the bias.

Both $\Delta\beta$ and β can vary with a given parameter, and the USL is typically expressed as a function of the parameter. Normally, the most important system parameter that affects bias is the degree of moderation of the neutrons. This parameter can be expressed in several different ways, such as the energy of average lethargy causing fission (EALF), moderator-to-fuel volume ratio (v^m/v^f), or moderator-to-fuel atomic ratio (H/Pu ratio).

In general, the "bias" can be broken down into components caused by system modeling error, code modeling inaccuracies, cross-sectional inaccuracies, etc. Biases associated with individual inaccuracies are usually combined into a total bias to represent the combined effect from all sources that prevent code and cross-sections from calculating the experimental value of k_{eff} (see Section 3.4).

One or two calculations are insufficient to determine calculation bias. In practice, it is necessary to determine the "average bias" for a group of experiments. A statistical analysis of the variation of biases around this average value is used to establish an uncertainty associated with the bias value when it is applied to a future calculation of a similar critical system. The lower limit of this band of uncertainty establishes an upper bound for which a future calculation of k_{eff} for a similar critical system can be considered subcritical with a high degree of confidence.

NUREG/CR-6361 [9] describes two statistical methods for the determination of an USL from the bias and uncertainty terms associated with the calculation of criticality. The first method applies a statistical calculation of the bias and its uncertainty, plus an administrative margin, to a linear fit of critical experimental benchmark data. The second method applies a statistical calculation to determine a combined lower confidence band and subcritical margin. Both methods assume that the distribution of data points is normal. The following discussion of each method is taken from NUREG/CR-6361 [9] and is based on equations and techniques described in Dryer, Jordan, and Cain [10], Easter [11], Bowden and Graybill [12], Johnson [13], and Cain [14].

3.2 USL Method 1: Confidence Band with Administrative Margin

This method applies a statistical calculation of the bias (β) and its uncertainty ($\Delta\beta$) plus an administrative safety margin (Δk_m) to a linear fit of calculated results for a selected set of critical experiments. A confidence band (W) is determined statistically based on the existing data and a specified level of confidence; the greater the standard deviation in the data or the larger the confidence desired, the larger the band width will be. This confidence band, W, accounts for uncertainties in the experiments, the calculational approach, and calculational data (e.g., cross sections) and is therefore a statistical basis for $\Delta\beta$, the uncertainty in the value of β. W is defined for a confidence level of $(1-\gamma_1)$ using the relationship:

$$W = \max\{w(x)|_{x\,min,\,x\,max}\} \qquad \text{(Eq. 3.7)}$$

where

$$w(x) = t_{1-\gamma_1} s_p \left[1 + \frac{1}{n} + \frac{(x-\bar{x})^2}{\sum_{i=1,n}(x_i-\bar{x})^2} \right]^{\frac{1}{2}} \qquad \text{(Eq. 3.8)}$$

and

n = the number of critical calculations used in establishing $k_c(x)$

$t_{1-\gamma_1}$ = the Student - t distribution for $1-\gamma_1$ and n - 2 degrees of freedom

$\bar{x}$ = the mean value of parameter x in the set of calculations

s_p = the pooled standard deviation for the set of criticality calculations.

The function w(x) is a curvilinear function. For simplicity, it is desirable to obtain a constant width margin. Therefore, for conservatism, the confidence band, W, is defined as the maximum of $(w(x_{min}), w(x_{max}))$, where x_{min} and x_{max} are the minimum and maximum values of the independent parameter x, respectively. Typically, W is determined at a 95% confidence level.

The pooled standard deviation is obtained from the pooled variance $S_p = \sqrt{S_p^2}$, where S_p is given as:

$$s_p^2 = s_{k(x)}^2 + s_w^2 \qquad \text{(Eq. 3.9)}$$

Where $S_{k(x)}^2$ is the variance (or mean square error) of the regression fit, and is given by:

$$s_{k(x)}^2 = \frac{1}{(n-2)}\left[\sum_{i=1,n}(k_i-\bar{k})^2 - \frac{\left\{\sum_{i=1,n}(x_i-\bar{x})(k_i-\bar{k})\right\}^2}{\sum_{i=1,n}(x_i-\bar{x})^2}\right] \qquad \text{(Eq. 3.10)}$$

and S_w^2 is the within-variance of the data:

$$s_w^2 = \frac{1}{n}\sum_{i=1,n}\sigma_i^2 \qquad \text{(Eq. 3.11)}$$

where σ_i is the standard deviation associated with k_i for a Monte Carlo calculation. It is recommended that the individual standard deviations for Monte Carlo calculations be roughly uniform in value for the best results. For deterministic codes that do not have a standard deviation associated with a computed value of k, the standard deviation is zero. However, this term can also be used as a mechanism to include known uncertainties in experimental data.

In USL Method 1, Δk_m is given an arbitrary administrative value. NUREG-1718 [3] states that a "minimum subcritical margin (Δk_m) of 0.05 is generally considered acceptable without additional justification when both the bias and its uncertainty are determined to be negligible." The MFFF criticality analyses use a value of 0.05. Section 6 provides further justification of the 0.05 administrative margin.

Having determined the constant W and substituting for $\Delta\beta$ in equation 3.6, the expression for the USL may be written as:

$$USL_1(x) = 1.0 - \Delta k_m - W + \beta(x). \qquad \text{(Eq. 3.12)}$$

3.3 USL Method 2: Single-Sided Uniform Width Closed Interval Approach

In USL Method 2, sometimes referred to as a lower tolerance band (LTB) approach, statistical techniques are applied to determine a combined lower confidence band plus subcritical margin. In USL Method 1, Δk_m and $\Delta\beta$ are determined independently, and in USL Method 2 (LTB method), a combined statistical lower bound is determined.

The purpose of this method is to determine a uniform tolerance band over a specified closed interval for a linear least-squares model. The level of confidence in the limit being calculated is α and is typically in the range of 0.90 to 0.999.

The USL Method 2 is defined as:

$$USL_2(x) = 1.0 - (C_{\alpha/P} \cdot s_p) + \beta(x) \qquad \text{(Eq. 3.13)}$$

where s_p is the pooled variance of k_c described earlier. The term $C_{\alpha/P} \cdot s_p$ provides a band for which there is a probability *P* with a confidence α that an additional calculation of k_{eff} for a critical system will lie within the band. For example, a $C_{95/99.5}$ multiplier produces a USL for which there is a 95% confidence that 995 out of 1000 future calculations of critical systems will yield a value of k_{eff} above the USL.

The analysis is over the closed interval from $x = a$ to $x = b$. $C_{\alpha/P}$ is calculated according to the following equations:

$$g = \sqrt{\frac{1}{n} + \frac{(a-\bar{x})^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2}} \qquad \text{(Eq. 3.14)}$$

$$h = \sqrt{\frac{1}{n} + \frac{(b-\bar{x})^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2}} \qquad \text{(Eq. 3.15)}$$

$$\rho = \frac{1}{gh} \cdot \left\{ \frac{1}{n} + \frac{(a-\bar{x})(b-\bar{x})}{\sum_{i=1}^{n}(x_i-\bar{x})^2} \right\} \qquad \text{(Eq. 3.16)}$$

$$A = \frac{g}{h} \qquad \text{(Eq. 3.17)}$$

A, ρ, and $(n\text{-}2)$ are used to determine the value of D from Table 3 in Bowden [12], which covers values of $0.5 \le A \le 1.5$. The procedure to follow when A is in this range is:

$$C^* = D \cdot g. \qquad \text{(Eq. 3.18)}$$

When A is outside the above range, A is replaced by $1/A$ for the determination of D, and C^* is given by:

$$C^* = D \cdot h. \qquad \text{(Eq. 3.19)}$$

Next,

$$C_{\alpha/P} = C^* + z_p \cdot \sqrt{\frac{n-2}{\chi^2}}, \qquad \text{(Eq. 3.20)}$$

where

z_p = the Student t statistic depending on n and P
χ^2 = the chi square distribution, a function of n-2 and α.

This approach provides a statistically based subcritical margin, Δk_m which can be determined as the difference $(C_{\alpha/P} \cdot s_p)$-W. In criticality safety applications, such a statistically determined approach generally, but not necessarily, yields a margin of less than 0.05, which serves to illustrate the adequacy of the administrative margin specified in USL Method 1. The recommended purpose of USL Method 2 is to apply it in tandem with USL Method 1 to verify that the administrative margin is conservative relative to a purely statistical basis.

3.4 Uncertainties

Uncertainties, as used in this report, refer to the uncertainty in k_{eff} associated with experimental unknowns or assumptions and to the uncertainty values associated with Monte Carlo analyses.

Experimental uncertainty (σ_e) – Modeling of validation experiments frequently result in assumptions about experimental conditions. In addition, experimental uncertainties (such as measurement tolerances) influence the development of a computer model. Recent efforts by the OECD – NEA [5] have resulted in the quantification of these uncertainties in validation experiments.

Statistical uncertainty (σ_s) – Monte Carlo calculation techniques result in a statistical uncertainty associated with the actual calculation. This type of uncertainty is dependent of upon many factors, including number of neutron generations performed, variance reduction techniques employed, and problem geometry. For this document, σ_s refers to the statistical Monte Carlo uncertainty associated with the computer modeled validation experiment.

Total uncertainty –This is the total uncertainty associated with a calculated k_{eff} on a benchmark experiment. The total uncertainty for an individual benchmark is the combined error of the experimental and statistical uncertainties:

$$\sigma_i = \sqrt{\sigma_{e,i}^2 + \sigma_{s,i}^2} \qquad \text{(Eq. 3.21)}$$

where the subscript (i) refers to an individual benchmark calculation.

3.5 Normalizing k_{eff}

In many instances, benchmark experiments used for validation may not be exactly critical. Experimental results may show that the experiment is slightly above or below a $k_{eff} = 1.0$. For these cases, the calculated k_{eff} values should be normalized to the experimental value. This assumes that any inherent bias in the calculation is not affected by the normalization, which is valid for small differences in k_{eff}. To normalize k_{eff}, the following formula applies:

$$k_{eff}\text{ (normalized)} = k_{eff}\text{ (calculated)} / k_{eff}\text{ (experimental)} \qquad \text{(Eq. 3.22)}$$

The normalized k_{eff} values are to be used in the determination of the USL. Since only small adjustments to the calculated k_{eff} value are made as a result of normalization, no adjustment to the total uncertainty, σ_i, is made.

3.6 Application of the USL

The equations for USL Methods 1 and 2 (equations 3.12 and 3.13) represent an upper bound to assure subcriticality for a given configuration when the calculated k_{eff} plus uncertainty for the configuration is less than the USL. USLs may be calculated for a number of independent parameters for a given system. Here, the subcritical limit is taken as the minimum of all USLs computed for the specific parameters of the system. This approach is conservative with respect to the guidance provided in NUREG/CR-6361 [9] in which the USL is determined based on the statistical results for the parameter "*with the strongest correlation to the calculated k_{eff} values.*"

Another advantage of the USL is that it may also be used to establish guidelines for quantitatively determining the applicability of the bias (or validation) to specific applications. For a given parameter, the USL is valid over the range of that parameter in the set of calculations used to determine the USL. However, ANSI/ANS-8.1 [2] allows the range of applicability to be extended beyond this range by extrapolating the trends established for the bias. No precise guidelines are specified for the limits of extrapolation. Thus, engineering judgment should be applied when extrapolating beyond the range of the parameter bounds.

Appendix C in NUREG/CR-6361 [9] documents the USLSTATS computer program that was developed to perform the required statistical analysis and calculate USLs based on USL Methods 1 and 2.

In this validation report, USLSTATS is used to trend the following parameters:

- Moderator to fuel atomic ratio (H/Pu)
- Energy of Average Lethargy Causing Fission (EALF)

The H/Pu ratio is a parameter that describes the moderation of the neutrons in the fissile medium. The EALF parameter is a measure of the energy dependent fission efficiency of the fissile medium.

The administrative margin, Δk_m, is fixed in order to have a sufficient confidence that the calculated results are subcritical.

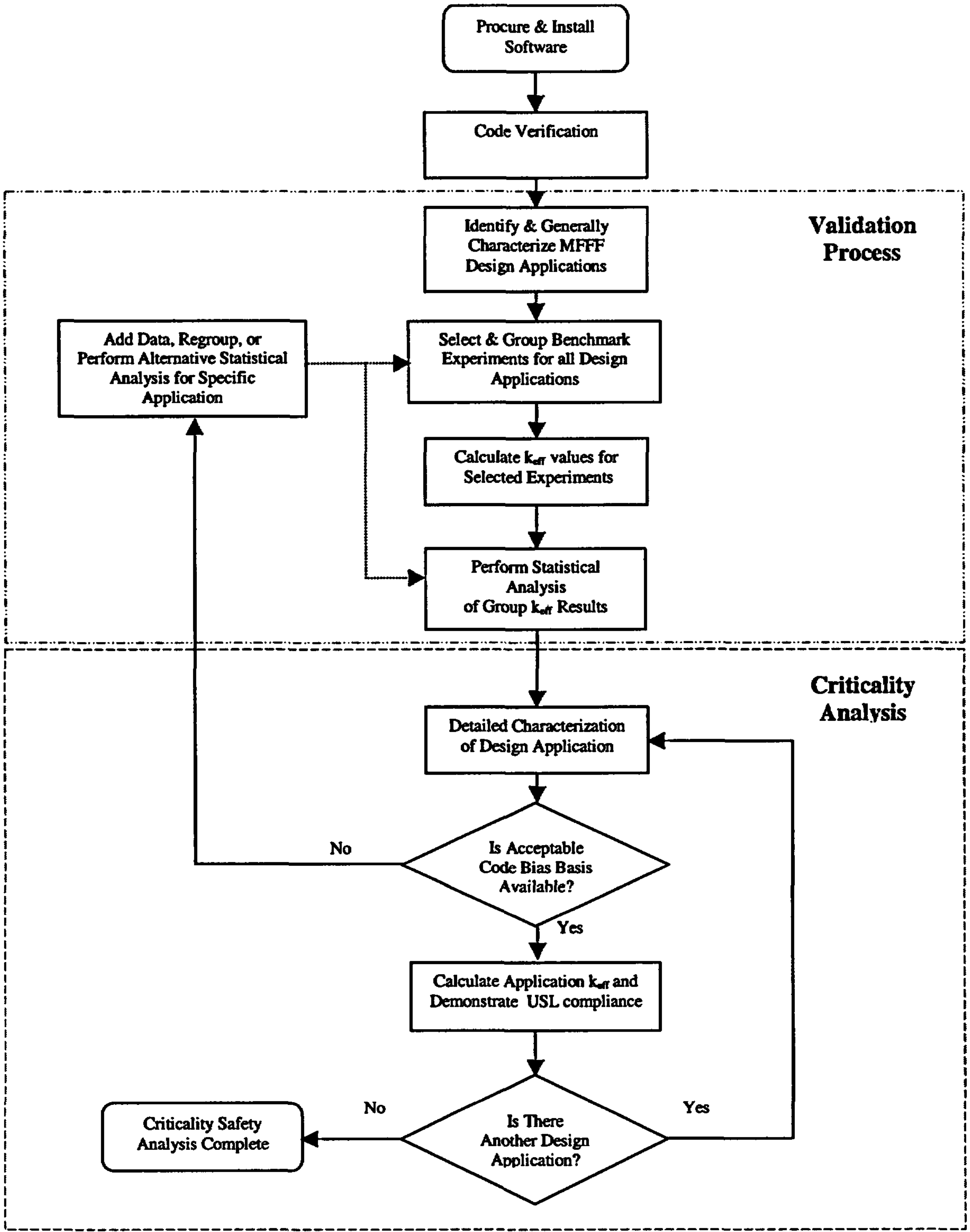


Figure 3–1 Overview of the Criticality Analysis Process of the MFFF

Table 3–1 Characteristics of the MFFF Design Application Areas*

Parameter	Pu-nitrate solution	MOX pellets, fuel rods, FAs	PuO_2 powder/water mixtures	MOX powder/water mixtures	Aqueous solutions of Pu compounds
Fissile Material Physical/Chemical Form	Pu-nitrate	MOX green and sintered pellets, MOX rods and FAs	PuO_2 powder	MOX powder	(a) Pu-oxalate (b) PuO_2F_2 “standard salt”
Isotopic composition of fissile material **	96% ^{239}Pu 4% ^{240}Pu	96% ^{239}Pu 4% ^{240}Pu depleted U	96% ^{239}Pu 4% ^{240}Pu	96% ^{239}Pu 4% ^{240}Pu depleted U	96% ^{239}Pu 4% ^{240}Pu
$PuO_2/(UO_2+PuO_2)$	100 %	≤ 6.3 %	100 %	6.3% – 22%	100 %
Maximum oxide density [g/cm^3]	–	7.0, 11.0	3.5, 7.0, 11.46	4.1, 5.5	–
Pu concentration [g/liter]7	125 – 237	–	–	–	(a) 242 (b) 767
Type of moderation	Homogeneous	Heterogeneous	Homogeneous	Homogeneous	Homogeneous
Optimum moderation ***	H/Pu=100–200	$v^m/v^f = 1.9 - 9$	H/Pu= 0.3 – 6	H/Pu=1.6 – 291	(a) H/Pu=100 (b) H/Pu=30
Low density moderation [wt.% H_2O]	–	≤ 5 ****	≤ 5	≤ 5	–
Anticipated absorber/reflector materials	Water Cd/water Concrete Borated concrete	Water Concrete Borated concrete	Water Borated concrete	Water	Water Cd/water Concrete
Typical geometry	Annular cylinders Cylinders Slabs	Cylinders Arrays Cuboids	Various configurations	Various configurations	Annular cylinders Cylinders Slabs

* Characteristics presented typically refer to optimal or bounding values or ranges associated with respective MFFF design applications

** Bounding design isotopic composition from Aqueous Polishing System basis of design

*** Per calculation

**** Green Pellets (i.e., unsintered pellets) < 5; sintered pellets < 1

4. MFFF Design Application Classification

This section describes the characteristics of the established AOAs based on the various fuel configurations encountered in the MFFF. AOAs covering Pu and MOX applications are as follows (see Table 3–1):

- Pu-nitrate aqueous solution,
- MOX pellets, fuel rods, and fuel assemblies (FA),
- PuO_2 powders,
- MOX powders,
- Aqueous solutions of Pu compounds, precipitated Pu-oxalates.

The following sections address the fifth AOA based on the various fuel configurations encountered in the Aqueous Polishing process (Pu-oxalate solutions and precipitated Pu-oxalates).

It will be demonstrated that for H/Pu ratios greater than 50, AOA(5) is bounded by AOA(1). For the low moderated range, H/Pu < 50, the benchmarks used for AOA(3) [15] will also be used for AOA(5) because the PuO_2+polystyrene experiments have Pu concentrations and H/Pu ratios that are typical of wet powders (addressed in AOA(3)), precipitates and powder slurries [6], [7].

4.1 MFFF Design Application (5) – Aqueous Solutions of Pu Compounds

Table 4–1 and Table 4–2 summarize the anticipated criticality calculations to be performed for the design of the MFFF in which aqueous Pu compounds will be processed or stored. The tables provide the relevant parameters (i.e., chemical form, isotopic vector, moderator to fuel atomic ratio [H/Pu], and energy of average lethargy causing fission [EALF]) for each criticality design application under nominal Aqueous Polishing process conditions (Table 4–1) and abnormal process conditions (Table 4–2).

The normal process conditions are characterized by Pu concentrations in the process solution of less than 500 g/liter. On the other hand, the abnormal conditions are characterized by higher Pu concentrations limited by the theoretical density of the Pu compound in the process solution (values as high as 7000 g/liter or higher).

Typically, design parameters for Aqueous Polishing process equipment are based on geometry control mode. This means that the design dimensions are safe for any credible Pu concentration and for any credible degree of moderation (H/Pu ratio). Under normal process conditions (aqueous solution of Pu compounds with low Pu concentrations) the fissile medium is typically overmoderated and a thermal neutron spectrum will be found.

Nevertheless for criticality control the fissile solution is analyzed at the point of optimum moderation to determine a maximum k_{eff}. In this case, the thermal spectrum shifts towards higher energies and epithermal spectra can occur.

The H/Pu range in which the maximum k_{eff} occurs depends on the composition of the Pu compound [19]. For PuO_2+H_2O mixtures the maximum k_{eff} will occur at the maximum Pu concentration (corresponding to the maximum abnormal PuO_2 density in the aqueous polishing process). For high PuO_2 densities between 7.0 g/cm^3 and the theoretical maximum density of 11.46 g/cm^3 intermediate to fast neutron spectra can occur at the maximum k_{eff}.

In some other abnormal situations, Pu precipitates and slurry powders with high compound densities can occur (see Table 4-11 in Section 4.4). In these cases geometry control is used and the calculations are performed either at the optimum moderation or at the maximum Pu concentration (H/Pu = 0) if there exists a maximum k_{eff}.

The following primary Aqueous Process situations are considered in AOA(5):

- Oxalic mother liquor solution and aqueous solutions of Pu compounds in nominal process concentrations,
- Precipitated Pu^{IV}-oxalates: $Pu(C_2O_4)_2 \cdot 6H_2O$, $Pu(C_2O_4)_2 \cdot 2H_2O$, $Pu(C_2O_4)_2$.

Homogeneous PuO_2+H_2O systems and PuO_2 slurry powders that can occur in the Aqueous Polishing process are addressed in AOA(3) [15]. Nevertheless PuO_2+H_2O systems are also discussed in the following sections for a better understanding of the differences between the PuO_2+H_2O systems and the Pu compound solutions in the low moderated range.

In the Basis of Design of the MFFF Aqueous Polishing process [18] a bounding fissile media, PuO_2F_2 "standard salt," is defined to describe all the possible Pu compounds, other than PuO_2 (for instance Pu-oxalate and various other Pu precipitates) in a conservative manner. In these cases it will be shown on a case by case basis whether the maximum k_{eff} occurs at the optimum of moderation or at the maximum possible Pu concentration in the dry compound.

Section 4.2 shows that the selected experiments are sufficient to describe the physical properties of the PuO_2F_2 "standard salt" solution as well as the Pu-oxalate solution. Section 4.3 shows that the EALF values found for the optimum moderation of each solution are in or near the range of the EALF values for the experimental configuration. Section 4.4 shows that the PuO_2F_2 "standard salt" is bounding for the Pu-oxalate solution and Pu-oxalate precipitates over the full range of applicability.

Table 4–1 Anticipated Criticality Calculation Derived Characteristics for Design Applications Involving Aqueous Solutions of Pu Compounds in Nominal Process Conditions

Fuel configuration	Reflector conditions	Chemical form	C(Pu) [g/liter]	H/Pu	EALF [eV]
AP: KCA Oxalic Precipitation Conversion					
Flat Filter FLT 7000	Water/borated concrete	PuO_2F_2 "standard salt" solution	1234 [1]	30 [3]	-
Precipitators PREC 5000/6000	Water	PuO_2F_2 "standard salt" solution	1234 [1]	30 [3]	-
AP: KCD Oxalic Mother Liquor Recovery					
Evaporator EV 3000	Water	PuO_2F_2 "standard salt" solution	10.1 – 20 [2]	2800	-
Evaporator EV 5000	Water	PuO_2F_2 "standard salt" solution	-	-	-
Tanks TK 1000/1500/2000	Water/borated concrete	PuO_2F_2 "standard salt" solution	0.18 – 0.3 [2]	83000	-

1) Maximum Pu concentration in Pu-oxalate $Pu(C_2O_4)_2 \cdot 6H_2O$ [21], [22]

2) Maximum nominal value

3) Optimum H/Pu value

Table 4–2 Anticipated Criticality Calculation Derived Characteristics for Design Applications Involving Aqueous Solution of Pu Compounds in Abnormal Process Conditions

Fuel configuration	Reflector conditions	Chemical form	C(Pu) [g/liter]	H/Pu	EALF [eV]
AP: KCA Oxalic Precipitation Conversion					
Flat Filter FLT 7000	Water/borated concrete	PuO_2F_2 "standard salt" solution	767 [1]	30 [3]	0.70
Precipitators PREC 5000/6000	Water	PuO_2F_2 "standard salt" solution	767 [1]	30 [3]	3.0
AP: KCD Oxalic Mother Liquor Recovery					
Evaporator EV 3000	Water	PuO_2F_2 "standard salt" solution	767 [2]	30 [3]	1.39
Evaporator EV 5000	Water	PuO_2F_2 "standard salt" solution	767 [2]	30 [3]	1.42
Tanks TK 1000/1500/2000	Water/borated concrete	PuO_2F_2 "standard salt" solution	767 [1]	30 [3]	3.08
Tank TK 6000	Water	PuO_2F_2 "standard salt" solution	767 [1]	30 [3]	0.78
Tanks TK 4000/4100/4200	Water/cadmium	PuO_2F_2 "standard salt" solution	767 [1]	30 [3]	4.69

[1] PuO_2F_2 "standard salt" is used as a bounding media for Pu-oxalate $Pu(C_2O_4)_2{\cdot}6H_2O$.

[2] PuO_2F_2 "standard salt" is used as a bounding media for $PuO_2(NO_3)_2$,$Pu(NO_3)_4$ and Pu-oxalate $Pu(C_2O_4)_2{\cdot}6H_2O$.

[3] Optimum H/Pu value

4.2 Comparison of Neutron Physical Parameters

An atomic comparison between the benchmark fissile medium PuO_2+polystyrene and the reference fissile media used in the MFFF applications (PuO_2+H_2O, Pu-oxalate+H_2O and $PuO_2F_2+H_2O$) is presented in Table 4–3 and Table 4-4.

Table 4–3 Atomic Comparison of the PuO_2-Polystyrene Experiments and of Pu Compounds in the MFFF Applications

Benchmark Experiment	**Reference Fissile Media Used in the MFFF Design Application**			
PuO_2 in polystyrene $(CH)_n$	**PuO_2 in water PuO_2+H_2O**	**Pu^{III}-nitrate $Pu(NO_3)_3.5(H_2O)$ $+H_2O$**	**Pu-oxalate $Pu(C_2O_4)_2.6(H_2O)$ $+H_2O$**	**"Standard salt" $PuO_2F_2+H_2O$**
$\rho_{(comp)}$ [1]	$\rho_{(comp)} = 11.460$ [2] [g/cm³]	$\rho_{(comp)} = 2.150$ [3] [g/cm³]	$\rho_{(comp)} = 2.700$ [4] [g/cm³]	$\rho_{(comp)} = 4.187$ [5] [g/cm³]
Pu	Pu	Pu	Pu	Pu
O	O	O	O	O
H	H	H	H	H
C	-	-	C	-
-	-	N	-	F

[1] PuO_2 densities in the experiments of both benchmarks PU-COMP-MIXED-01 and PU-COMP-MIXED-02 (cf. Table 5-1) are between 0.425 g/cm³ and 6.581 g/cm³

[2] theoretical density [20].

[3] compound (crystal) density $Pu(NO_3)_4\ 5H_2O$ [23].

[4] compound (crystal) density $Pu(C_2O_4)_2\ 6H_2O$ [21], [22] (see Table 4-11). The dilution law used for this assumed homogeneous mixture is a simple AIVM as described in [23].

[5] The PuO_2F_2 "standard salt" law is used in criticality studies only as a bounding media (cf. Section 4.4) to cover all salt solutions [23]. Therefore, this law is not valid for genuine PuO_2F_2 media. The crystal density of 6.5 g/cm³ [20] is not relevant for the MFFF application because PuO_2F_2 never appears in the process.

Table 4-3 and Table 4-4 show that the most important atoms in the reference fissile media are covered by the experiments. In the well moderated (optimum of moderation) and overmoderated range, the influence of C, F and N on the neutron spectrum (EALF) is small. The increasing influence of C, F, N on the neutron spectrum in the low moderated range is discussed in the following sections.

As discussed in Section 4.1 the physical parameter (H/Pu) of the design application (5) varies from H/Pu = 0 to H/Pu = 83000. To cover the relevant range of H/Pu between 12 and 500 where the maximum of k_{eff} occurs, two groups of benchmark experiments are established:

Group 1: Benchmarks with PuO_2 powder-polystyrene compacts with H/Pu < 50.

Group 2: Benchmarks with Pu-nitrate solution with H/Pu > 50.

Table 4–4 Atomic Comparison of the Pu-nitrate Experiments and of Pu Compounds in the MFFF Applications

Benchmark Experiment	**Reference fissile media used in the MFFF Design Application**			
Pu-nitrate solution	**PuO_2 in water** **PuO_2+H_2O**	**Pu^{III}-nitrate** **$Pu(NO_3)_3.5(H_2O)$** **+H_2O**	**Pu-oxalate** **$Pu(C_2O_4)_2.6(H_2O)$** **+H_2O**	**"Standard Salt"** **PuO_2F_2+H_2O**
$\rho_{(comp)}$ [1]	$\rho_{(comp)} = 11.460$ [2] [g/cm^3]	$\rho_{(comp)} = 2.150$ [3] [g/cm^3]	$\rho_{(comp)} = 2.700$ [4] [g/cm^3]	$\rho_{(comp)} = 4.187$ [5] [g/cm^3]
Pu	Pu	Pu	Pu	Pu
O	O	O	O	O
H	H	H	H	H
-	-	-	C	-
N	-	N	-	F

[1] Pu concentrations in the Pu-nitrate experiments of benchmarks PU-SOL-THERM (cf. Table 5-1) are between 115 g/l and 268.7 g/l.

[2] theoretical density [20].

[3] compound (crystal) density $Pu(NO_3)_4$ $5H_2O$ [23].

[4] compound (crystal) density $Pu(C_2O_4)_2$ $6H_2O$ [21], [22] (see Table 4-11). The dilution law used for this assumed homogeneous mixture is a simple AIVM as described in [23].

5) The PuO_2F_2 "standard salt" law is used in criticality studies only as a bounding media (cf. Section 4.4) to cover all salt solutions [23]. Therefore, this law is not valid for genuine PuO_2F_2 media. The crystal density of 6.5 g/cm^3 [20] is not relevant for the MFFF application because PuO_2F_2 never appears in the process.

Table 4–5 through Table 4–8 show that the EALF values of the applications are within or near the range of the experimental EALF values. The following experiments are used for this comparison:

Group 1: PU_COMP_MIXED_001, 002 (Polystyrene moderated PuO_2 powder).

Group 2: PU_SOL_THERM_001, 008, 014, 015, 016, 017 (Pu-nitrate solutions).

Table 4–5 through Table 4–8 present a comparison of the EALF values of the PuO_2+Polystyrene experiments (Group 1) and the Pu-nitrate experiments (Group 2) in comparison with the EALF values found for water and Plexiglas reflected infinite slabs and infinite cylinders containing different fissile media. The EALF values for the two standard geometry are calculated for a critical full water reflected system as described in [19] and for a full Plexiglas reflected system. The primary result of this comparison is that the EALF values for the different reference fissile media of the MFFF design applications for H/Pu ratios equal or higher than 15 are within or near the experimental EALF range of Group 1. It is also apparent that the Pu nitrate experiments (Group 2) are suitable to describe the Pu compounds in aqueous solution with H/Pu > 50.

For H/Pu ratios lower than 15, larger differences between the different Pu compounds occur. The differences are larger for slab geometry than for cylindrical geometry. On the other hand it is obvious that the EALF value depends not only on the geometrical shape of the fissile media but also on the reflector material composition, because both effects (geometric shape and reflector material) influence the neutron spectrum in the lateral zones of the fissile medium, particularly if the core dimensions are small compared to the mean free path of the fast neutrons. To study the different factors that affect the neutron energy spectrum in the fissile medium zone and therefore the key parameter EALF, a parametric study of EALF is presented in Section 4.3.

Table 4–5 Comparison of EALF Values Found for the Experiments and in the Design Applications (Infinite Critical Slab with 30 cm Plexiglas Reflector)

Parameter	Experiment [2]		PuO_2+H_2O	Pu-oxalate+H_2O	$PuO_2F_2+H_2O$
H/Pu	EALF [eV]	Geometry	EALF [eV]	EALF [eV]	EALF [eV]
(g1) 0.04	1850 to 4900	Parallelepiped	154	- (1)	140
(g1) 5	56.8 to 92.9	Parallelepiped	17.3	- (1)	16.3
(g1) 15	4.12 to 6.65	Parallelepiped	2.72	2.62	2.67
(g1) 50	0.70 to 0.74	Parallelepiped	0.41	0.41	0.41
(g2) 85.03	0.55	Sphere	0.22	0.22	0.22
(g2) 88.43	0.52	Sphere	0.21	0.21	0.21
(g2) 155.27	0.24	Cylinder	0.13	0.13	0.13
(g2) 210.18	0.17	Cylinder	0.10	0.10	0.10

(g1) Group 1: Critical experiments with PuO_2 powder in polystyrene $(CH)_n$ [5], [6], [7].
(g2) Group 2: Critical experiments with Pu-nitrate solutions [5].
(1) H/Pu > 12 in $Pu(C_2O_4)_2.6H_2O$ [21], [22].
(2) cf. Table 5-1.

Table 4–6 Comparison of EALF Values Found for the Experiments and in the Design Applications (Infinite Critical Slab with 30 cm Water Reflector)

Parameter	Experiment [2]		PuO_2+H_2O	Pu-oxalate+H_2O	$PuO_2F_2+H_2O$
H/Pu	EALF [eV]	Geometry	EALF [eV]	EALF [eV]	EALF [eV]
(g1) 0.04	1850 to 4900	Parallelepiped	323	- (1)	286
(g1) 5	56.8 to 92.9	Parallelepiped	26.9	- (1)	25.2
(g1) 15	4.12 to 6.65	Parallelepiped	3.56	3.41	3.48
(g1) 50	0.70 to 0.74	Parallelepiped	0.47	0.46	0.47
(g2) 85.03	0.55	Sphere	0.24	0.24	0.24
(g2) 88.43	0.52	Sphere	0.23	0.23	0.23
(g2) 155.27	0.24	Cylinder	0.13	0.13	0.13
(g2) 210.18	0.17	Cylinder	0.11	0.11	0.11

(g1) Group 1: Critical experiments with PuO2 powder in polystyrene $(CH)_n$ [5], [6], [7].
(g2) Group 2: Critical experiments with Pu-nitrate solutions [5].
(1) H/Pu > 12 $Pu(C_2O_4)_2.6H_2O$ [21], [22].
(2) cf. Table 5-1.

Table 4–7 Comparison of EALF Values Found for the Experiments and in the Design Applications (Infinite Critical Cylinder with 30 cm Plexiglas Reflector)

Parameter	Experiment 2)		PuO_2+H_2O	Pu-oxalate+H_2O	$PuO_2F_2+H_2O$
H/Pu	EALF [eV]	Geometry	EALF [eV]	EALF [eV]	EALF [eV]
(g1) 0.04	1850 to 4900	Parallelepiped	6945	- (1)	1386
(g1) 5	56.8 to 92.9	Parallelepiped	95.1	- (1)	58.7
(g1) 15	4.12 to 6.65	Parallelepiped	6.69	5.68	5.96
(g1) 50	0.70 to 0.74	Parallelepiped	0.62	0.61	0.62
(g2) 85.03	0.55	Sphere	0.30	0.29	0.30
(g2) 88.43	0.52	Sphere	0.28	0.28	0.28
(g2) 155.27	0.24	Cylinder	0.15	0.15	0.15
(g2) 210.18	0.17	Cylinder	0.12	0.12	0.12

(g1) Group 1: Critical experiments with PuO2 powder in polystyrene (CH)n [5], [6], [7].
(g2) Group 2: Critical experiments with Pu-nitrate solutions [5].
(1) H/Pu > 12 in $Pu(C_2O_4)_2.6H_2O$ [21], [22].
(2) cf. Table 5-1.

Table 4–8 Comparison of EALF Values Found for the Experiments and in the Design Applications (Infinite Critical Cylinder with 30 cm Water Reflector)

Parameter	Experiment 2)		PuO_2+H_2O	Pu-oxalate+H_2O	$PuO_2F_2+H_2O$
H/Pu	EALF [eV]	Geometry	EALF [eV]	EALF [eV]	EALF [eV]
(g1) 0.04	1850 to 4900	Parallelepiped	9049	- (1)	1988
(g1) 5	56.8 to 92.9	Parallelepiped	113.0	- (1)	72.3
(g1) 15	4.12 to 6.65	Parallelepiped	7.46	6.40	6.71
(g1) 50	0.70 to 0.74	Parallelepiped	0.66	0.64	0.65
(g2) 85.03	0.55	Sphere	0.24	0.30	0.31
(g2) 88.43	0.52	Sphere	0.23	0.29	0.29
(g2) 155.27	0.24	Cylinder	0.13	0.16	0.16
(g2) 210.18	0.17	Cylinder	0.11	0.12	0.12

(g1) Group 1: Critical experiments with PuO2 powder in polystyrene (CH)n [5], [6], [7].
(g2) Group 2: Critical experiments with Pu-nitrate solutions [5].
(1) H/Pu > 12 in Pu-oxalate $Pu(C_2O_4)_2.6H_2O$ [21], [22].
(2) cf. Table 5-1.

4.3 Sensitivity Studies on EALF for Different Pu Compounds

In MFFF design applications, the H/Pu ratio of the reference fissile media is defined on the basis of the Pu isotopes ^{239}Pu and ^{240}Pu since other Pu isotopes are assumed to be absent. In addition to the Pu isotopes, the presence of other atoms in the compound with significant macroscopic scattering and absorption cross sections can have an influence on the system reactivity.

As shown in the MFFF document "*Minimum critical and maximum permissible parameters of Pu containing media*" [19] a potential criticality risk ($k_{inf} > 1$) exists over a wide range of Pu concentrations from 10 g/liter up to the highest possible concentration defined by the crystal density of the dry Pu-compound . Figure 4–1 shows the basic physical parameter k_{inf} versus H/Pu in the range $0 < H/Pu < 1000$ for different Pu compounds in aqueous solution.

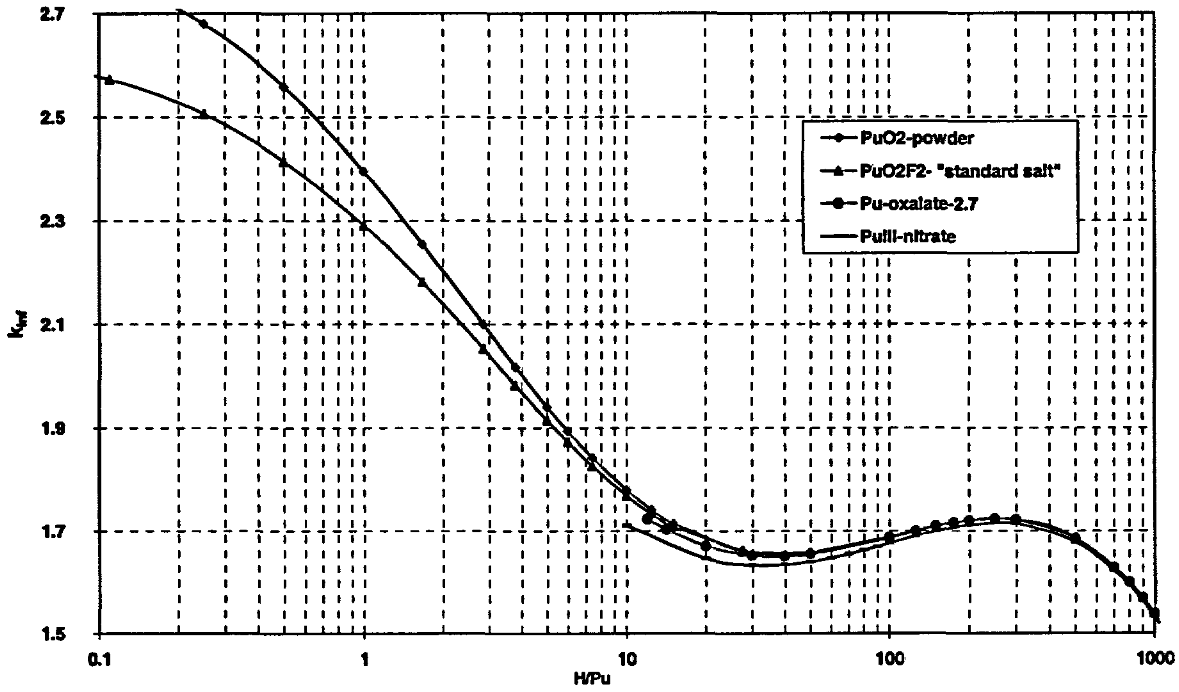


Figure 4–1 k_{inf} versus H/Pu for different Pu compounds in aqueous solution

It can be seen from the Figure 4–1 that for higher H/Pu ratios (lower Pu concentrations) the k_{inf} is determined only by the H/Pu ratio. The influence of other atoms in the compound on k_{inf} can be neglected. This means the k_{inf} in the range of higher H/Pu values is only influenced by hydrogen, oxygen (coming from H_2O) and the Pu isotopes.

If the Pu concentration in the aqueous solution increases (H/Pu decreases) the different numbers of oxygen, nitrogen and carbon atoms per Pu isotope in the Pu compound (molecule) changes the neutron flux spectrum and therefore affects the k_{inf} and the EALF value.

In the following, the influence of three factors on the EALF value will be determined as a function of the H/Pu ratio:

- Composition of the Pu compounds,
- Geometric shape of the fissile medium zone,
- Reflector material composition.

4.3.1 Plutonium Compound Composition

Figure 4–2 shows the EALF value versus the H/Pu ratio for different Pu compounds. The EALF values shown are calculated for full water reflected cylinders in admissible dimensions ($k_{eff} = 0.93$). It is apparent that the difference in the EALF values for the different compounds increases with lower H/Pu values.

The PuO_2+H_2O system leads for a given H/Pu to the highest EALF value. The more complex compounds lead to smaller values because of their lower Pu density. If the H/Pu is fixed the density of the fissile media (Pu concentration in case of solutions) as well as the geometrical shape and dimensions have an influence of EALF.

For higher H/Pu ratios the differences between the EALF values found for the different Pu-compounds decreases so that there is practically no significant difference between the different Pu compounds in water above H/Pu = 50. Figure 4–3 shows the relative difference DELTA-EALF between the EALF values versus the H/Pu ratio for different Pu compounds over the full range of moderation. The PuO_2-polystyrene media (exp) is used as the basis media. Thus the difference in EALF expressed as:

DELTA-EALF = (EALF(media i) – EALF(exp))/EALF(exp)

is a measure of how far the EALF value of a reference medium of the MFFF application is from the EALF value found for the experiment at the same H/Pu ratio.

Figure 4–4 shows the DELTA-EALF values versus the H/Pu in the low moderated range: 0 < H/Pu < 30 in a linear scale.

Therefore, it can be concluded that all design applications with H/Pu values higher than 50 have similar EALF values as was also shown in Figure 4–2. Significant differences between EALF values appear only in the low moderated and unmoderated range with H/Pu values lower than 50. This is also significant by comparison of the neutron flux spectrum obtained for infinite full water reflected slabs filled with PuO_2 and Pu-oxalate, cf. Attachment 1, Figure A1-1 and Figure A1-2. It is obvious that differences in the dry neutron spectrum occur over the full energy range at H/Pu = 0.04. In the dry moderated range (H/Pu = 0.04), the PuO_2-polystyrene experiments are in a good agreement with the PuO_2-powder application, whereas significant differences occur when H/Pu ratio increases.

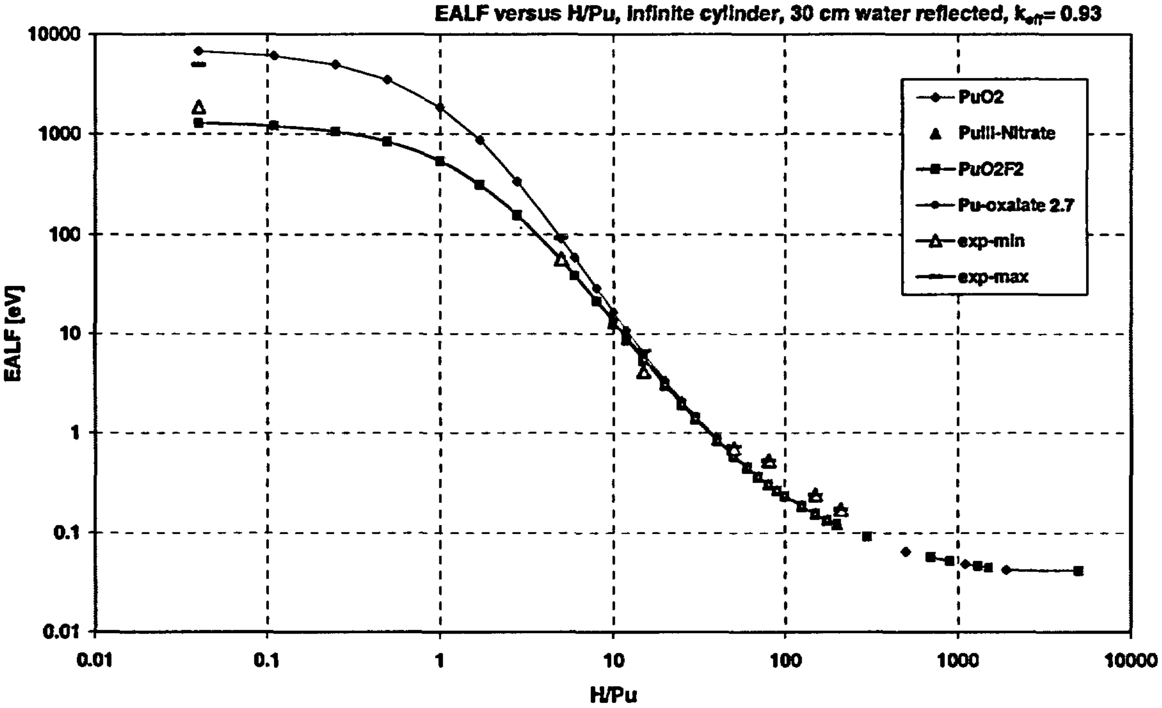


Figure 4–2 EALF versus H/Pu for different Pu compounds in aqueous solution over the full range of H/Pu

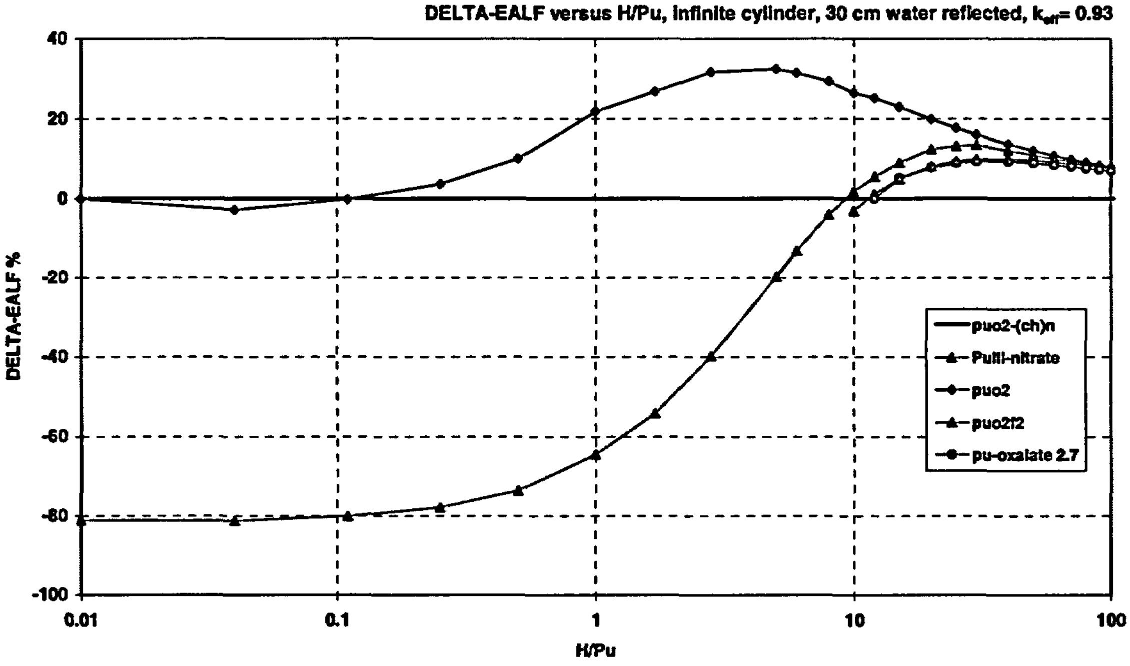


Figure 4–3 DELTA-EALF versus H/Pu for different Pu compounds in water over the full range of H/Pu

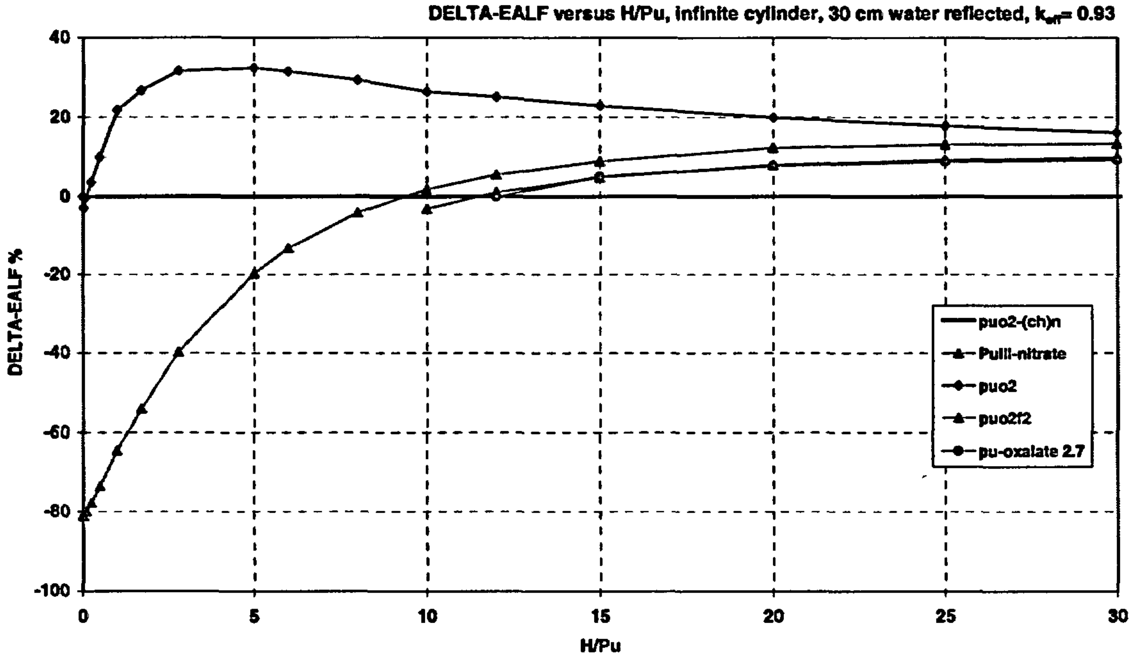


Figure 4–4 DELTA-EALF versus H/Pu for different Pu compounds in water in the range of 0 < H/Pu < 30

4.3.2 Geometrical Shape

Calculations also show that the geometrical shape has a significant influence on the EALF values. In order to eliminate this geometrical shape effect, the experimental configuration geometry of the PuO_2-polystyrene experiments (parallelepiped compacts) is used to model different Pu compounds. This means the PuO_2-polystyrene compacts filled with the reference fissile media instead of the PuO_2-polystyrene medium (exp) preserving the same H/Pu ratio as in the experimental fissile medium. Table 4-9 shows the differences in the EALF values in the function DELTA-EALF.

From Table 4-9, the PuO_2-polystyrene experiments describe the EALF situation in the Pu-oxalate solution at H/Pu = 15 nearly exactly (differences lower than 2%). The differences with the PuO_2F_2 "standard salt" solution are smaller than 11%, whereas the differences with the PuO_2 systems is between 45% and 55%.

Detailed EALF values are presented in Attachment 1.

Table 4–10 shows the range of EALF values obtained for the reference fissile media assumed in the experimental configuration. The EALF values for a given H/Pu ratio of 15 calculated for the Pu-oxalate systems are in excellent agreement with the EALF values of the PuO_2-polystyrene experiments.

Besides the application with Pu-oxalate solution and Pu-oxalate precipitates the PuO_2 powder H_2O systems with high powder densities between 3.5 g/cm^3 (H/Pu = 5.973) and 7.0 g/cm^3 (H/Pu = 1.674) are an important application in the MFFF.

The following figures illustrate how far the PuO_2 powder application (full saturated powder with full H_2O reflector) is from the critical experiment with PuO_2-polystyrene and full Plexiglas reflector. Figure 4–5 shows the EALF as a function of H/Pu for critical full reflected infinite cylinders and critical full reflected infinite slabs representing the experimental configuration and the PuO_2+H_2O application. Figure 4–6 and Figure 4–7 show the differences between the EALF values in the relevant application range of $1 < H/Pu < 10$.

The differences between the experimental EALF value and the EALF value found for the same H/Pu = 1.674 for the PuO_2-powder application are 87% in case of slab geometry and 78% in case of cylindrical geometry.

Table 4–9 Comparison of DELTA-EALF Values of the Experimental Configuration Filled with PuO_2-Polystyrene and Other Reference Fissile Media

Case	C (Pu) [g/cm^3]	wt. % Pu-240	H/Pu	DELTA EALF PuO_2 [%]	DELTA EALF PuO_2F_2 [%]	DELTA EALF Pu-Oxalate [%]
10	1.12	2.2	15	55.1	11.4	0.4
11	1.12	2.2	15	53.5	10.3	0.2
12	1.12	2.2	15	53.4	9.8	0.2
13	1.12	2.2	15	52.5	9.8	0.2
14	1.12	2.2	15	52.2	10.4	0.9
15	1.12	2.2	15	51.5	9.4	1.7
16	1.12	2.2	15	51.9	10.6	0.5
17	1.05	8.06	15	51.5	11.8	1.2
18	1.05	8.06	15	48.2	9.4	1.5
19	1.05	8.06	15	46.9	9.5	1.8
20	1.05	8.06	15	46.5	9.3	1.4
21	1.05	8.06	15	46.2	9.1	1.5
22	1.05	8.06	15	48.2	9.9	1.2

DELTA-EALF = (EALF(media i) – EALF(exp))/EALF(exp)

Table 4–10 Comparison of the Range of EALF Values of the Experimental Configuration Filled with PuO_2-Polystyrene and Other Reference Fissile Media

Cases	PuO_2+H_2O	$PuO_2F_2+H_2O$	Pu-oxalate+H_2O	Experiments [5], [6] $PuO_2+(CH)_n$
Cases 10 – 16	6.39 – 8.48	4.59 – 6.15	4.14 – 5.66	4.12 – 5.57
Cases 17 – 22	7.47 – 9.77	5.51 – 7.29	4.99 – 6.78	4.93 – 6.68

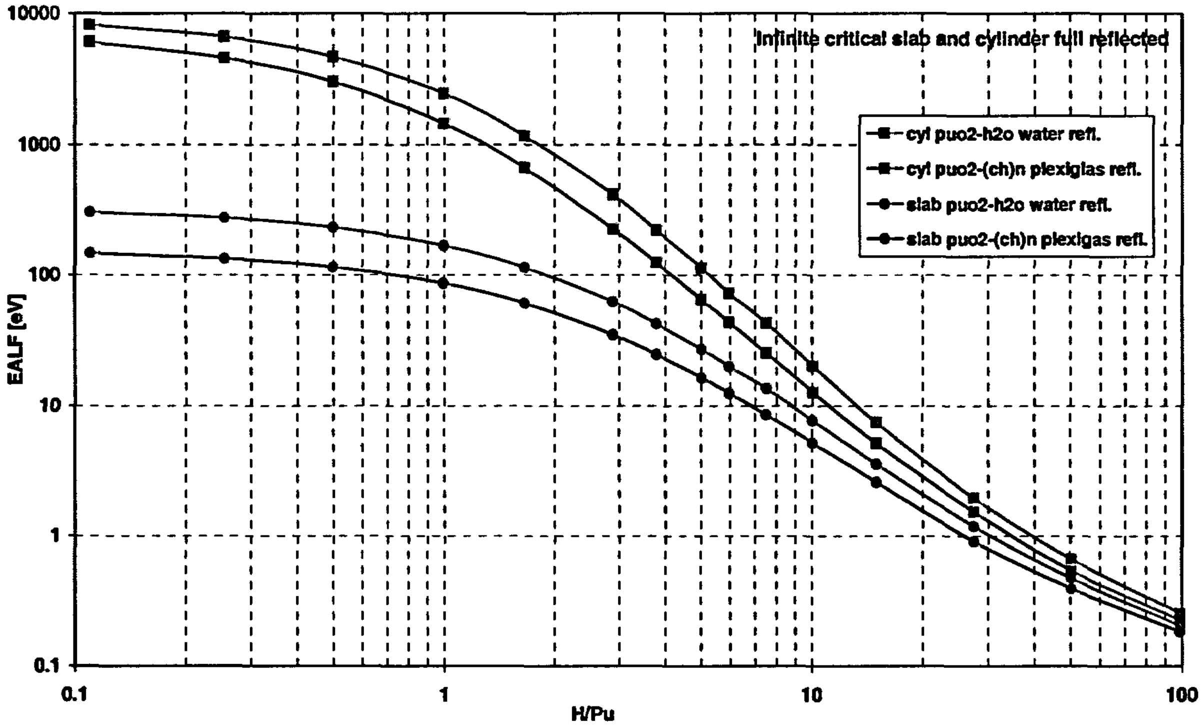


Figure 4–5 EALF versus H/Pu for a critical full reflected infinite cylinder and slab for PuO_2-polystyrene with Plexiglas reflector and PuO_2+H_2O with water reflector over the full range of H/Pu

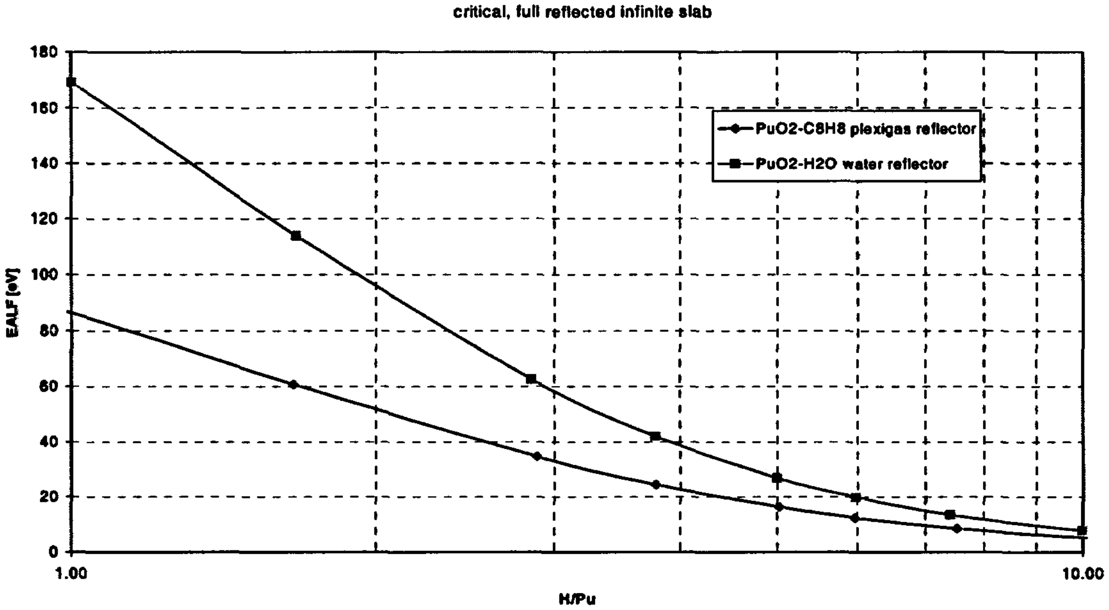


Figure 4–6 EALF versus H/Pu for different reflector materials in the range of 1 ≤ H/Pu ≤ 10, infinite critical slab

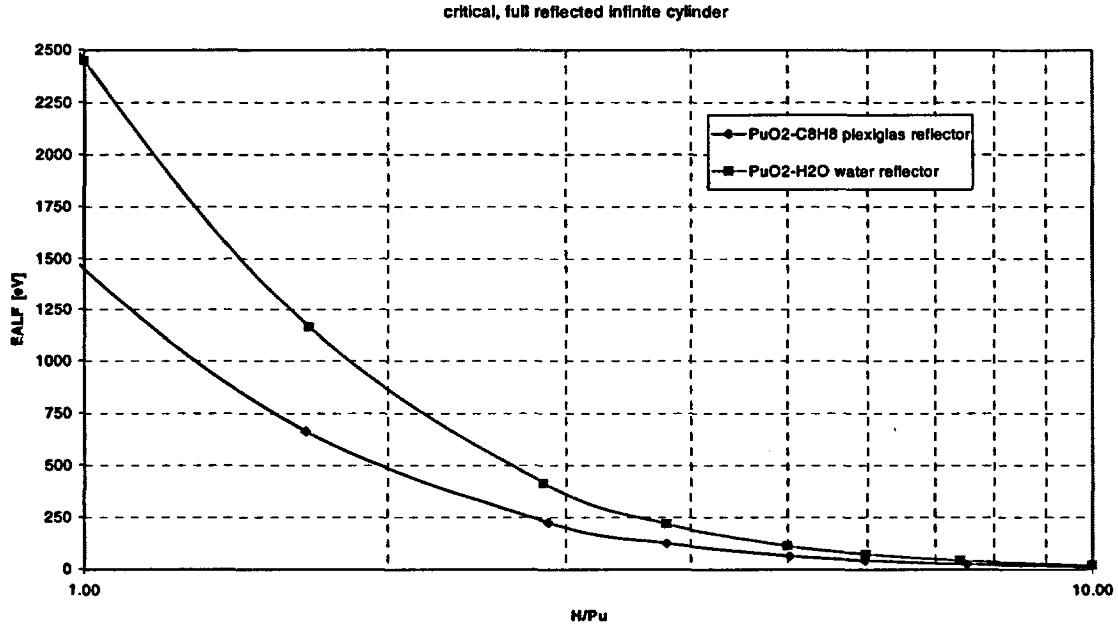


Figure 4–7 EALF versus H/Pu for different reflector materials in the range of 1 ≤ H/Pu ≤ 10, infinite critical cylinder

4.3.3 Reflector Material Composition

The comparison of the EALF values presented in Table 4–6 and Table 4–7 shows the increasing influence of the reflector material composition on EALF with decreasing H/Pu.

Figure 4–8 compares the EALF values for four different reflector materials used in the MFFF for the case of slab geometry. It was shown in Table 4–6 and Table 4–7 that the slab geometry shows the strongest influence of the reflector materials on EALF.

Therefore, in the following figures the influence of Plexiglas reflector, water reflector, concrete reflector and borated concrete reflector materials on the EALF is studied for an infinite slab filled with PuO_2-polystyrene mixture corresponding to the experiments of Group 1 and Pu-nitrate experiments of Group 2.

Figure 4–8 shows the strong influence of borated concrete and Cd-steel+water reflectors on the EALF value in the $H/Pu < 50$ range. Again in the range over $H/Pu = 50$ there is no significant difference between concrete, Plexiglas and water reflectors whereas the differences to the borated concrete still remain but with decreasing influence. In the range between $10 < H/Pu < 1000$, It is evident that these differences between concrete reflector, Plexiglas reflector and water reflector are small.

Therefore Figure 4–9 shows the DELTA-EALF values as a function of the H/Pu for three different reflector materials used in MFFF design applications over the full range of H/Pu (DELTA-EALF is defined as: (EALF(refl i) - EALF(plex)) / EALF(plex)). The reference reflector material is Plexiglas (plex) used in the experiments of Group 1.

In the H/Pu range between 10 and 1000, the differences between concrete reflector and Plexiglas reflector in this range are smaller then 20%. Hence, the MFFF applications of AOA(5) with concrete reflector (e.g., the tanks filled with Pu-oxalate in the AP cells) are well described by the PuO_2-polystyrene experiments of Group 1.

Next the influence of different reflector materials is studied for a infinite slab filled with Pu-nitrate solution. Figure 4-10 shows the EALF values as a function of the H/Pu for an infinite slab filled with Pu-nitrate solution with different reflector materials in the H/Pu range between 10 and 1000. There is no other trend in this H/Pu range as in the case of Pu-oxalate solution.

Figure 4–11 shows DELTA-EALF as a function of H/Pu in the range of $10 < H/Pu < 1000$. The reference EALF value in this case is the EALF value of the full water reflected slab (water) to be in agreement with the experiments of Group 2.

The difference between the EALF values of regular concrete (reg-concrete) reflected slabs with Pu-nitrate solution at $H/Pu = 100$ and water reflected slabs with the same solution is lower than 10 %. The difference between colemanite concrete reflected slabs and water reflected slabs filled with Pu-nitrate solution at $H/Pu = 100$ is larger. Therefore in applications with colemanite concrete the EALF values found for the application have to be compared with the experimental EALF values in a case by case manner.

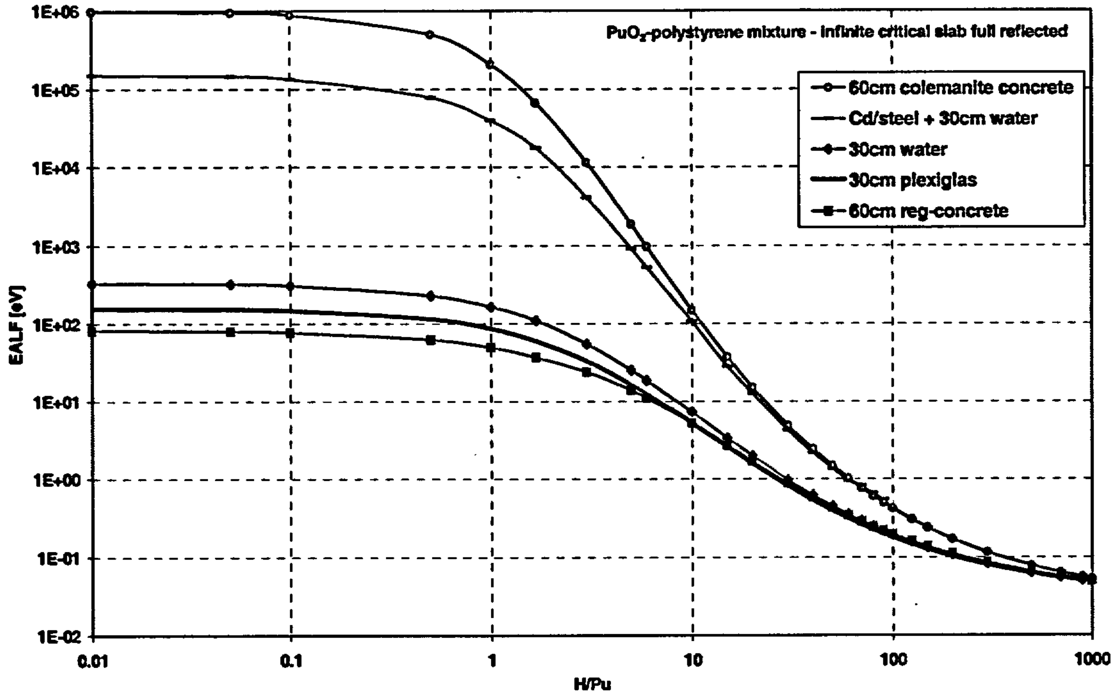


Figure 4–8 EALF versus H/Pu for different reflector materials over the full range of H/Pu, critical infinite slab with PuO$_2$-polystyrene mixtures

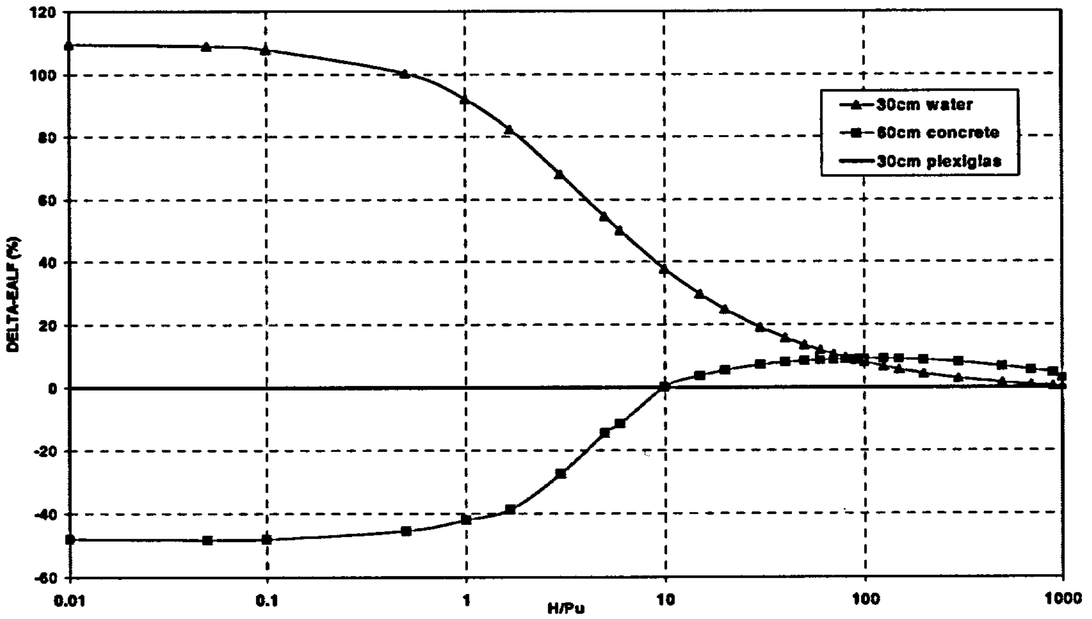


Figure 4–9 DELTA-EALF versus H/Pu for different reflector materials over the full range of H/Pu, critical full reflected slab filled with PuO$_2$-polystyrene mixtures

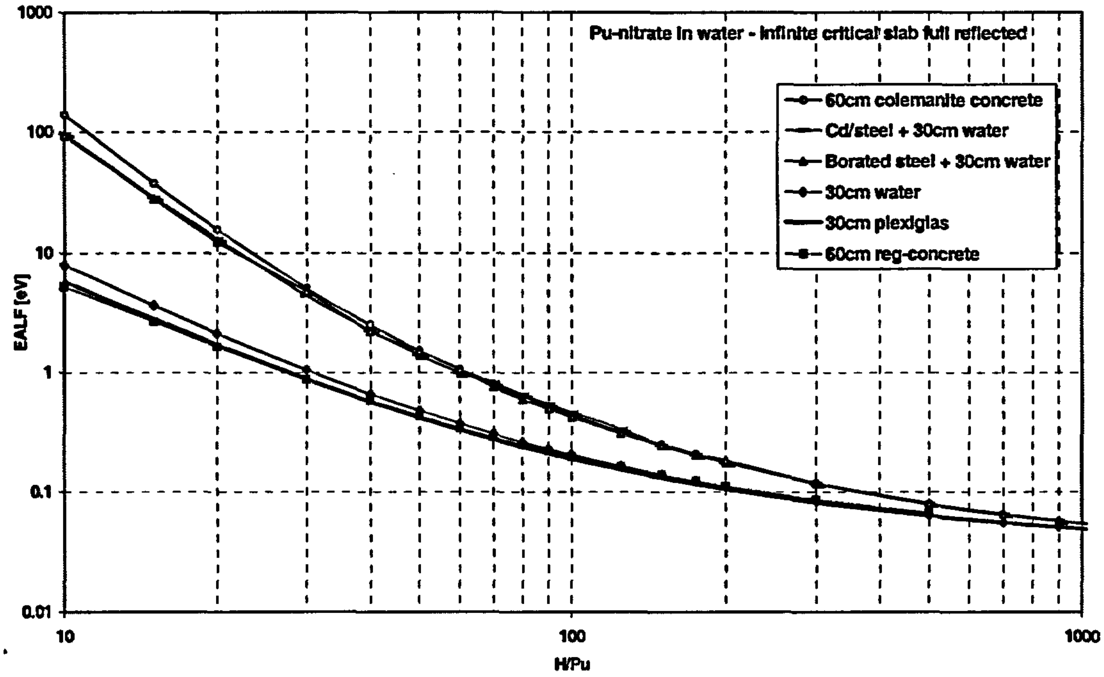


Figure 4–10 EALF versus H/Pu for different reflector materials over the range of 10 < H/Pu < 1000, critical full reflected slab filled with Pu-nitrate solution

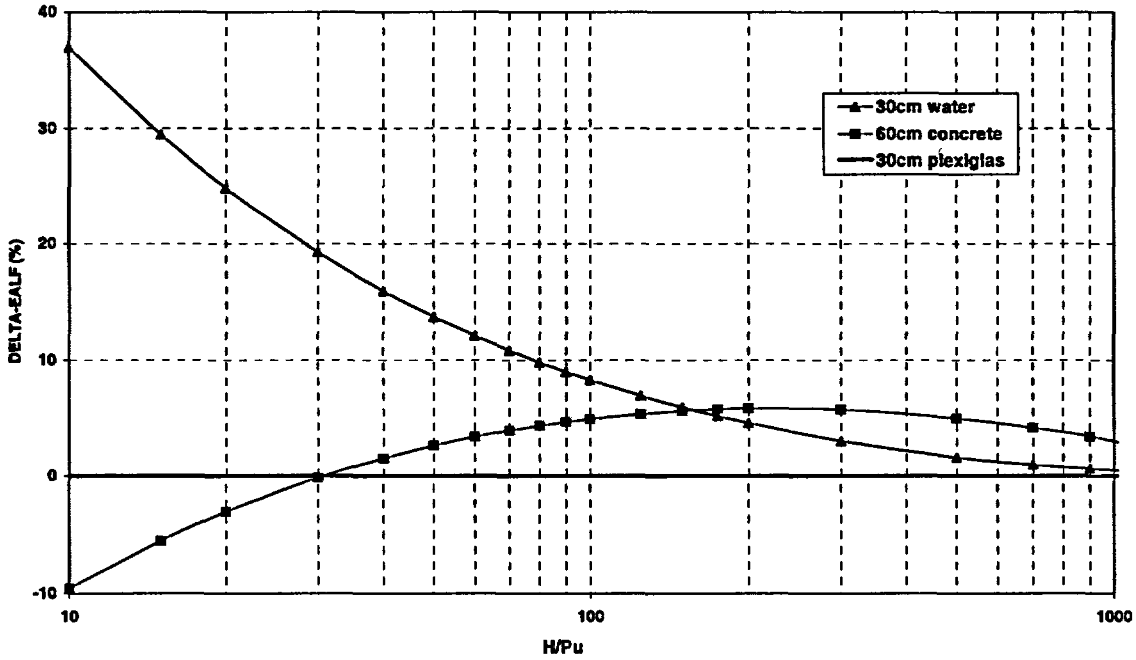


Figure 4–11 DELTA-EALF versus H/Pu for different reflector materials in the range of 10 ≤ H/Pu ≤ 1000, critical full reflected slab filled with Pu-nitrate solution

4.4 Determination of a Reactivity Bounding Fissile Medium

Due to the Aqueous Polishing process the range of the fissile media concentrations in the different process stages vary from nominal Pu concentrations of 10 g/liter (H/Pu < 1000) up to the highest possible concentrations of the Pu-oxalate and PuO_2 powders of 3.5 g/cm^3 [18] (see Table 4-11).

For the criticality safety analysis it is important to know at which Pu concentration or H/Pu ratio the absolute maximum of k_{eff} occurs and whether a second relative maximum exists. The code validation for this AOA(5) has to cover the EALF range or H/Pu range where the maximum k_{eff} values of the application occur. The height of the maximum depends on the Pu compound density. In order to cover the variety of Pu compounds and compound densities that can occur in the AP process, a bounding media, PuO_2F_2 "standard salt," is introduced in the MFFF application [18]. This approach was first employed in the criticality studies of Paxton et al. [27] and justified for application in the French reprocessing plants by Fruchard et al. in [28].

The advantage of the PuO_2F_2 "standard salt" defined in [23] is that it also describes the low moderated range between H/Pu = 0 and H/Pu = 12. Furthermore, it is demonstrated in Table 4-11 that PuO_2F_2 bounds all possible Pu^{IV} oxalate compounds in the MFFF.

Table 4–11 Comparison of experimental and estimated Pu compounds densities

Pu compound	Density [g/cm^3]	Reference
$Pu(C_2O_4)_2.6H_2O$	2.70	Experimental Pu^{IV}-oxalate density deduced from the unit cell parameters in [21], [22]
$Pu(C_2O_4)_2.2H_2O$	3.05	Experimental Pu^{IV}-oxalate density deduced from the unit cell parameters in [21], [22]
$Pu(C_2O_4)_2$	3.225[1)]	Estimated Pu^{IV}-oxalate density by linear extrapolation from the values of $Pu^{IV}.6H_2O$-2.70 and $Pu^{IV}.2H_2O$-3.05
"Standard salt" PuO_2F_2	4.187	Estimated PuO_2F_2 "standard salt" density used in criticality studies only to covers the MFFF Pu compounds [23]. This law is not valid for genuine PuO_2F_2 media (crystal density of 6.5 g/cm^3 [20])
PuO_2	3.50	Basis of Design [18]

1)An estimated conservative value of 3.50 g/cm^3 is used in the calculations as shown in Figure 4-13

In the following figures, typical k_{eff} curves are presented as a function of H/Pu for slab geometry. Figure 4–12 shows the k_{eff} for a slab filled with different Aqueous Process reference fissile media versus H/Pu over a wide range of H/Pu.

All k_{eff}-values corresponding to the Figure 4-12 through Figure 4-14 are presented in Attachment 2, TableA2-1. The fissile media number densities are addressed in [19].

For the Aqueous Polishing process the range of H/Pu between 0 (C(Pu) ≈ 3.0 g/cm^3) and 500 (C(Pu) ≈ 0.05 g/cm^3) is of interest. Therefore Figure 4-13 and Figure 4-14 compares k_{eff}-values respectively versus H/Pu and C(Pu) in this range to demonstrate that the PuO_2F_2 "standard salt" bounds various Pu^{IV}-oxalate solutions which can occur in the AP process. It appears that the number of crystal water molecules in the Pu precipitate is as important as the density. Thus, the most reactive Pu-oxalate is the following one: $Pu(C_2O_4)_2.6H_2O$ with a crystal density of 2.7 g/cm^3. Based on measurements of Pu-oxalate density, [29] provides a maximum density of 2.7 g/cm^3 with six H_2O crystalline water molecules. This value is considered in the MFFF AP process.

It is also obvious from Figure 4–12 and that the maximum of k_{eff} occurs for Pu-nitrate and Pu-oxalate in the same range around H/Pu = 100, whereas the maximum of PuO_2F_2 occurs at H/Pu = 30. Therefore the calculational bias for Pu oxalate solutions is better described by the Pu-nitrate experiments with H/Pu values between 78 and 211 whereas the calculational bias for PuO_2F_2 "standard salt" solutions is better described by the PuO_2-polystyrene experiments.

Under these conditions, Pu oxalate as shown in Figure 4–12 and Figure 4–13 is of similar reactivity as the validated Pu nitrate and validated PuO_2 powder (it falls between them), and is clearly bounded (by over 2% at H/Pu=30) by PuO_2F_2 which is used for the calculations. Thus, the use of PuO_2F_2 (rather than Pu oxalate) represents additional calculational margin and is also validated in this region. Therefore, for PuO_2F_2, a lower limit for the bounding, abnormal cases of H/Pu=30 is appropriate.

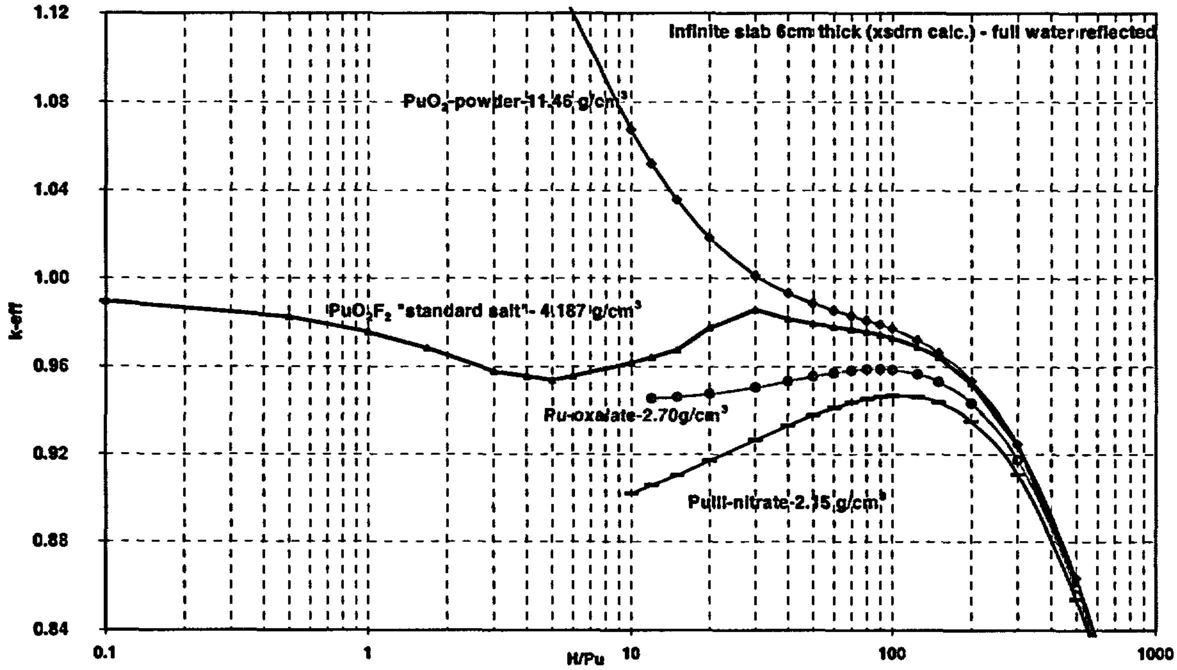


Figure 4–12 k_{eff} of a full water reflected infinite slab versus H/Pu for the main Pu-compounds of MFFF in water

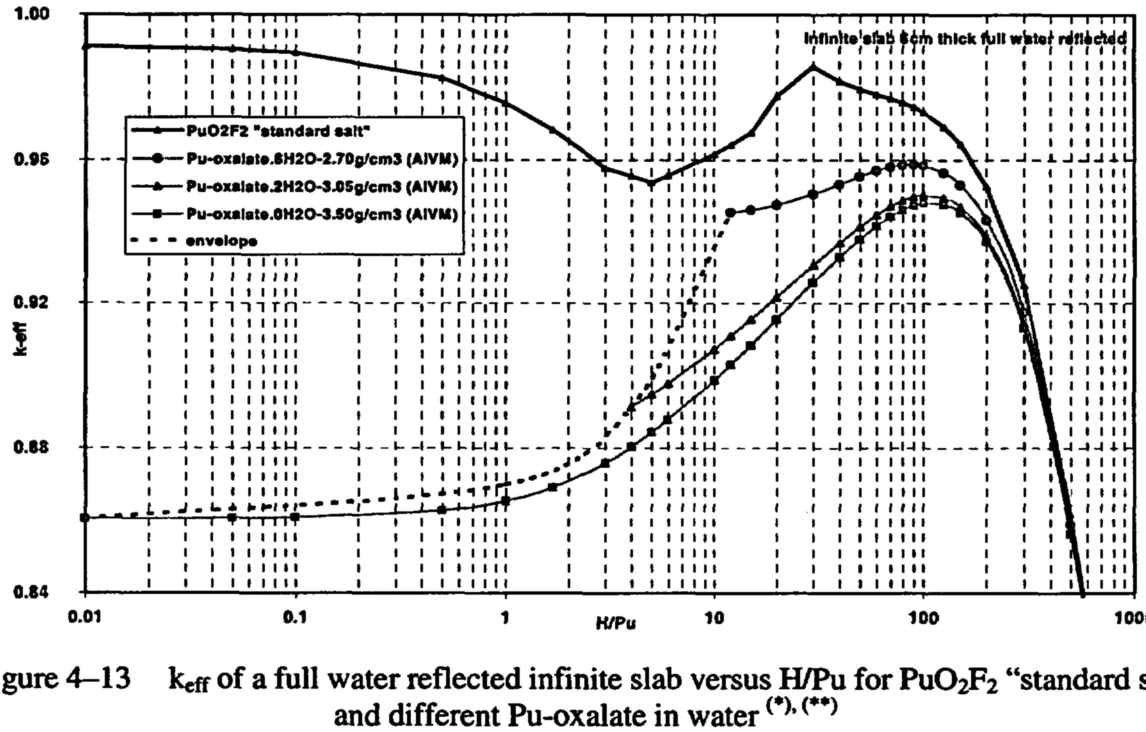


Figure 4–13 k_{eff} of a full water reflected infinite slab versus H/Pu for PuO_2F_2 "standard salt" and different Pu-oxalate in water (*), (**)

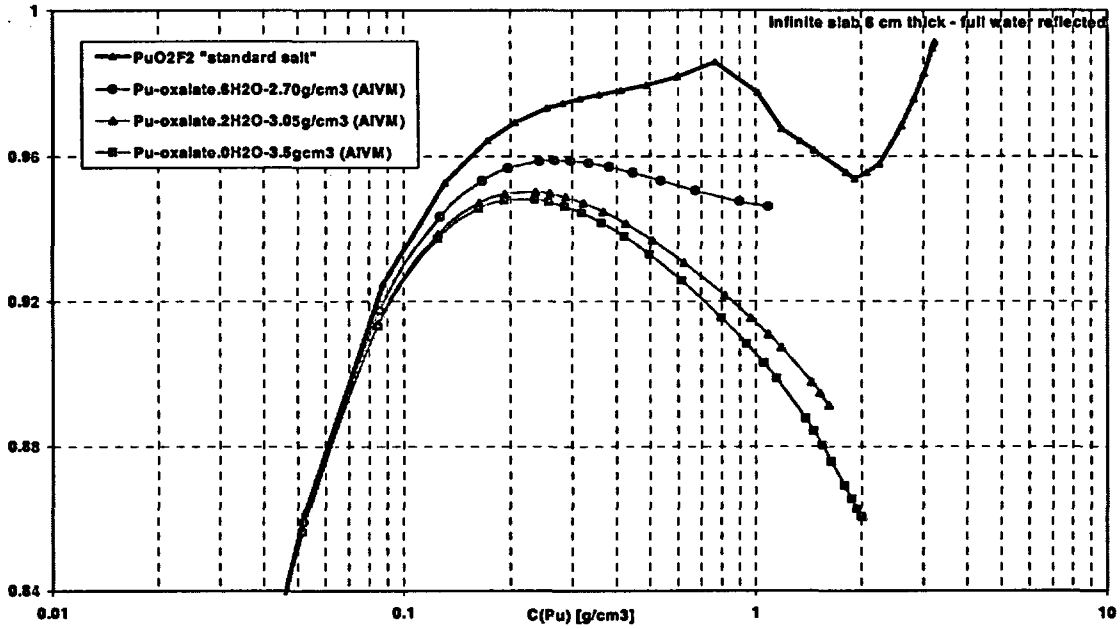


Figure 4–14 k_{eff} of a full water reflected infinite slab versus C(Pu) for PuO_2F_2 “standard salt” and different Pu-oxalate in water (*)

(*) AIVM means that the dilution law used for these assumed homogeneous Pu oxalate-water mixtures is a simple Addition of Individual Volumes and Masses as described in [23],

(**) The envelope curve points out the k_{eff}-values corresponding to the minimum H/Pu of Pu^{IV}-oxalate compounds depending from the number of crystalline water molecules in the complex.

5. Benchmark Experiments

5.1 AOA (5) – PuO_2-Polystyrene Mixtures and Pu-Nitrate Solutions

The MFFF design applications include Pu compound solutions and Pu-oxalate precipitates. For these compounds, no benchmark experiments are available. To cover this range of design applications (see Table 5-2), two benchmark sets of thirty two experiments with PuO_2-polysterene compacts and six benchmark sets of Pu-nitrate solution experiments are selected from the ICSBEP Handbook [5]. These experiments cover a suitable range of H/Pu ratios, EALF values, geometry and reflectors which correspond to AOA (5). Table 5–1 lists the experiments along with a description and key parameters.

Table 5–2 provides a comparison of the key AOA parameters of the critical experiments and design applications parameters. The experiments involving Pu-nitrate solutions are chosen to cover the range of the EALF values for MFFF design applications from low moderated Pu precipitates to well moderated solutions of Pu compounds.

A description of the key parameters of these experiments is presented in Table 5–1. Table 5–2 provides a comparison of the key AOA parameters for the critical benchmark experiments and the design applications. The validated AOA is established based on the more limiting (smaller range) of the design application and benchmark experiment values as shown in Table 5–2.

The validation methodology described in this validation report requires that consistent code options be employed in modeling both benchmark experiments and design applications. Due to the multigroup energy treatment employed in KENO-VI, the most important such option is the resonance treatment employed in the Material Information Processor (MIP) of SCALE. The validation performed here employs applies to the INFHOMMEDIUM model. This model must be used in design application analyses considered applicable to this AOA.

Generally, the resulting validated AOA contain the corresponding key parameters of the anticipated design applications for which the code system will be used to determine reactivity. In some cases, parameter values for design applications may fall outside the validated area of applicability. In these cases, DCS commits to identifying additional margin, referred to as AOA margin, in the associated calculations or NCSEs, consistent with the approach described in NUREG-6698. The required margin is typically quantified by extrapolating observed trends in the bias as a function of the parameter.

Table 5–1 Critical Experiments Selected for AOA(5)

Experiment of AOA 5 *	H/Pu	EALF [eV]	Reflector and Geometrical form	^{240}Pu [wt. %]	Description
PU-COMP-MIXED-001	5 to 49.6	1.548 to 175000	Bare rectangular parallelepipeds	2.2 to 18.35	PuO_2–polystyrene compacts
PU-COMP-MIXED-002	0.04 to 49.6	0.685 to 4900	Plexiglas-reflected rectangular parallelepipeds	2.2 to 18.35	PuO_2–polystyrene compacts
PU-SOL-THERM-001	87-354	0.35-0.09	Water reflected sphere	4.67	11.5" Diameter sphere
PU-SOL-THERM-008	85-858	0.55-0.05	Concrete reflected and concrete /Cd reflected sphere	4.67	14" Diameter sphere
PU-SOL-THERM-014	210	0.17-0.14	Unreflected array of cylinders	4.23	Interacting cylinders in air with 115.1 g Pu/l
PU-SOL-THERM-015	155	0.24	Unreflected array of cylinders	4.23	Interacting cylinders in air with 152.5 g Pu/l
PU-SOL-THERM-016	155-210	0.24-0.17	Unreflected array of cylinders	4.23	Interacting cylinders in air with 152.5 and 115.1 g Pu/l
PU-SOL-THERM-017	210	0.17	Unreflected array of cylinders	4.23	Interacting cylinders in air with 115.1 g Pu/l

* From (Nuclear Energy Agency 1999) [5]

Table 5–2 AOA (5) – Comparison of Key Parameters and Definition of Validated AOA

Parameter	Design application	Benchmarks (cf. Table 5–1)	Validated AOA
Geometric shape	Parallelepipeds Arrays of cylinders Spheres	a) Parallelepipeds[1] b) Arrays of cylinders	Parallelepipeds Arrays of cylinders Spheres
Absorber/ reflector	Water, Cd, Borated concrete	a) Plexiglas, air b) Air/ water	Water, Cd, Borated concrete[2]
Chemical form	Pu compounds in water and precipitated oxalates	a) PuO_2-polystyrene mixture b) Pu-nitrate solution	PuO_2F_2 solution
Isotopic composition	4 wt. % ^{240}Pu	a) 2.2 to 18.35 wt. % ^{240}Pu b) 4.23 to 4.67 wt.% ^{240}Pu	4 wt. % ^{240}Pu
H/Pu	30 to 50	a) 0.04 to 49.6 b) 78 to 858	a) 30 to 50 b) 78 to 858
EALF [eV]	0.7 to 4.69	a) 0.685 to 4900 b) 0.135 to 0.551	a) 0.685 to 4900 b) 0.135 to 0.551

[1] a) refers to Group 1 b) refers to Group 2

[2] Justification for borated and cadmium-containing reflectors provided in Part 1 [15] is applicable here.

6. Analysis of Validation Results

6.1 AOA (5) – PuO_2-Polystyrene Mixtures and Pu-Nitrate Solutions

Eight benchmarks (cf. Table 5–1) are modeled with CSAS26/KENO VI using the 238 group library 238GROUPNDF5. These experiments are grouped as follows:

- Group 1 (for use with H/Pu < 50): Thirty-two experiments with PuO_2-powder in polystyrene.
- Group 2 (for use with H/Pu > 50): Eighty-seven experiments with Pu-nitrate solution.

Two benchmark sets, PU-COMP-MIXED-001 and PU-COMP-MIXED-002 are used for Group 1 (0.4<H/Pu<49.9). From the PU-SOL-THERM benchmarks, four sets with H/Pu < 250 are chosen to cover the EALF values of the design application in the range of H/Pu > 50. The selection of the Pu-nitrate solution experiments for Group 2 in addition to the PuO_2-polystyrene experiments of Group 1 is necessary to cover the full range of H/Pu and EALF values met in the applications, cf. Table 4–1 and Table 4–2.

The calculated k_{eff} values for the two groups of AOA(5) are presented in Attachment 4. As can be seen from the USLSTATS results shown in Attachment 5, all cases are normally distributed. Figure 6–1 shows the distribution of the calculated k_{eff} values for Group 1 experiments calculated with SCALE 4.4a on the PC platform. Similarly, Figure 6–2 shows the distribution of the calculated k_{eff} values for Group 2 experiments.

The k_{eff} values of the two groups are analyzed statistically using the USLSTATS computer code[2]. (see Attachment 5). For Group 1 EALF ranges from 0.7 eV to 4900 eV. (cf. Table A3-1). For Group 2 EALF ranges from 0.135 eV to 0.551 eV (cf. Tables A3-2). Table 6–1 and Table 6–2 in Section 6.1.2 summarize the statistical results of the USLSTATS program for both groups (PuO_2-polysterene and Pu-nitrate solutions). Note that the range of EALF obtained with these experiments covers the EALF values of AOA(5), cf. Table 4–1. Figure 6–3 through Figure 6–6 show the results graphically.

---

[2] Many of the benchmark experiments in the International Handbook of Evaluated Criticality Safety Benchmark Experiments (Nuclear Energy Agency 1999) are considered to be critical (i.e., k_{eff} =1.000), while other experiments are not considered critical (i.e., k_{eff}≠1.000). Therefore, all calculated k_{eff} values are normalized to the handbook values (cf. Section 3.5).

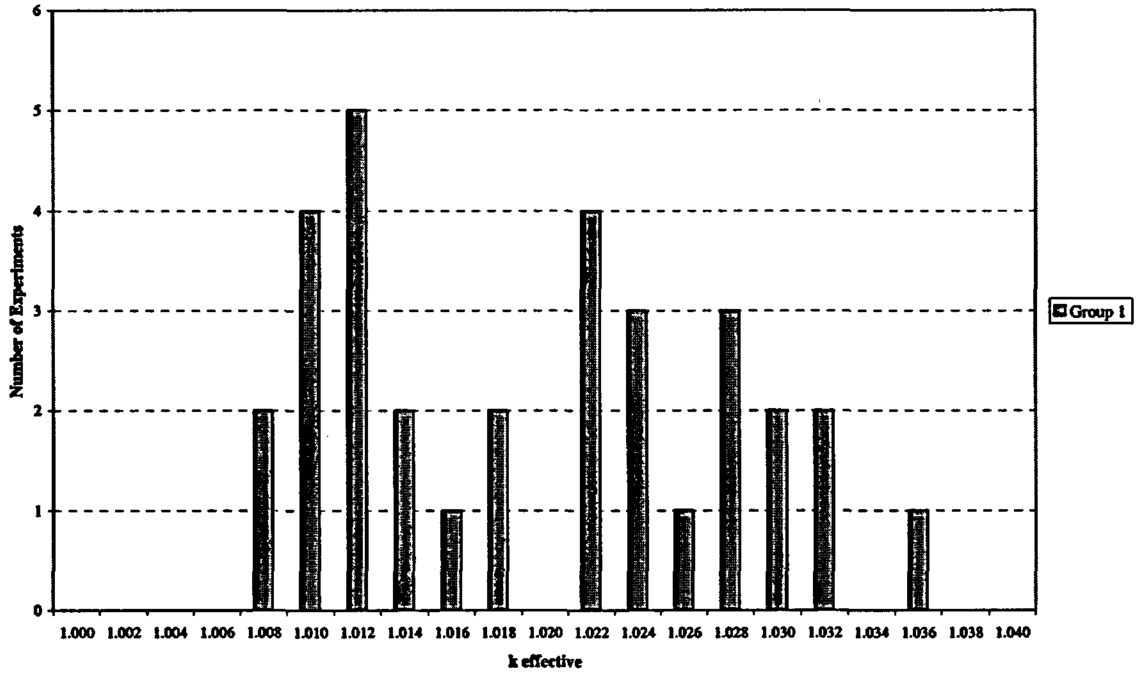


Figure 6–1 Histogram of k_{eff} Occurrences for AOA(5) Group 1

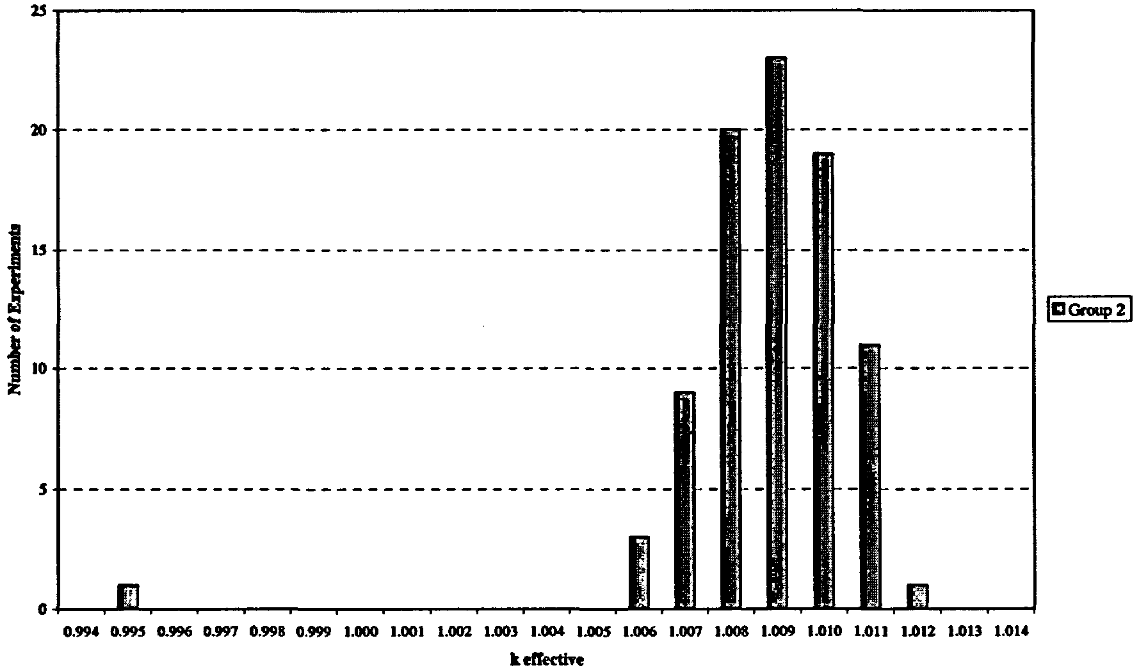


Figure 6–2 Histogram of k_{eff} Occurrences for AOA(5) Group 2

6.1.1 USL with EALF and H/Pu Ratio

Figure 6–3 and Figure 6–4 show the k_{eff} values and the corresponding values of USL-1 and USL-2 values versus the trending parameters EALF and H/Pu for the Group 1 experiments (PuO_2-polystyrene).

The k_{eff} values calculated for Group 2 (experiments with Pu-nitrate solution) are shown in Figure 6–5 and Figure 6–6 as a function of EALF and H/Pu, respectively.

The corresponding USLSTATS output listings are provided in Attachment 5.

Table 6–1 shows that for AOA(5) Group 1 the minimum USL-1 with a 0.05 administrative margin is 0.9328. The minimum USL-2 found for the PuO_2 systems is 0.9534.

Table 6–2 shows that for the AOA(5) Group 2 the minimum USL-1 with a 0.05 administrative margin is 0.9411. The minimum USL-2 found for the Pu-metal systems is 0.9779.

For the PuO_2-polystyrene experiments, the conservative minimum margin to subcriticality Δk_m=0.0239 calculated with the USL-2 method suggests that the administrative margin (Δk_m=0.05) applied to the USL-1 value is adequate for the AOA(5) provided the EALF and H/Pu ratio fall within this range of applicability[3]. The same is found for the Pu nitrate experiments with a conservative minimum margin to subcriticality Δk_m=0.0121

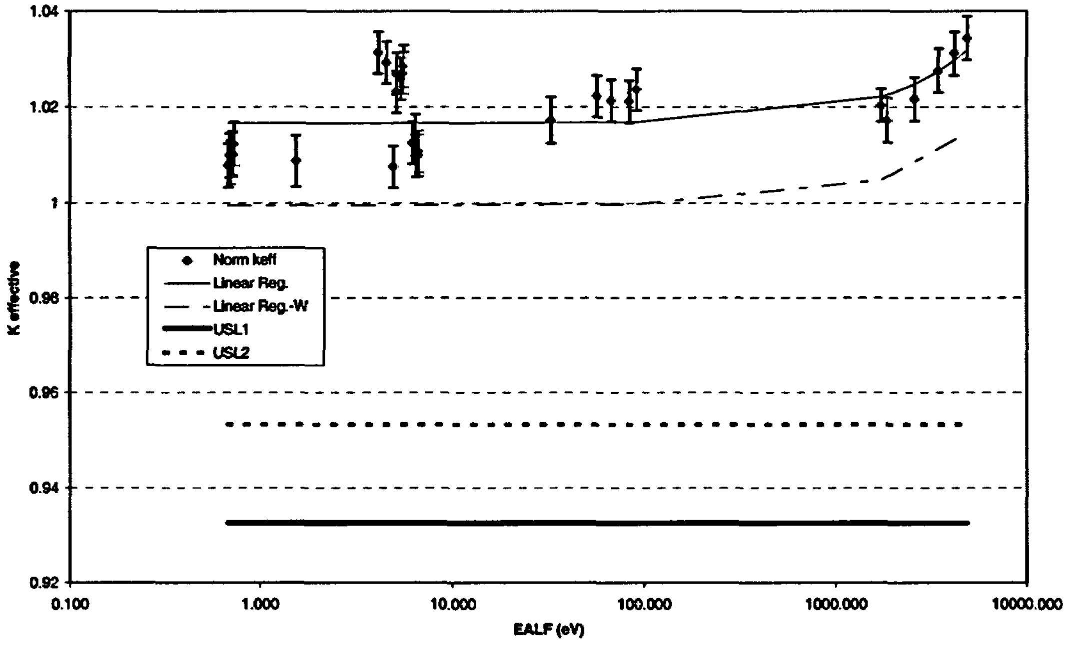


Figure 6–3 k_{eff} as Function of EALF (Pu-Comp-Mixed) AOA(5) Group 1

---

[3] ANSI/ANS-8.1 allows the range of applicability to be extended beyond this range by extrapolating the trends established for the bias; however, no precise guidelines are specified for the limits of extrapolation. Therefore, engineering judgment must be applied when extrapolating beyond the range of the parameter bounds. If extrapolation is necessary, it will be discussed on a case-by-case basis in the individual criticality calculations.

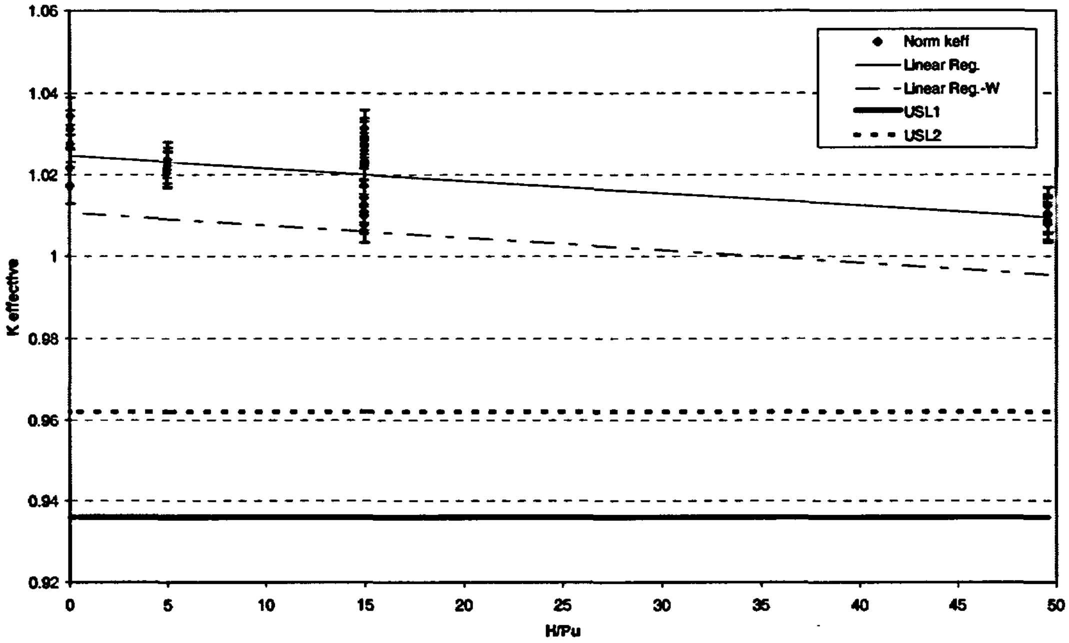


Figure 6–4 k_{eff} as Function of H/Pu (Pu-Comp-Mixed) AOA(5) Group 1

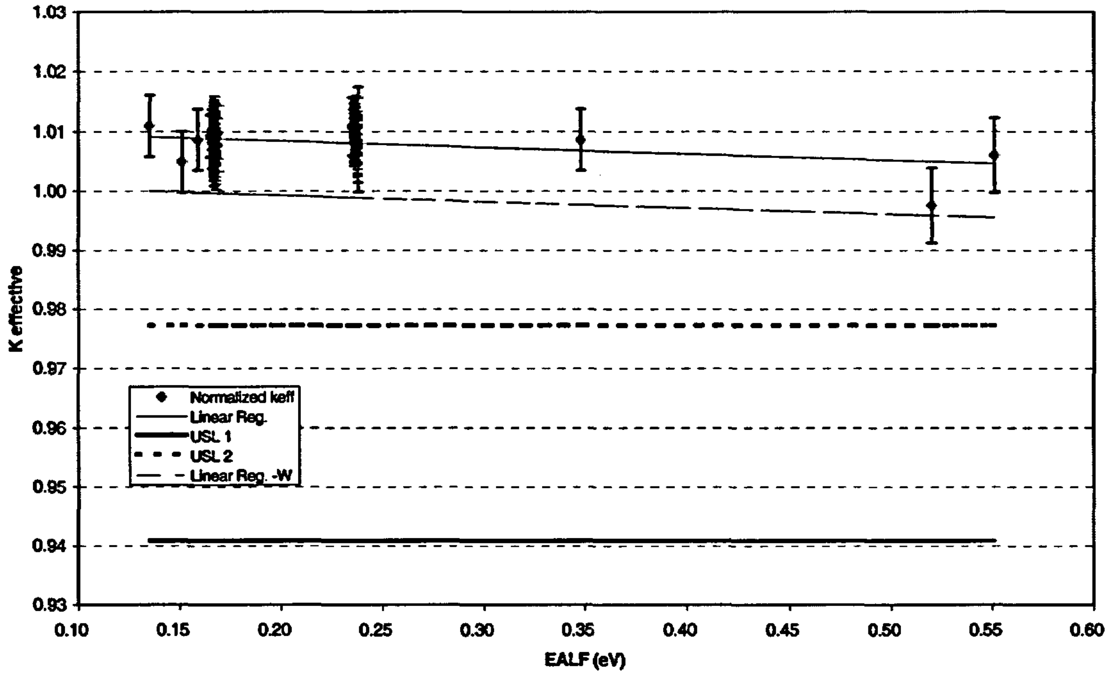


Figure 6–5 k_{eff} as Function of EALF (Pu-Nitrate Solution) AOA(5) Group 2

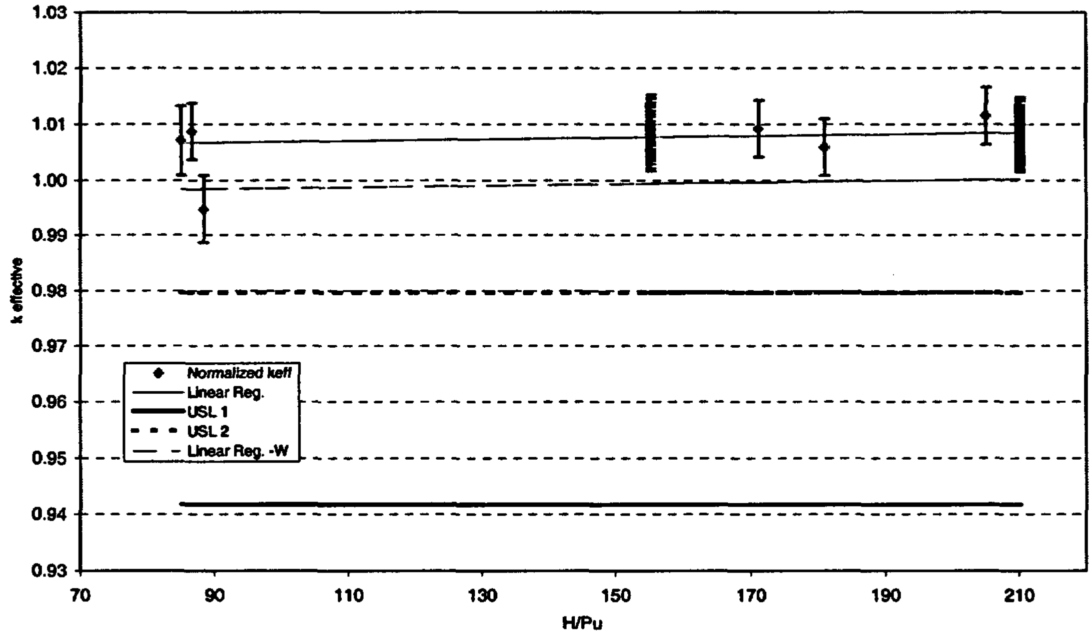


Figure 6–6 k_{eff} as Function of H/Pu (Pu-Nitrate Solution) AOA(5) Group 2

6.1.2 Summary of USL for AOA(5)

The USL-1 for the Group 2 experiments involving plutonium nitrate solution with a thermal fission spectrum (USL-1 of Group 2 is 0.9411) is found to be significantly higher than the USL-1 for the Group 1 experiments involving PuO_2-polystyrene mixture systems with intermediate to fast fission spectrums. Therefore, the minimum USL for AOA(5) is based on the Group 1 result of 0.9328. This value includes a 0.05 administrative margin and consideration for calculational bias and uncertainties. The adequacy of the administrative margin is further discussed in Section 7.1. The calculated USL values for AOA(5) are summarized in the following tables.

Table 6–1 Summary of USL Calculations from SCALE 4.4a on PC Platform AOA(5)
Group 1: PU-COMP-MIXED-001 and PU-COMP-MIXED-002

Correlated Parameter (X)	No. of Exp.	Range of X	k_c(X) Linear regression	Average k_c	Min USL_1 (Δkm=0.05)	Min USL_2	Min Δkm (USL_2)
EALF [eV]	32	0.686 to 4900	1.0167+(3.1025E-06)*X	1.0186	0.9328	0.9534	0.0294
H/Pu	32	0.04 to 49.60	1.0246+(-3.0367E-04)*X	1.0186	0.9360	0.9621	0.0239
^{240}Pu [wt. %]	32	2.20 to 18.35	1.0237+(-4.5199E-04)*X	1.0186	0.9338	0.9561	0.0277

Table 6–2 Summary of USL Calculations with SCALE 4.4a on PC Platform AOA(5),
Group 2: Pu-Nitrate Solution

Correlated parameter (X)	No. of Exp.	Range of X	k_c(X) Linear regression	Average k_c	Min USL_1 (Δk_m=0.05)	Min USL_2	Min Δk_m (USL_2)
H/Pu	87	85.03 to 210.18	1.0054 + (1.4797E-05)*X	1.00824	0.9418	0.9797	0.0121
EALF [eV]	87	0.135 to 0.549	1.0108 +(-1.3126E-02)*X	1.00824	0.9411	0.9779	0.0132

7. Conclusions

The SCALE 4.4a code package using the CSAS26 (KENO-VI) sequence and the 238 energy group cross section library 238GROUPDF5 has been validated to perform criticality calculations for the MFFF. It has been validated for the fifth area of applicability AOA (5). Two groups of experiments are established to cover the range of design applications: PuO_2-polystyrene mixtures and Pu-nitrate solutions.

The USLs for the two groups of AOA (5) are as follows:

- AOA(5) Group 1 representative of design applications with H/Pu < 50 USL = 0.9328.
- AOA(5) Group 2 representative of design applications with H/Pu > 50 USL = 0.9411.

The USL accounts for the computational bias, uncertainties, and an administrative margin. The administrative margin is established at 0.05 such that $k_{eff} + 2\sigma - bias \leq 0.95$ for all normal and credible abnormal conditions. Section 7.1 contains a detailed justification of the administrative margin.

No extrapolation outside the range of applicability is expected for AOA(5) USL values; however, ANSI/ANS-8.1 [2] does allow for extrapolation outside the area of applicability by extrapolating the trends established for the bias and USL. If extrapolation is necessary, for instance with the design application involving colemanite concrete reflectors or Cd/water reflectors, it will be discussed on a case-by-case basis in the respective calculation.

7.1 Justification for Administrative Margin

The administrative margin applied in the determination of the USL is intended as an added level of conservatism. The code validation effort accounts for all code bias and the effects of both code and experimental benchmark uncertainties. The administrative margin is applied *in addition* to the code bias and bias uncertainty in determining the USL.

The USL values determined here are based on an administrative margin of 0.05. Based on actual process conditions, including 1) the degree to which application parameters fall within the validated Area of Applicability (AOA) of the calculational method and 2) the results of sensitivity analyses demonstrating the sensitivity of k_{eff} values to variations in controlled parameters, the USL may be adjusted. Each NCSE and criticality calculation will include a discussion of the appropriateness of the USL applied for each specific design application.

Typically, the NCSEs and criticality calculations will present k_{eff} results for various scenarios, including normal operation and credible abnormal situations. The results of these analyses permit a quantitative assessment of the degree of subcriticality of the system measured in terms of variation of one or more controlled parameters. Hence, the NCSEs/criticality calculations for specific design applications will verify the conformance with the AOA used in the validation reports.

In general, based on the discussion below, the administrative margin used in criticality analyses is 0.05. This assessment is based on a comparison against administrative margin practices at both NRC and DOE facilities, and past NRC guidance and practice, and is further substantiated by a statistical analysis of the benchmark validation results.

7.1.1 Fuel Cycle and Industry Practice

A review of NRC materials licensees and analogous DOE facilities (including plutonium facilities) indicates that administrative margins range from 0.02 to 0.05 as shown in Table 7-1. These values apply to applications within the validated AOAs; adjustments to the administrative margin are typically made for application outside the validated region.

These values are consistent with precedent information provided by the NRC Staff [26], which indicates administrative margins with a similar range to those indicated in Table 7-1. An administrative margin of 0.05 is greater than or equal to the most conservative margins identified in Table 7-1 and other NRC precedent [26] for analysis of credible abnormal conditions.

This margin is consistent with guidance provided in NUREG-1718 [3], which supports an administrative margin of 0.05 for the MFFF. It is also consistent with past NRC-accepted practice in reactor operations (10 CFR 50) [25], and transportation (10 CFR 71) and on-site storage (10 CFR 72) of spent nuclear fuel. Examination of various precedents indicates 0.05 is a conservative administrative margin for activities falling within the validated AOA. For criticality analyses applied outside the validated AOA, specific guidance is provided in ANSI/ANS–8.1–1998 which indicates that the administrative margin may be adjusted based on established trends in the bias, if necessary.

7.1.2 USLSTATS Method 2 Quantitative Assessment

Once an administrative margin has been determined (in this case, based on NRC guidance in NUREG-1718 [3] and based on conservative comparison with applicable precedent), NUREG/CR-6361 [9] provides a quantitative method of assessing the suitability of the administrative margin based on a statistical analysis which generates a recommended minimum margin of subcriticality. NUREG/CR-6361 suggests that this minimum margin of subcriticality be compared against the administrative margin in order to verify that the administrative margin is conservative relative to a purely statistical basis[4].

This mechanism provides an independent, quantitative means of substantiating the administrative margin selected based on the statistics of the benchmarks themselves. The use of this methodology requires the specification of two important statistical parameters: α, the level of confidence in the limit being calculated and P, the probability future calculations will lie within the statistical band. The result of this methodology is the assurance that by using at least the calculated minimum margin of subcriticality, there is a probability P with a confidence α that an additional calculation of k_{eff} for a critical system will lie within the band. For example, a calculation with α=0.95 and P=0.95 would yield a USL for which there is a 95% confidence that 95 out of 100 future calculations of critical systems will yield a value of k_{eff} above the USL (which is conservative). This level of statistical treatment is consistent with the statistics usually employed in the inclusion of 2σ in the treatment of Monte Carlo criticality calculations. It is also consistent with the statistical recommendations in NUREG/CR-6698 [24]. As can be seen in the figures in Section 6, use of this traditional statistical treatment would lead to the conclusion that,

---

[4] See NUREG/CR-6361 §4.1.3. For example, Westinghouse is approved to use a 0.02 Δk administrative margin unless a higher margin of subcriticality is calculated using USL–2 methodology.

based on the usual statistical approach, a margin as low as 0.01 to 0.02 would be necessary to ensure that the USL was conservative based upon a statistical evaluation of the data.

However, this report uses USLSTATS to examine the statistics at a higher level of certainty. That is, values of $\alpha = 0.95$ and $P = 0.999$ were used. This means that the derived USL–2 is such that there is a 95% confidence that 999 out of 1000 future calculations of critical systems will yield a value of k_{eff} above the USL. The resulting conclusion using 95/99.9 statistics is that the added conservatism over the 1-2% amount, which would be required using traditional statistical levels, is available to ensure that the results are conservative for other potential mechanisms for which conservatisms would be prudent.

An analysis of the benchmarks using a value of $\alpha = 0.95$ and $P = 0.999$ yield the subcritical margins listed in Table 7–2. If one were to base an administrative margin solely on this very conservative statistical analysis, an administrative margin of at most 0.03 is necessary to statistically justify the use of these benchmarks. This is significantly less than the 0.05 administrative margin used for the two AOAs. Note that the administrative margin is applied in addition to the calculated bias and uncertainty for each AOA. This means that the proposed 0.05 administrative margin is still more conservative than that determined in the 95/99.9 statistical treatment and is justified in the MFFF.

7.1.3 Summary of Administrative Margin Practice

This effort involves the validation of the code to applications within one or more specific areas of applicability. There is no intent to account for or to address the uncertainties and unknowns involved in the actual design applications. This approach is consistent with NUREG/CR-6698 which states "*the subcritical margin is not intended to account for process upset conditions or for uncertainties associated with a process.*" These issues are properly addressed in the nuclear criticality safety evaluations (NCSEs). These evaluations will demonstrate that the design application falls within the required AOA, that design uncertainties and unknowns are properly and conservatively addressed, that sensitivity to controlled parameters is adequately addressed, and that the criticality models themselves are suitably conservative representations of the actual physical phenomena. In cases where calculated k_{eff} values are shown to be sensitive to controlled parameters, the NCSE will demonstrate the adequacy of the control. In conclusion, an administrative margin of 0.05, selected on the basis of NRC guidance and conservative comparison with applicable precedent, and substantiated through statistical methods, is justified, and is sufficiently conservative to provide for an adequate margin of subcriticality.

Table 7–1 Fuel Cycle and Industry Practice

Facility	Process/Application	Material	Administrative Margin
Framatome Cogema Fuels	Fuel assembly manufacture	Low enriched U	0.05
Westinghouse Columbia Site	Fuel assembly manufacture	Low enriched U	0.02
Nuclear Fuel Services	Fuel processing (solutions, powder, pellets, etc.)	Various U enrichments	0.03 LEU 0.05 HEU
Paducah Uranium Enrichment Plant	Uranium enrichment	Low enriched U	0.02
Rocky Flats	Weapons material processing	Plutonium	0.03
BWXT	Fuel assembly manufacture	Low to high enriched U	0.03 LEU 0.05 HEU
Savannah River Site	a) MTR fuel assemblies b) Pipe overpack material storage c) Mark 42 tube dissolution d) Ion exchange columns with fissile solutions e) DDF-1 package	a) High enriched U b) ^{239}Pu c) ^{239}Pu d) ^{239}Pu solution e) Pu metal and oxide	a) 0.02 b) 0.02 c) 0.05 d) 0.04 e) 0.05
Y-12	Weapons material processing	High enriched U	0.02 – 0.05[1]
Idaho National Engineering and Environmental Lab	Solutions/spent fuel/powders/pieces	Low to high enriched U, including ^{233}U; some Pu	0.02 – 0.05 0.05 typical
Hanford Site	Waste tanks packaging and transportation	Various	0.05

[1] Pending final approval of validation document.

Table 7–2 USLSTATS Method 2 Analysis Results

Area of Applicability	Maximum USL-2 Minimum Margin of Subcriticality	Administrative Margin
AOA(5)	0.0239	0.05

8. References

[1] Oak Ridge National Laboratory, "SCALE 4.4: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation," NUREG/CR-0200 (ORNL/NUREG/CSD-2/R6), Volumes I, II and III. Available from Radiation Shielding Information Center as CCC-545.

[2] ANSI/ANS (American National Standards Institute/American Nuclear Society), "American National Standard for Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors," ANSI/ANS–8.1–1998, La Grange Park, IL, 1998.

[3] NRC (U.S. Nuclear Regulatory Commission), "Standard Review Plan for the Review of an Application for a Mixed Oxide (MOX) Fuel Fabrication Facility," NUREG-1718, U.S. Nuclear Regulatory Commission, Washington, DC, 2000.

[4] SGN, Verification of the SCALE 4.4a Code Package on SGN Pentium PCs, Document NT 12046 00 028 A.

[5] Nuclear Energy Agency, *International Handbook of Evaluated Criticality Safety Benchmark Experiments*, NEA/NSC/DOC(95)03, Nuclear Energy Agency, Organization for Economic Cooperation and Development, 1999.

[6] C. R. Richey, J. D. White, E. D. Clayton and R. C. Lloyd, "Criticality of Homogeneous Plutonium Oxide-Plastic Compacts at H/Pu = 15," Nuclear Science and Engineering 23, 150-158, 1965.

[7] S. R. Bierman, L. E. Hansen, R. C. Lloyd and E. D. Clayton, "Critical Experiments with Homogeneous PuO_2-Polystyrene at 5 H/Pu," Nuclear Applications, Vol. 6, 23-26, 1968.

[8] ANSI/ANS (American National Standards Institute/American Nuclear Society), "Criticality Safety Criteria for Handling Storage, and Transportation of LWR Fuel Outside Reactors," ANSI/ANS-8.17, La Grange Park, IL, 1984.

[9] J. J. Lichtenwalter, S. M. Bowman, M. D. DeHart, and C. M. Hopper, "Criticality Benchmark Guide for Light-Water-Reactor Fuel in Transportation and Storage Packages," NUREG/CR-6361 (ORNL/TM-13211), Lockheed Martin Energy Research Corp., Oak Ridge National Laboratory, Oak Ridge, TN, 1997.

[10] H. R. Dyer, W. C. Jordan, and V. R. Cain, "A Technique for Code Validation for Criticality Safety Calculations," Trans. Am. Nucl. Soc. 63, 238, June 1991.

[11] M. E. Easter, "Validation of KENO V.a and Two Cross-Section Libraries for Criticality Calculations of Low-Enriched Uranium Systems," ORNL/CSD/TM-223, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., July 1985.

[12] D. C. Bowden and F. A. Graybill, "Confidence Bands of Uniform and Proportional Width for Linear Models," Am. Stat. Assoc. J. 61, 182, March 1966.

[13] N. L. Johnson, Ed., "Query," Technometrics 10, 207-209, February 1968.

[14] V. R. Cain, "A Computer Code to Perform Analyses of Criticality Validation Results," Y/DD-574, Martin Marietta Energy Systems, Inc., Oak Ridge Y-12 Plant, September 1995.

[15] Duke, COGEMA, Stone & Webster, "Mixed Oxide Fuel Fabrication Facility Criticality Code Validation, Part I," September, 2002.

[16] Duke, COGEMA, Stone & Webster, "Mixed Oxide Fuel Fabrication Facility Criticality Code Validation, Part II," December, 2002.

[17] Comparison of original and patched versions of SCALE4.4a, Document in preparation.

[18] Duke, COGEMA, Stone & Webster, "Basis of Design for MOX Fuel Fabrication Process Criteria," Document No. DCS01 AAJ CG DOB F 03143 C

[19] Duke, COGEMA, Stone & Webster, "Minimum Critical and Maximum Permissible Parameters of Pu-containing Media (96% ^{239}Pu, 4% ^{240}Pu)," Document No. DCS01 RRJ CG CAL H 06008 B.

[20] O.J. Wick, "Plutonium Handbook, A Guide to the Technology", Vol 1, Pacific Northwest Laboratory, 1965.

[21] G. T. Seaborg and L. R. Morss, "The Chemistry of the Actinides Elements", Chapman and Hall London, 1986.

[22] I. L. Jenkins, F. H. Moore and J. Waterman, "X-ray powder crystallographic data on plutonium and other oxalate I-II", Journal of Inorganic Chemistry, 1965, Vol. 27, pp. 77-80. Pergamon Press.

[23] "Fissile Compound Dilution Laws for Criticality Calculations – Calculation of Atomic Composition," IPSN/SEC/T/99.090.

[24] J. C. Dean, R. W. Tayloe, Jr., "Guide for Validation of Nuclear Criticality Safety Calculational Methodology," NUREG/CR-6698, Science Applications International Corporation, Oak Ridge, TN, January 2001.

[25] NRC Memorandum, L. Kopp to T. Collins, "Guidance on the regulatory requirements for criticality analysis of fuel storage at light-water reactor power plants," August, 1998.

[26] NRC Letter, A. Persinko to P. S. Hastings, "Nuclear Criticality Safety Staff Qualifications and Administrative Margins for Fuel Fabrication Facilities," 09 November 2001.

[27] H. C. Paxton et al., “Criticality Dimensions of Systems Containing ^{235}U, ^{239}Pu, ^{233}Pu”, Los Alamos Scientific Laboratory and Oak Ridge National Laboratory Report TID-7028, 1964.

[28] Y. Fruchard et al., “Données Fondamentales Relatives à la Criticité des Systèmes simples”, SM-70/15 (p.12) in “Criticality Control of Fissile Materials ”, Proceedings of a Symposium Stockholm, 1-5 Nov. 1965, IAEA, Vienna (1966).

[29] “UP3 Projet – Précipitateur d’oxalate de plutonium – Etude de sureté-criticité”, IPSN/SEC/T/N° 80/69, 04 March 1980, MFP/JCP/CP.

ATTACHMENT NUMBER 1

Sensitivity Study Results

Table A1–1 Critical experiment with PuO_2-polystyrene with plexiglas reflector at H/Pu=15, cf. Table A4-1b

Case	C (Pu) [g/cm^3]	wt. % ^{240}Pu	H/Pu	k_{eff}	σ	GEN	NPG	NSK	EALF [eV]
10	1.12	2.2	15	1.0314	0.0007	1500	1000	30	4.12
11	1.12	2.2	15	1.0293	0.0008	1500	1000	7	4.55
12	1.12	2.2	15	1.0270	0.0008	1500	1000	21	5.14
13	1.12	2.2	15	1.0259	0.0007	1500	1000	20	5.44
14	1.12	2.2	15	1.0285	0.0008	1500	1000	7	5.57
15	1.12	2.2	15	1.0271	0.0008	1500	1000	21	5.57
16	1.12	2.2	15	1.0232	0.0008	1500	1000	14	5.15
17	1.05	8.06	15	1.0064	0.0007	1500	1000	3	4.93
18	1.05	8.06	15	1.0114	0.0008	1500	1000	4	6.19
19	1.05	8.06	15	1.0086	0.0007	1500	1000	29	6.47
20	1.05	8.06	15	1.0096	0.0008	1500	1000	176	6.67
21	1.05	8.06	15	1.0088	0.0008	1500	1000	42	6.68
22	1.05	8.06	15	1.0130	0.0007	1500	1000	5	6.42

Table A1–2 PuO_2+ H_2O mixture at H/Pu=15 in the same experimental configuration of Table A1-1

Case	C (Pu) [g/cm^3]	wt. % ^{240}Pu	H/Pu	k_{eff}	σ	GEN	NPG	NSK	EALF [eV]
10	1.5059	4	15	1.0932	0.0007	1500	1000	7	6.39
11	1.5059	4	15	1.0942	0.0008	1500	1000	17	6.98
12	1.5059	4	15	1.0975	0.0008	1500	1000	73	7.88
13	1.5059	4	15	1.0968	0.0007	1500	1000	13	8.30
14	1.5059	4	15	1.1002	0.0008	1500	1000	75	8.48
15	1.5059	4	15	1.0994	0.0008	1500	1000	8	8.44
16	1.5059	4	15	1.0926	0.0007	1500	1000	11	7.82
17	1.5059	4	15	1.1602	0.0007	1500	1000	21	7.47
18	1.5059	4	15	1.1749	0.0008	1500	1000	23	9.18
19	1.5059	4	15	1.1785	0.0008	1500	1000	64	9.50
20	1.5059	4	15	1.1785	0.0008	1500	1000	16	9.77
21	1.5059	4	15	1.1798	0.0007	1500	1000	37	9.77
22	1.5059	4	15	1.1807	0.0008	1500	1000	29	9.51

Table A1–3 $PuO_2F_2+H_2O$ mixture at H/Pu=15 in the same experimental of Table A1-1

Case	C (Pu) [g/cm^3]	wt. % ^{240}Pu	H/Pu	k_{eff}	σ	GEN	NPG	NSK	EALF [eV]
10	1.1842	4	15	1.0085	0.0007	1500	1000	5	4.59
11	1.1842	4	15	1.0052	0.0007	1500	1000	50	5.02
12	1.1842	4	15	1.0020	0.0007	1500	1000	13	5.64
13	1.1842	4	15	0.9987	0.0008	1500	1000	48	5.98
14	1.1842	4	15	1.0017	0.0007	1500	1000	3	6.15
15	1.1842	4	15	0.9994	0.0007	1500	1000	6	6.10
16	1.1842	4	15	0.9977	0.0007	1500	1000	44	5.69
17	1.1842	4	15	1.0763	0.0007	1500	1000	40	5.51
18	1.1842	4	15	1.0826	0.0008	1500	1000	102	6.77
19	1.1842	4	15	1.0822	0.0007	1500	1000	17	7.09
20	1.1842	4	15	1.0810	0.0008	1500	1000	23	7.29
21	1.1842	4	15	1.0817	0.0008	1500	1000	37	7.29
22	1.1842	4	15	1.0853	0.0008	1500	1000	3	7.05

Table A1–4 Pu-oxalate+H_2O mixture at H/Pu=15 in the same experimental configuration of Table A1-1

Case	C (Pu) [g/cm^3]	wt. % ^{240}Pu	H/Pu	k_{eff}	σ	GEN	NPG	NSK	EALF [eV]
10	1.0829	4	15	0.9917	0.0008	1500	1000	33	4.14
11	1.0829	4	15	0.9915	0.0007	1500	1000	111	4.56
12	1.0829	4	15	0.9881	0.0007	1500	1000	34	5.15
13	1.0829	4	15	0.9878	0.0007	1500	1000	3	5.45
14	1.0829	4	15	0.9911	0.0007	1500	1000	17	5.62
15	1.0829	4	15	0.9889	0.0007	1500	1000	17	5.66
16	1.0829	4	15	0.9838	0.0008	1500	1000	7	5.17
17	1.0829	4	15	1.0612	0.0009	1500	1000	5	4.99
18	1.0829	4	15	1.0713	0.0008	1500	1000	12	6.28
19	1.0829	4	15	1.0710	0.0007	1500	1000	33	6.59
20	1.0829	4	15	1.0715	0.0007	1500	1000	9	6.76
21	1.0829	4	15	1.0709	0.0007	1500	1000	7	6.78
22	1.0829	4	15	1.0747	0.0008	1500	1000	19	6.49

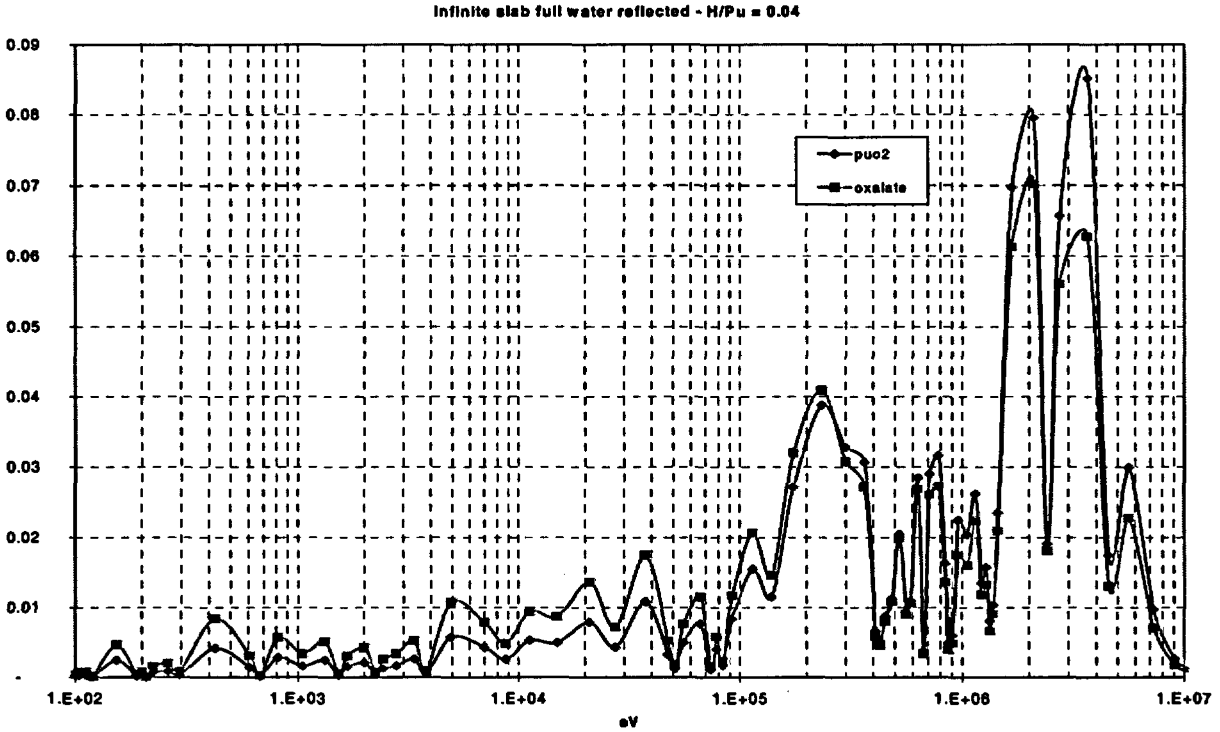


Figure A1–1 Normalized flux in an infinite full water reflected slab for two dry Pu compounds (H/Pu=0.04) in the range of 1.E02 eV < Energy < 1.E07 eV

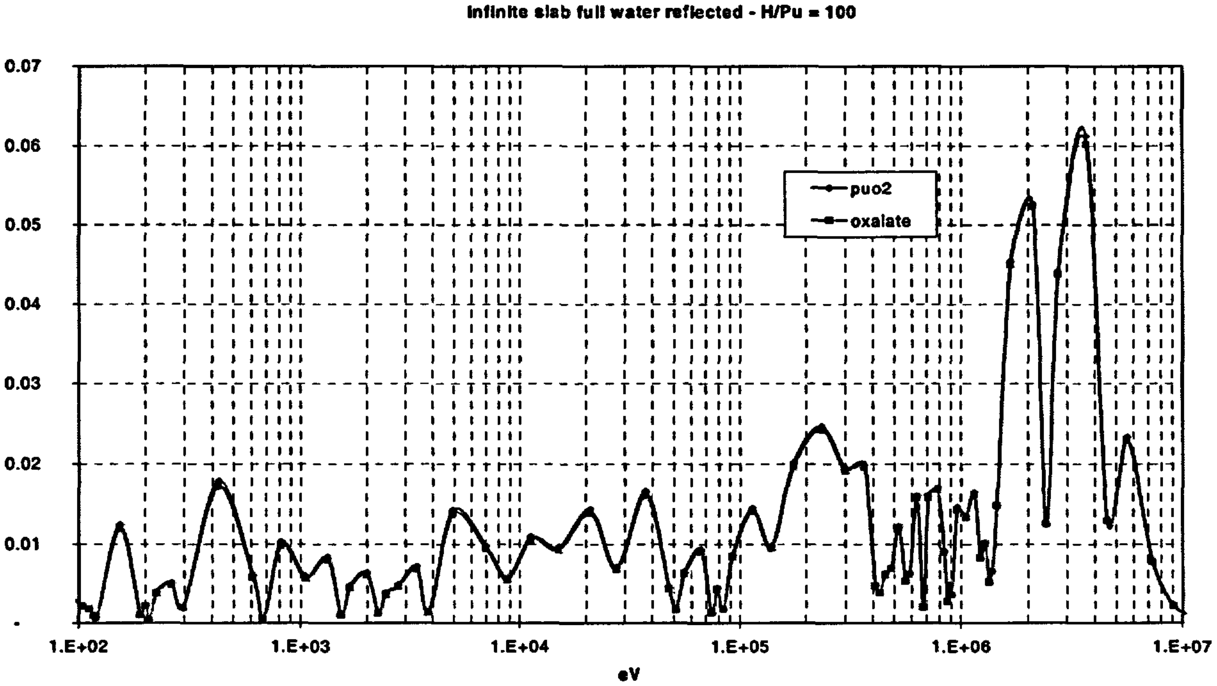


Figure A1–2 Normalized flux in an infinite full water reflected slab for two Pu compounds in water (H/Pu=100) in the range of 1.E02 eV < Energy < 1.E07 eV

ATTACHMENT NUMBER 2
REACTIVITY BOUNDING FISSILE MEDIUM RESULTS

Table A2–1 k_{eff}-values of an infinite slab 6 cm thick, full water reflected, filled with Pu compounds of MFFF versus H/Pu ratio – XSDRNPM calculations

H/Pu	**PuO_2 powder 11.46 g/cm^3**	**PuO_2F_2 « standard salt » 4.187 g/cm^3**	**Pu-oxalate. $6H_2O$ (*) 2.70 g/cm^3**	**Pu-oxalate. $2H_2O$ (*) 3.05 g/cm^3**	**Pu-oxalate. $0H_2O$ 3.50 g/cm^3**	**Pu(III)-nitrate. $5H_2O$ (*) 2.15 g/cm^3**
0.01	1.4724	0.9912	-	-	0.8605	-
0.05	1.4641	0.9905	-	-	0.8606	-
0.1	1.4540	0.9895	-	-	0.8608	-
0.5	1.3875	0.9826	-	-	0.8628	-
1	1.3289	0.9757	-	-	0.8655	-
1.674	1.2735	0.9684	-	-	0.8691	-
3	1.2030	0.9579	-	-	0.8759	-
4	1.1676	0.9556	-	0.8914	0.8804	-
5	1.1407	0.9538	-	0.8949	0.8844	-
5.973	1.1202	0.9556	-	0.8979	0.8878	-
10	1.0676	0.9617	-	0.9073	0.8989	0.9018
12	1.0521	0.9642	0.9456	0.9109	0.9031	0.9057
15	1.0356	0.9676	0.9462	0.9155	0.9084	0.9104
20	1.0185	0.9776	0.9476	0.9216	0.9155	0.9171
30	1.0013	0.9858	0.9506	0.9306	0.9258	0.9265
40	0.9933	0.9817	0.9534	0.9369	0.9329	0.9331
50	0.9887	0.9796	0.9556	0.9415	0.9380	0.9378
60	0.9856	0.9782	0.9572	0.9448	0.9418	0.9413
70	0.9832	0.9770	0.9582	0.9472	0.9445	0.9437
80	0.9811	0.9758	0.9588	0.9488	0.9463	0.9453
90	0.9791	0.9746	**0.9589**	0.9498	0.9475	0.9463
100	0.9772	0.9733	0.9586	**0.9502**	**0.9481**	**0.9468**
125	0.9721	0.9693	0.9567	0.9496	0.9479	0.9462
150	0.9665	0.9644	0.9533	0.9471	0.9456	0.9438
200	0.9537	0.9528	0.9434	0.9386	0.9373	0.9352
300	0.9248	0.9249	0.9175	0.9141	0.9132	0.9108
500	0.8635	0.8618	0.8590	0.8568	0.8562	0.8538
700	0.8057	0.8045	0.8024	0.8009	0.8005	0.7982
900	0.7536	0.7526	0.7510	0.7498	0.7495	0.7475
1000	0.7296	0.7288	0.7274	0.7263	0.7260	0.7240
1300	0.6655	0.6649	0.6638	0.6630	0.6628	0.6612
1500	0.6284	0.6279	0.6269	0.6263	0.6261	0.6246

(*) No values below the minimum H/Pu corresponding to the number of crystalline water in these Pu compounds

ATTACHMENT NUMBER 3

BENCHMARKS USED - AOA(5)

ICSBEP PUO$_2$ POWDER BENCHMARKS

The ICSBEP Handbook [5] includes a number of experiments relevant to PuO$_2$ powder applications. The list below provides the reasoning for inclusion of each candidate experiment.

PU-COMP-MIX-001:	All the experiments are selected. The input files are directly obtained from the Handbook and translated to a CSAS26 input file using the c5toc6 program. The 27 group library is replaced by the 238 group library.
PU-COMP-MIX-002:	All the experiments are selected. The input files are directly obtained from the Handbook and translated to a CSAS26 input file using the c5toc6 program. The 27 group library is replaced by the 238 group library.
PU-SOL-THERM-001:	All the experiments are selected. The input file are directly obtained from the Handbook and translated to CSAS26 using the c5toc6 program. The 27 group library is replaced by the 238 group library.
PU-SOL-THERM-008:	All the experiments are selected. The ICSBEP calculated keff are not in good agreement with the experimental keff but this benchmark is interesting because of the concrete reflection. The input file are directly obtained from the Handbook and translated to CSAS26 using the c5toc6 program. The 27 group library is replaced by the 238 group library.
PU-SOL-THERM-014:	All the experiments are selected. The input file are directly obtained from the Handbook and translated to CSAS26 using the c5toc6 program. The 27 group library is replaced by the 238 group library.
PU-SOL-THERM-015:	All the experiments are selected. The input file are directly obtained from the Handbook and translated to CSAS26 using the c5toc6 program. The 27 group library is replaced by the 238 group library.
PU-SOL-THERM-016:	All the experiments are selected. The input file are directly obtained from the Handbook and translated to CSAS26 using the c5toc6 program. The 27 group library is replaced by the 238 group library.
PU-SOL-THERM-017:	All the experiments are selected. The input file are directly obtained from the Handbook and translated to CSAS26 using the c5toc6 program. The 27 group library is replaced by the 238 group library.

ATTACHMENT NUMBER 4

CRITICALITY CALCULATION RESULTS FOR AOA(5)

Table A4-1: SCALE 4.4a calculations on PC

Experiment	H/Pu	^{240}Pu	Exp. k_{eff}	Exp. Uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF	GEN	NPG	NSK
PU-COMP-MIXED-001										
Case 2	5	11.46	1	0.0033	1.0204	0.0007	1.75E+03	1503	1000	15
Case 3	15	2.2	0.999	0.0047	1.0163	0.0009	3.27E+01	1503	1000	5
Case 5	49.6	18.35	0.9989	0.0053	1.0077	0.0009	1.55E+00	1503	1000	44
PU-COMP-MIXED-002										
Case 1	0.04	18.35	0.999	0.0045	1.0334	0.0007	4.90E+03	1503	1000	3
Case 2	0.04	18.35	0.999	0.0045	1.0302	0.0007	4.20E+03	1503	1000	51
Case 3	0.04	18.35	0.999	0.0045	1.0266	0.0008	3.46E+03	1503	1000	42
Case 4	0.04	18.35	0.999	0.0045	1.0207	0.0007	2.60E+03	1503	1000	7
Case 5	0.04	18.35	0.999	0.0045	1.0163	0.0007	1.87E+03	1503	1000	78
Case 6	5	11.46	1	0.0043	1.0237	0.0007	9.21E+01	1503	1000	7
Case 7	5	11.46	1	0.0043	1.0212	0.0008	8.42E+01	1503	1000	11
Case 8	5	11.46	1	0.0043	1.0214	0.0008	6.79E+01	1503	1000	8
Case 9	5	11.46	1	0.0043	1.0223	0.0007	5.70E+01	1503	1000	3
Case 10	15	2.2	1	0.0043	1.0314	0.0007	4.12E+00	1503	1000	30
Case 11	15	2.2	1	0.0043	1.0293	0.0008	4.55E+00	1503	1000	7
Case 12	15	2.2	1	0.0043	1.027	0.0008	5.14E+00	1503	1000	21
Case 13	15	2.2	1	0.0043	1.0259	0.0007	5.44E+00	1503	1000	20
Case 14	15	2.2	1	0.0043	1.0285	0.0008	5.57E+00	1503	1000	7
Case 15	15	2.2	1	0.0043	1.0271	0.0008	5.57E+00	1503	1000	21
Case 16	15	2.2	1	0.0043	1.0232	0.0008	5.15E+00	1503	1000	14
Case 17	15	8.06	0.9988	0.0043	1.0064	0.0007	4.93E+00	1503	1000	3
Case 18	15	8.06	0.9988	0.0043	1.0114	0.0008	6.19E+00	1503	1000	4
Case 19	15	8.06	0.9988	0.0043	1.0086	0.0007	6.47E+00	1503	1000	29
Case 20	15	8.06	0.9988	0.0043	1.0096	0.0008	6.67E+00	1503	1000	176
Case 21	15	8.06	0.9988	0.0043	1.0088	0.0008	6.68E+00	1503	1000	42
Case 22	15	8.06	0.9988	0.0043	1.0130	0.0007	6.42E+00	1503	1000	5
Case 23	49.6	18.35	1	0.0045	1.0079	0.0007	6.86E-01	1503	1000	7
Case 24	49.6	18.35	1	0.0045	1.0100	0.0008	6.97E-01	1503	1000	9
Case 25	49.6	18.35	1	0.0045	1.0086	0.0008	7.06E-01	1503	1000	42
Case 26	49.6	18.35	1	0.0045	1.0101	0.0007	7.13E-01	1503	1000	66
Case 27	49.6	18.35	1	0.0045	1.0105	0.0007	7.23E-01	1503	1000	14
Case 28	49.6	18.35	1	0.0045	1.0101	0.0008	7.29E-01	1503	1000	49
Case 29	49.6	18.35	1	0.0045	1.0124	0.0008	7.36E-01	1503	1000	5

GEN : = Number of generations
NPG : = Number of neutrons per generation
NSK : = Number of generations skipped prior to collecting data

Table A4-2: SCALE 4.4a calculations on PC

Experiment	C(Pu)	H/X	^{240}Pu [wt. %]	Exp. k_{eff}	Exp. Uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF	GEN	NPG	NSK
PU-SOL-THERM-001											
Case 3	119.00	205.14	4.67	1.0000	0.005	1.0115	0.0008	1.35E-01	1503	1000	17
Case 4	132.00	180.97	4.67	1.0000	0.005	1.0059	0.0008	1.51E-01	1503	1000	48
Case 5	140.00	171.21	4.67	1.0000	0.005	1.0092	0.0008	1.60E-01	1503	1000	42
Case 6	268.70	86.66	4.67	1.0000	0.005	1.0087	0.0008	3.47E-01	1503	1000	61

Experiment	C(Pu)	H/X	^{240}Pu [wt. %]	Exp. k_{eff}	Exp. Uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF	GEN	NPG	NSK
PU-SOL-THERM-008											
Case 9	232	85.03	4.67	1.0000	0.0061	1.0071	0.0008	5.49E-01	1503	1000	24
Case 22	232	88.43	4.67	1.0000	0.0061	0.9948	0.0008	5.20E-01	1503	1000	10

GEN : = Number of generations
NPG : = Number of neutrons per generation
NSK : = Number of generations skipped prior to collecting data

Experiment	C(Pu)	H/X	^{240}Pu [wt. %]	Exp. k_{eff}	Exp. Uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF	GEN	NPG	NSK
PU-SOL-THERM-014											
Case 1	115.10	210.18	4.23	0.9980	0.0032	1.0071	0.0008	1.68E-01	1503	1000	31
Case 2	115.10	210.18	4.23	0.9980	0.0032	1.0059	0.0009	1.67E-01	1503	1000	28
Case 3	115.10	210.18	4.23	0.9980	0.0032	1.0080	0.0009	1.67E-01	1503	1000	11
Case 4	115.10	210.18	4.23	0.9980	0.0032	1.0060	0.0008	1.67E-01	1503	1000	22
Case 5	115.10	210.18	4.23	0.9980	0.0032	1.0074	0.0009	1.67E-01	1503	1000	35
Case 6	115.10	210.18	4.23	0.9980	0.0032	1.0060	0.0009	1.67E-01	1503	1000	4
Case 7	115.10	210.18	4.23	0.9980	0.0032	1.0059	0.0009	1.68E-01	1503	1000	29
Case 8	115.10	210.18	4.23	0.9980	0.0032	1.0055	0.0008	1.68E-01	1503	1000	23
Case 9	115.10	210.18	4.23	0.9980	0.0032	1.0052	0.0008	1.67E-01	1503	1000	9
Case 10	115.10	210.18	4.23	0.9980	0.0032	1.0038	0.0009	1.67E-01	1503	1000	9
Case 11	115.10	210.18	4.23	0.9980	0.0032	1.0053	0.0008	1.67E-01	1503	1000	7
Case 12	115.10	210.18	4.23	0.9980	0.0032	1.0070	0.0009	1.67E-01	1503	1000	58
Case 13	115.10	210.18	4.23	0.9980	0.0043	1.0077	0.0008	1.68E-01	1503	1000	3
Case 14	115.10	210.18	4.23	0.9980	0.0043	1.0043	0.0009	1.68E-01	1503	1000	99
Case 15	115.10	210.18	4.23	0.9980	0.0043	1.0070	0.0008	1.67E-01	1503	1000	10
Case 16	115.10	210.18	4.23	0.9980	0.0043	1.0057	0.0009	1.67E-01	1503	1000	7
Case 17	115.10	210.18	4.23	0.9980	0.0043	1.0055	0.0009	1.67E-01	1503	1000	5
Case 18	115.10	210.18	4.23	0.9980	0.0043	1.0080	0.0009	1.68E-01	1503	1000	7
Case 19	115.10	210.18	4.23	0.9980	0.0043	1.0049	0.0010	1.68E-01	1503	1000	9
Case 20	115.10	210.18	4.23	0.9980	0.0043	1.0068	0.0009	1.67E-01	1503	1000	114
Case 21	115.10	210.18	4.23	0.9980	0.0043	1.0063	0.0008	1.67E-01	1503	1000	22
Case 22	115.10	210.18	4.23	0.9980	0.0043	1.0060	0.0009	1.67E-01	1503	1000	4
Case 23	115.10	210.18	4.23	0.9980	0.0043	1.0053	0.0009	1.67E-01	1503	1000	28
Case 24	115.10	210.18	4.23	0.9980	0.0043	1.0082	0.0008	1.69E-01	1503	1000	36
Case 25	115.10	210.18	4.23	0.9980	0.0043	1.0042	0.0009	1.68E-01	1503	1000	65
Case 26	115.10	210.18	4.23	0.9980	0.0043	1.0068	0.0009	1.67E-01	1503	1000	20
Case 27	115.10	210.18	4.23	0.9980	0.0043	1.0059	0.0009	1.67E-01	1503	1000	70
Case 28	115.10	210.18	4.23	0.9980	0.0043	1.0053	0.0009	1.67E-01	1503	1000	15
Case 29	115.10	210.18	4.23	0.9980	0.0043	1.0057	0.0009	1.67E-01	1503	1000	5
Case 30	115.10	210.18	4.23	0.9980	0.0043	1.0051	0.0008	1.68E-01	1503	1000	32
Case 31	115.10	210.18	4.23	0.9980	0.0043	1.0039	0.0009	1.68E-01	1503	1000	5
Case 32	115.10	210.18	4.23	0.9980	0.0043	1.0045	0.0009	1.68E-01	1503	1000	23
Case 33	115.10	210.18	4.23	0.9980	0.0043	1.0063	0.0008	1.67E-01	1503	1000	10
Case 34	115.10	210.18	4.23	0.9980	0.0043	1.0043	0.0010	1.68E-01	1503	1000	44
Case 35	115.10	210.18	4.23	0.9980	0.0043	1.0050	0.0010	1.67E-01	1503	1000	12

Experiment	C(Pu)	H/X	^{240}Pu [wt. %]	Exp. k_{eff}	Exp. Uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF	GEN	NPG	NSK
PU-SOL-THERM-015											
Case 1	152.50	155.21	4.23	0.9980	0.0038	1.0073	0.0009	2.38E-01	1503	1000	61
Case 2	152.50	155.27	4.23	0.9980	0.0038	1.0080	0.0008	2.37E-01	1503	1000	5
Case 3	152.50	155.27	4.23	0.9980	0.0038	1.0059	0.0009	2.37E-01	1503	1000	3
Case 4	152.50	155.27	4.23	0.9980	0.0038	1.0063	0.0009	2.37E-01	1503	1000	38
Case 5	152.50	155.27	4.23	0.9980	0.0038	1.0047	0.0009	2.37E-01	1503	1000	231
Case 6	152.50	155.27	4.23	0.9980	0.0038	1.0073	0.0008	2.36E-01	1503	1000	40
Case 7	152.50	155.27	4.23	0.9971	0.0047	1.0075	0.0009	2.38E-01	1503	1000	71
Case 8	152.50	155.27	4.23	0.9971	0.0047	1.0070	0.0009	2.37E-01	1503	1000	19
Case 9	152.50	155.27	4.23	0.9971	0.0047	1.0068	0.0008	2.37E-01	1503	1000	15
Case 10	152.50	155.27	4.23	0.9971	0.0047	1.0055	0.0009	2.36E-01	1503	1000	6
Case 11	152.50	155.27	4.23	0.9971	0.0047	1.0040	0.0009	2.38E-01	1503	1000	150
Case 12	152.50	155.27	4.23	0.9971	0.0047	1.0036	0.0008	2.38E-01	1503	1000	4
Case 13	152.50	155.27	4.23	0.9971	0.0047	1.0060	0.0009	2.37E-01	1503	1000	6
Case 14	152.50	155.27	4.23	0.9971	0.0047	1.0067	0.0009	2.36E-01	1503	1000	19
Case 15	152.50	155.27	4.23	0.9971	0.0047	1.0071	0.0008	2.39E-01	1503	1000	22
Case 16	152.50	155.27	4.23	0.9971	0.0047	1.0053	0.0009	2.38E-01	1503	1000	53
Case 17	152.50	155.27	4.23	0.9971	0.0047	1.0062	0.0009	2.37E-01	1503	1000	4

Experiment	C(Pu)	H/X	^{240}Pu [wt. %]	Exp. k_{eff}	Exp. Uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF	GEN	NPG	NSK
PU-SOL-THERM-016											
Case 1	152.50	155.27	4.23	0.9980	0.0043	1.0061	0.0009	2.37E-01	1503	1000	3
Case 2	152.50	155.27	4.23	0.9980	0.0043	1.0053	0.0009	2.37E-01	1503	1000	14
Case 3	152.50	155.27	4.23	0.9980	0.0043	1.0071	0.0009	2.37E-01	1503	1000	10
Case 4	152.50	155.27	4.23	0.9980	0.0043	1.0068	0.0009	2.36E-01	1503	1000	16
Case 5	115.10	210.18	4.23	0.9969	0.0038	1.0043	0.0009	1.68E-01	1503	1000	11
Case 6	115.10	210.17	4.23	0.9969	0.0038	1.0044	0.0009	1.67E-01	1503	1000	6
Case 7	115.10	210.17	4.23	0.9969	0.0038	1.0070	0.0009	1.67E-01	1503	1000	13
Case 8	115.10	210.17	4.23	0.9969	0.0038	1.0077	0.0009	1.67E-01	1503	1000	35
Case 9	115.10	210.17	4.23	0.9963	0.0033	1.0059	0.0009	1.66E-01	1503	1000	34
Case 10	115.10	210.17	4.23	0.9963	0.0033	1.0050	0.0010	1.66E-01	1503	1000	6
Case 11	115.10	210.17	4.23	0.9963	0.0033	1.0064	0.0009	1.67E-01	1503	1000	10

Experiment	C(Pu)	H/X	^{240}Pu [wt. %]	Exp. k_{eff}	Exp. Uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF	GEN	NPG	NSK
PU-SOL-THERM-017											
Case 1	115.10	210.18	4.23	0.9969	0.0038	1.0042	0.0009	1.67E-01	1503	1000	72
Case 2	115.10	210.18	4.23	0.9969	0.0038	1.0057	0.0009	1.67E-01	1503	1000	12
Case 3	115.10	210.18	4.23	0.9969	0.0038	1.0052	0.0009	1.67E-01	1503	1000	27
Case 4	115.10	210.18	4.23	0.9969	0.0038	1.0049	0.0008	1.67E-01	1503	1000	20
Case 5	115.10	210.18	4.23	0.9969	0.0038	1.0062	0.0009	1.67E-01	1503	1000	15
Case 6	115.10	210.18	4.23	0.9969	0.0038	1.0056	0.0009	1.67E-01	1503	1000	8
Case 7	115.10	210.18	4.23	0.9969	0.0038	1.0038	0.0010	1.67E-01	1503	1000	86
Case 8	115.10	210.18	4.23	0.9969	0.0038	1.0052	0.0010	1.67E-01	1503	1000	25
Case 9	115.10	210.18	4.23	0.9969	0.0038	1.0059	0.0010	1.67E-01	1503	1000	17
Case 10	115.10	210.18	4.23	0.9969	0.0038	1.0047	0.0009	1.68E-01	1503	1000	20
Case 11	115.10	210.18	4.23	0.9969	0.0038	1.0058	0.0009	1.67E-01	1503	1000	36
Case 12	115.10	210.18	4.23	0.9969	0.0038	1.0056	0.0010	1.67E-01	1503	1000	25
Case 13	115.10	210.18	4.23	0.9969	0.0038	1.0060	0.0009	1.67E-01	1503	1000	17
Case 14	115.10	210.18	4.23	0.9969	0.0038	1.0061	0.0009	1.67E-01	1503	1000	71
Case 15	115.10	210.18	4.23	0.9969	0.0038	1.0071	0.0008	1.67E-01	1503	1000	61
Case 16	115.10	210.18	4.23	0.9969	0.0038	1.0070	0.0009	1.67E-01	1503	1000	52
Case 17	115.10	210.18	4.23	0.9969	0.0038	1.0057	0.0009	1.67E-01	1503	1000	39
Case 18	115.10	210.18	4.23	0.9969	0.0038	1.0064	0.0009	1.67E-01	1503	1000	14

ATTACHMENT NUMBER 5

OUTPUT LISTING OF USLSTATS V1.0

FOR PC CALCULATIONS

Figure A5-1: USLSTATS output listing for AOA(5) Group 1: PuO_2 powder k_{eff} versus EALF as trending parameter, SCALE 4.4a on PC

```
uslstats: a utility to calculate upper subcritical
                        limits for criticality safety applications

  **************************************************************************
                        Version 1.3.7, May 18, 1999
                         Oak Ridge National Laboratory
  **************************************************************************


   Input to statistical treatment from file:ealf.in

Title: PuO2 powder EALF

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =  32
   Minimum value of closed band =   0.00
   Maximum value of closed band =   0.00
   Administrative margin        =   0.05

   independent     dependent       deviation               independent     dependent       deviation
   variable - x    variable - y     in y                   variable - x    variable - y     in y

    4.90213E+03     1.03443E+00     4.65296E-03             4.92600E+00     1.00761E+00     4.45533E-03
    4.20132E+03     1.03123E+00     4.65296E-03             6.19100E+00     1.01262E+00     4.47214E-03
    3.46319E+03     1.02763E+00     4.66905E-03             6.46700E+00     1.00981E+00     4.45533E-03
    2.60173E+03     1.02172E+00     4.65296E-03             6.67400E+00     1.01081E+00     4.47214E-03
    1.87477E+03     1.01732E+00     4.65296E-03             6.68200E+00     1.01001E+00     4.47214E-03
    9.20880E+01     1.02370E+00     4.45533E-03             6.42000E+00     1.01422E+00     4.45533E-03
    8.42160E+01     1.02120E+00     4.47214E-03             6.86000E-01     1.00790E+00     4.65296E-03
    6.78560E+01     1.02140E+00     4.47214E-03             6.97000E-01     1.01000E+00     4.66905E-03
    5.69610E+01     1.02230E+00     4.45533E-03             7.06000E-01     1.00860E+00     4.66905E-03
    4.12300E+00     1.03140E+00     4.45533E-03             7.13000E-01     1.01010E+00     4.65296E-03
    4.55400E+00     1.02930E+00     4.47214E-03             7.23000E-01     1.01050E+00     4.65296E-03
    5.13800E+00     1.02700E+00     4.47214E-03             7.29000E-01     1.01010E+00     4.66905E-03
    5.43700E+00     1.02590E+00     4.45533E-03             7.36000E-01     1.01240E+00     4.66905E-03
    5.57000E+00     1.02850E+00     4.47214E-03             1.74727E+03     1.02040E+00     3.37343E-03
    5.57100E+00     1.02710E+00     4.47214E-03             3.26850E+01     1.01732E+00     4.78539E-03
    5.15100E+00     1.02320E+00     4.47214E-03             1.54800E+00     1.00881E+00     5.37587E-03

   WARNING *** the test for normal may be unreliable due to insufficient data.

   chi =  8.0000 (upper bound = 9.49). The data tests normal.


         Output from statistical treatment

   PuO2 powder EALF

    Number of data points (n)                          32
    Linear regression, k(X)                           1.0167 + ( 3.1025E-06)*X
    Confidence on fit (1-gamma) [input]                95.0%
Confidence on proportion (alpha) [input]           95.0%
    Proportion of population falling above
    lower tolerance interval (rho) [input]             99.9%
    Minimum value of X                                    0.6860
    Maximum value of X                                 4902.1300
    Average value of X                                  600.11431
    Average value of k                                  1.01858
    Minimum value of k                                  1.00761
    Variance of fit, s(k,X)^2                          5.4730E-05
    Within variance, s(w)^2                            2.0709E-05
    Pooled variance, s(p)^2                            7.5439E-05
    Pooled std. deviation, s(p)                        8.6855E-03
    C(alpha,rho)*s(p)                                  4.6595E-02
    student-t @ (n-2,1-gamma)                          1.69700E+00
    Confidence band width, W                           1.7218E-02
    Minimum margin of subcriticality, C*s(p)-W         2.9376E-02

    Upper subcritical limits: ( 0.68600     <= X <=    4902.1     )
    ***** *********** *******
```

```
    USL Method 1 (Confidence Band with
    Administrative Margin)             USL1 = 0.9328 ( 0.68600    < X <  4902.1    )

    USL Method 2 (Single-Sided Uniform
    Width Closed Interval Approach)    USL2 = 0.9534 ( 0.68600    < X <  4902.1    )


    USLs Evaluated Over Range of Parameter X:
    **** ********* **** ***** ** ********* **

    X:  6.86E-1  7.01E+2  1.40E+3  2.10E+3  2.80E+3  3.50E+3  4.20E+3  4.90E+3
       -----------------------------------------------------------------------
USL-1:    0.9328   0.9328   0.9328   0.9328   0.9328   0.9328   0.9328   0.9328
USL-2:    0.9534   0.9534   0.9534   0.9534   0.9534   0.9534   0.9534   0.9534
       -----------------------------------------------------------------------

  ***************************************************************************
                           Thus spake USLSTATS
                                  Finis.
```

Figure A5-2: USLSTATS output listing for AOA(5) Group 1: PuO_2 powder k_{eff} versus H/Pu as trending parameter, SCALE 4.4a on PC

```
uslstats: a utility to calculate upper subcritical
                        limits for criticality safety applications

  ****************************************************************************
                        Version 1.3.7, May 18, 1999
                         Oak Ridge National Laboratory
  ****************************************************************************


   Input to statistical treatment from file:hpu.in

Title: PuO2 powder H/Pu

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =   32
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05

   independent     dependent       deviation               independent     dependent       deviation
   variable - x    variable - y     in y                   variable - x    variable - y     in y

    4.00000E-02     1.03443E+00     4.65296E-03             1.50000E+01     1.00761E+00     4.45533E-03
    4.00000E-02     1.03123E+00     4.65296E-03             1.50000E+01     1.01262E+00     4.47214E-03
    4.00000E-02     1.02763E+00     4.66905E-03             1.50000E+01     1.00981E+00     4.45533E-03
    4.00000E-02     1.02172E+00     4.65296E-03             1.50000E+01     1.01081E+00     4.47214E-03
    4.00000E-02     1.01732E+00     4.65296E-03             1.50000E+01     1.01001E+00     4.47214E-03
    5.00000E+00     1.02370E+00     4.45533E-03             1.50000E+01     1.01422E+00     4.45533E-03
    5.00000E+00     1.02120E+00     4.47214E-03             4.96000E+01     1.00790E+00     4.65296E-03
    5.00000E+00     1.02140E+00     4.47214E-03             4.96000E+01     1.01000E+00     4.66905E-03
    5.00000E+00     1.02230E+00     4.45533E-03             4.96000E+01     1.00860E+00     4.66905E-03
    1.50000E+01     1.03140E+00     4.45533E-03             4.96000E+01     1.01010E+00     4.65296E-03
    1.50000E+01     1.02930E+00     4.47214E-03             4.96000E+01     1.01050E+00     4.65296E-03
    1.50000E+01     1.02700E+00     4.47214E-03             4.96000E+01     1.01010E+00     4.66905E-03
    1.50000E+01     1.02590E+00     4.45533E-03             4.96000E+01     1.01240E+00     4.66905E-03
    1.50000E+01     1.02850E+00     4.47214E-03             5.00000E+00     1.02040E+00     3.37343E-03
    1.50000E+01     1.02710E+00     4.47214E-03             1.50000E+01     1.01732E+00     4.78539E-03
    1.50000E+01     1.02320E+00     4.47214E-03             4.96000E+01     1.00881E+00     5.37587E-03

   WARNING *** the test for normal may be unreliable due to insufficient data.

   chi =  8.0000 (upper bound = 9.49). The data tests normal.


         Output from statistical treatment

   PuO2 powder H/Pu

    Number of data points (n)                          32
    Linear regression, k(X)                          1.0246 + (-3.0367E-04)*X
    Confidence on fit (1-gamma) [input]                95.0%
Confidence on proportion (alpha) [input]           95.0%
    Proportion of population falling above
    lower tolerance interval (rho) [input]             99.9%
    Minimum value of X                                    0.0400
    Maximum value of X                                   49.6000
    Average value of X                                   19.75000
    Average value of k                                  1.01858
    Minimum value of k                                  1.00761
    Variance of fit, s(k,X)^2                          4.0344E-05
    Within variance, s(w)^2                            2.0709E-05
    Pooled variance, s(p)^2                            6.1053E-05
    Pooled std. deviation, s(p)                        7.8136E-03
    C(alpha,rho)*s(p)                                  3.7933E-02
    student-t @ (n-2,1-gamma)                          1.69700E+00
    Confidence band width, W                           1.4010E-02
    Minimum margin of subcriticality, C*s(p)-W         2.3923E-02

    Upper subcritical limits: ( 4.00000E-02 <= X <=  49.600     )
    ***** *********** *******
```

```
    USL Method 1 (Confidence Band with
    Administrative Margin)            USL1 = 0.9360 ( 4.00000E-2< X <  49.600   )

    USL Method 2 (Single-Sided Uniform
    Width Closed Interval Approach)   USL2 = 0.9621 ( 4.00000E-2< X <  49.600   )


    USLs Evaluated Over Range of Parameter X:
    **** ********* **** ***** ** ********* **

    X:  4.00E-2  7.12E+0  1.42E+1  2.13E+1  2.84E+1  3.54E+1  4.25E+1  4.96E+1
        ----------------------------------------------------------------------
USL-1:    0.9360   0.9360   0.9360   0.9360   0.9360   0.9360   0.9360   0.9360
USL-2:    0.9621   0.9621   0.9621   0.9621   0.9621   0.9621   0.9621   0.9621
        ----------------------------------------------------------------------

  ***************************************************************************
                           Thus spake USLSTATS
                                  Finis.
```

Figure A5-3: USLSTATS output listing for AOA(5) Group 1: PuO_2 powder k_{eff} versus ^{240}Pu as trending parameter, SCALE 4.4a on PC

```
uslstats: a utility to calculate upper subcritical
                        limits for criticality safety applications

  ****************************************************************************
                        Version 1.3.7, May 18, 1999
                         Oak Ridge National Laboratory
  ****************************************************************************


   Input to statistical treatment from file:%pu.in

Title: PuO2 powder %Pu

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =   32
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05

   independent     dependent       deviation               independent     dependent       deviation
   variable - x    variable - y     in y                   variable - x    variable - y     in y

    1.83500E+01     1.03443E+00     4.65296E-03             8.06000E+00     1.00761E+00     4.45533E-03
    1.83500E+01     1.03123E+00     4.65296E-03             8.06000E+00     1.01262E+00     4.47214E-03
    1.83500E+01     1.02763E+00     4.66905E-03             8.06000E+00     1.00981E+00     4.45533E-03
    1.83500E+01     1.02172E+00     4.65296E-03             8.06000E+00     1.01081E+00     4.47214E-03
    1.83500E+01     1.01732E+00     4.65296E-03             8.06000E+00     1.01001E+00     4.47214E-03
    1.14600E+01     1.02370E+00     4.45533E-03             8.06000E+00     1.01422E+00     4.45533E-03
    1.14600E+01     1.02120E+00     4.47214E-03             1.83500E+01     1.00790E+00     4.65296E-03
    1.14600E+01     1.02140E+00     4.47214E-03             1.83500E+01     1.01000E+00     4.66905E-03
    1.14600E+01     1.02230E+00     4.45533E-03             1.83500E+01     1.00860E+00     4.66905E-03
    2.20000E+00     1.03140E+00     4.45533E-03             1.83500E+01     1.01010E+00     4.65296E-03
    2.20000E+00     1.02930E+00     4.47214E-03             1.83500E+01     1.01050E+00     4.65296E-03
    2.20000E+00     1.02700E+00     4.47214E-03             1.83500E+01     1.01010E+00     4.66905E-03
    2.20000E+00     1.02590E+00     4.45533E-03             1.83500E+01     1.01240E+00     4.66905E-03
    2.20000E+00     1.02850E+00     4.47214E-03             1.14600E+01     1.02040E+00     3.37343E-03
    2.20000E+00     1.02710E+00     4.47214E-03             2.20000E+00     1.01732E+00     4.78539E-03
    2.20000E+00     1.02320E+00     4.47214E-03             1.83500E+01     1.00881E+00     5.37587E-03

   WARNING *** the test for normal may be unreliable due to insufficient data.

   chi =  8.0000 (upper bound = 9.49). The data tests normal.


         Output from statistical treatment

   PuO2 powder %Pu

    Number of data points (n)                           32
    Linear regression, k(X)                            1.0237 + (-4.5199E-04)*X
    Confidence on fit (1-gamma) [input]                 95.0%
    Confidence on proportion (alpha) [input]            95.0%
    Proportion of population falling above
    lower tolerance interval (rho) [input]              99.9%
    Minimum value of X                                     2.2000
    Maximum value of X                                    18.3500
    Average value of X                                    11.30656
    Average value of k                                   1.01858
    Minimum value of k                                   1.00761
    Variance of fit, s(k,X)^2                           6.3200E-05
    Within variance, s(w)^2                             2.0709E-05
    Pooled variance, s(p)^2                             8.3909E-05
    Pooled std. deviation, s(p)                         9.1602E-03
    C(alpha,rho)*s(p)                                   4.3914E-02
    student-t @ (n-2,1-gamma)                           1.69700E+00
    Confidence band width, W                            1.6242E-02
    Minimum margin of subcriticality, C*s(p)-W          2.7672E-02

    Upper subcritical limits: (  2.2000     <= X <=   18.350     )
    ***** *********** *******
```

```
    USL Method 1 (Confidence Band with
    Administrative Margin)            USL1 = 0.9338 (  2.2000   < X <  18.350   )

    USL Method 2 (Single-Sided Uniform
    Width Closed Interval Approach)   USL2 = 0.9561 (  2.2000   < X <  18.350   )


    USLs Evaluated Over Range of Parameter X:
    **** ********* **** ***** ** ********* **

    X:  2.20E+0  4.51E+0  6.81E+0  9.12E+0  1.14E+1  1.37E+1  1.60E+1  1.84E+1
       --------------------------------------------------------------------
USL-1:    0.9338   0.9338   0.9338   0.9338   0.9338   0.9338   0.9338   0.9338
USL-2:    0.9561   0.9561   0.9561   0.9561   0.9561   0.9561   0.9561   0.9561
       --------------------------------------------------------------------

  ******************************************************************************
                           Thus spake USLSTATS
                                  Finis.
```

Figure A5-4: USLSTATS output listing for AOA(5) Group 2: Pu Nitrate k_{eff} versus EALF as trending parameter, SCALE 4.4a on PC

```
uslstats: a utility to calculate upper subcritical
                       limits for criticality safety applications

  ***********************************************************************
                       Version 1.3.7, May 18, 1999
                        Oak Ridge National Laboratory
  ***********************************************************************


   Input to statistical treatment from file:ealfPC

Title: gr2 PC EALF

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =  87
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05

   independent     dependent       deviation                independent     dependent       deviation
   variable - x    variable - y     in y                    variable - x    variable - y     in y

    1.34839E-01     1.01150E+00     5.06360E-03              2.36831E-01     1.00830E+00     3.90513E-03
    1.50757E-01     1.00590E+00     5.06360E-03              2.36587E-01     1.00670E+00     3.90513E-03
    1.59544E-01     1.00920E+00     5.06360E-03              2.36202E-01     1.00930E+00     3.88330E-03
    3.46678E-01     1.00870E+00     5.06360E-03              2.38483E-01     1.01040E+00     4.78539E-03
    5.48519E-01     1.00710E+00     6.15224E-03              2.37274E-01     1.00990E+00     4.78539E-03
    5.20183E-01     9.94800E-01     6.15224E-03              2.36695E-01     1.00970E+00     4.76760E-03
    1.67812E-01     1.00910E+00     3.29849E-03              2.36058E-01     1.00840E+00     4.78539E-03
    1.67457E-01     1.00790E+00     3.32415E-03              2.38161E-01     1.00690E+00     4.78539E-03
    1.66807E-01     1.01000E+00     3.32415E-03              2.37891E-01     1.00650E+00     4.76760E-03
    1.67233E-01     1.00800E+00     3.29849E-03              2.36841E-01     1.00890E+00     4.78539E-03
    1.66668E-01     1.00940E+00     3.32415E-03              2.36296E-01     1.00960E+00     4.78539E-03
    1.66668E-01     1.00800E+00     3.32415E-03              2.38548E-01     1.01000E+00     4.76760E-03
    1.68142E-01     1.00790E+00     3.32415E-03              2.38276E-01     1.00820E+00     4.78539E-03
    1.67636E-01     1.00750E+00     3.29849E-03              2.37141E-01     1.00910E+00     4.78539E-03
    1.67279E-01     1.00720E+00     3.29849E-03              2.37431E-01     1.00810E+00     4.39318E-03
    1.67337E-01     1.00580E+00     3.32415E-03              2.36989E-01     1.00730E+00     4.39318E-03
    1.66955E-01     1.00730E+00     3.29849E-03              2.36537E-01     1.00910E+00     4.39318E-03
    1.66546E-01     1.00900E+00     3.32415E-03              2.36458E-01     1.00880E+00     4.39318E-03
    1.68373E-01     1.00970E+00     4.37379E-03              1.67942E-01     1.00740E+00     3.90513E-03
    1.67903E-01     1.00630E+00     4.39318E-03              1.67467E-01     1.00750E+00     3.90513E-03
    1.67166E-01     1.00900E+00     4.37379E-03              1.67208E-01     1.01010E+00     3.90513E-03
    1.66898E-01     1.00770E+00     4.39318E-03              1.66786E-01     1.01080E+00     3.90513E-03
    1.66630E-01     1.00750E+00     4.39318E-03              1.65519E-01     1.00960E+00     3.42053E-03
    1.68449E-01     1.01000E+00     4.39318E-03              1.66435E-01     1.00870E+00     3.44819E-03
    1.67790E-01     1.00690E+00     4.41475E-03              1.67131E-01     1.01010E+00     3.42053E-03
    1.66997E-01     1.00880E+00     4.39318E-03              1.66869E-01     1.00730E+00     3.90513E-03
    1.66691E-01     1.00830E+00     4.37379E-03              1.66968E-01     1.00880E+00     3.90513E-03
    1.66682E-01     1.00800E+00     4.39318E-03              1.67120E-01     1.00830E+00     3.90513E-03
    1.66969E-01     1.00730E+00     4.39318E-03              1.67064E-01     1.00800E+00     3.88330E-03
    1.68612E-01     1.01020E+00     4.37379E-03              1.67223E-01     1.00930E+00     3.90513E-03
    1.67699E-01     1.00620E+00     4.39318E-03              1.67150E-01     1.00870E+00     3.90513E-03
    1.67331E-01     1.00880E+00     4.39318E-03              1.67269E-01     1.00690E+00     3.92938E-03
    1.66818E-01     1.00790E+00     4.39318E-03              1.67189E-01     1.00830E+00     3.92938E-03
    1.66664E-01     1.00730E+00     4.39318E-03              1.67010E-01     1.00900E+00     3.92938E-03
    1.66641E-01     1.00770E+00     4.39318E-03              1.67538E-01     1.00780E+00     3.90513E-03
    1.68215E-01     1.00710E+00     4.37379E-03              1.66900E-01     1.00890E+00     3.90513E-03
    1.68357E-01     1.00590E+00     4.39318E-03              1.66967E-01     1.00870E+00     3.92938E-03
    1.67772E-01     1.00650E+00     4.39318E-03              1.67078E-01     1.00910E+00     3.90513E-03
    1.67416E-01     1.00830E+00     4.37379E-03              1.67248E-01     1.00920E+00     3.90513E-03
    1.67630E-01     1.00630E+00     4.41475E-03              1.66704E-01     1.01020E+00     3.88330E-03
    1.67462E-01     1.00700E+00     4.41475E-03              1.66824E-01     1.01010E+00     3.90513E-03
    2.37509E-01     1.00930E+00     3.90513E-03              1.66972E-01     1.00880E+00     3.90513E-03
    2.36912E-01     1.01000E+00     3.88330E-03              1.66697E-01     1.00950E+00     3.90513E-03
    2.36543E-01     1.00790E+00     3.90513E-03

   chi =  9.3793 (upper bound = 9.49). The data tests normal.


          Output from statistical treatment
```

```
gr2 PC EALF

 Number of data points (n)                      87
 Linear regression, k(X)                       1.0108 + (-1.3126E-02)*X
 Confidence on fit (1-gamma) [input]            95.0%
 Confidence on proportion (alpha) [input]       95.0%
 Proportion of population falling above
 lower tolerance interval (rho) [input]         99.9%
 Minimum value of X                                0.1348
 Maximum value of X                                0.5485
 Average value of X                                0.19394
 Average value of k                              1.00824
 Minimum value of k                              0.99480
 Variance of fit, s(k,X)^2                      3.0167E-06
 Within variance, s(w)^2                        1.7752E-05
 Pooled variance, s(p)^2                        2.0769E-05
 Pooled std. deviation, s(p)                    4.5573E-03
 C(alpha,rho)*s(p)                              2.2118E-02
 student-t @ (n-2,1-gamma)                      1.66558E+00
 Confidence band width, W                       8.9068E-03
 Minimum margin of subcriticality, C*s(p)-W     1.3211E-02

 Upper subcritical limits: ( 0.13484     <= X <=  0.54852    )
 ***** *********** *******

 USL Method 1 (Confidence Band with
 Administrative Margin)           USL1 = 0.9411 ( 0.13484   < X < 0.54852    )

 USL Method 2 (Single-Sided Uniform
 Width Closed Interval Approach)  USL2 = 0.9779 ( 0.13484   < X < 0.54852    )


 USLs Evaluated Over Range of Parameter X:
 **** ********* **** ***** ** ********* **

 X:  1.35E-1  1.94E-1  2.53E-1  3.12E-1  3.71E-1  4.30E-1  4.89E-1  5.49E-1
     ----------------------------------------------------------------------
USL-1:   0.9411   0.9411   0.9411   0.9411   0.9411   0.9411   0.9411   0.9411
USL-2:   0.9779   0.9779   0.9779   0.9779   0.9779   0.9779   0.9779   0.9779
     ----------------------------------------------------------------------

  ***************************************************************************
                              Thus spake USLSTATS
                                     Finis.
```

Figure A5-5: USLSTATS output listing for AOA(5) Group 2: Pu Nitrate k_{eff} versus H/Pu as trending parameter, SCALE 4.4a on PC

```
uslstats: a utility to calculate upper subcritical
                        limits for criticality safety applications

  ***************************************************************************
                        Version 1.3.7, May 18, 1999
                         Oak Ridge National Laboratory
  ***************************************************************************


   Input to statistical treatment from file:hpupc

Title: gr2 PC HPU

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =   87
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05

   independent     dependent       deviation              independent     dependent       deviation
   variable - x    variable - y      in y                 variable - x    variable - y      in y

    2.05140E+02     1.01150E+00     5.06360E-03            1.55270E+02     1.00830E+00     3.90513E-03
    1.80970E+02     1.00590E+00     5.06360E-03            1.55270E+02     1.00670E+00     3.90513E-03
    1.71210E+02     1.00920E+00     5.06360E-03            1.55270E+02     1.00930E+00     3.88330E-03
    8.66600E+01     1.00870E+00     5.06360E-03            1.55270E+02     1.01040E+00     4.78539E-03
    8.50300E+01     1.00710E+00     6.15224E-03            1.55270E+02     1.00990E+00     4.78539E-03
    8.84300E+01     9.94800E-01     6.15224E-03            1.55270E+02     1.00970E+00     4.76760E-03
    2.10180E+02     1.00910E+00     3.29849E-03            1.55270E+02     1.00840E+00     4.78539E-03
    2.10180E+02     1.00790E+00     3.32415E-03            1.55270E+02     1.00690E+00     4.78539E-03
    2.10180E+02     1.01000E+00     3.32415E-03            1.55270E+02     1.00650E+00     4.76760E-03
    2.10180E+02     1.00800E+00     3.29849E-03            1.55270E+02     1.00890E+00     4.78539E-03
    2.10180E+02     1.00940E+00     3.32415E-03            1.55270E+02     1.00960E+00     4.78539E-03
    2.10180E+02     1.00800E+00     3.32415E-03            1.55270E+02     1.01000E+00     4.76760E-03
    2.10180E+02     1.00790E+00     3.32415E-03            1.55270E+02     1.00820E+00     4.78539E-03
    2.10180E+02     1.00750E+00     3.29849E-03            1.55270E+02     1.00910E+00     4.78539E-03
    2.10180E+02     1.00720E+00     3.29849E-03            1.55270E+02     1.00810E+00     4.39318E-03
    2.10180E+02     1.00580E+00     3.32415E-03            1.55270E+02     1.00730E+00     4.39318E-03
    2.10180E+02     1.00730E+00     3.29849E-03            1.55270E+02     1.00910E+00     4.39318E-03
    2.10180E+02     1.00900E+00     3.32415E-03            1.55270E+02     1.00880E+00     4.39318E-03
    2.10180E+02     1.00970E+00     4.37379E-03            2.10180E+02     1.00740E+00     3.90513E-03
    2.10180E+02     1.00630E+00     4.39318E-03            2.10170E+02     1.00750E+00     3.90513E-03
    2.10180E+02     1.00900E+00     4.37379E-03            2.10170E+02     1.01010E+00     3.90513E-03
    2.10180E+02     1.00770E+00     4.39318E-03            2.10170E+02     1.01080E+00     3.90513E-03
    2.10180E+02     1.00750E+00     4.39318E-03            2.10170E+02     1.00960E+00     3.42053E-03
    2.10180E+02     1.01000E+00     4.39318E-03            2.10170E+02     1.00870E+00     3.44819E-03
    2.10180E+02     1.00690E+00     4.41475E-03            2.10170E+02     1.01010E+00     3.42053E-03
    2.10180E+02     1.00880E+00     4.39318E-03            2.10180E+02     1.00730E+00     3.90513E-03
    2.10180E+02     1.00830E+00     4.37379E-03            2.10180E+02     1.00880E+00     3.90513E-03
    2.10180E+02     1.00800E+00     4.39318E-03            2.10180E+02     1.00830E+00     3.90513E-03
    2.10180E+02     1.00730E+00     4.39318E-03            2.10180E+02     1.00800E+00     3.88330E-03
    2.10180E+02     1.01020E+00     4.37379E-03            2.10180E+02     1.00930E+00     3.90513E-03
    2.10180E+02     1.00620E+00     4.39318E-03            2.10180E+02     1.00870E+00     3.90513E-03
    2.10180E+02     1.00880E+00     4.39318E-03            2.10180E+02     1.00690E+00     3.92938E-03
    2.10180E+02     1.00790E+00     4.39318E-03            2.10180E+02     1.00830E+00     3.92938E-03
    2.10180E+02     1.00730E+00     4.39318E-03            2.10180E+02     1.00900E+00     3.92938E-03
    2.10180E+02     1.00770E+00     4.39318E-03            2.10180E+02     1.00780E+00     3.90513E-03
    2.10180E+02     1.00710E+00     4.37379E-03            2.10180E+02     1.00890E+00     3.90513E-03
    2.10180E+02     1.00590E+00     4.39318E-03            2.10180E+02     1.00870E+00     3.92938E-03
    2.10180E+02     1.00650E+00     4.39318E-03            2.10180E+02     1.00910E+00     3.90513E-03
    2.10180E+02     1.00830E+00     4.37379E-03            2.10180E+02     1.00920E+00     3.90513E-03
    2.10180E+02     1.00630E+00     4.41475E-03            2.10180E+02     1.01020E+00     3.88330E-03
    2.10180E+02     1.00700E+00     4.41475E-03            2.10180E+02     1.01010E+00     3.90513E-03
    1.55210E+02     1.00930E+00     3.90513E-03            2.10180E+02     1.00880E+00     3.90513E-03
    1.55270E+02     1.01000E+00     3.88330E-03            2.10180E+02     1.00950E+00     3.90513E-03
    1.55270E+02     1.00790E+00     3.90513E-03

   chi =   9.3793 (upper bound = 9.49). The data tests normal.


         Output from statistical treatment
```

```
gr2 PC HPU

 Number of data points (n)                        87
 Linear regression, k(X)                        1.0054 + ( 1.4797E-05)*X
 Confidence on fit (1-gamma) [input]             95.0%
 Confidence on proportion (alpha) [input]        95.0%
 Proportion of population falling above
 lower tolerance interval (rho) [input]          99.9%
 Minimum value of X                                85.0300
 Maximum value of X                               210.1800
 Average value of X                               191.82517
 Average value of k                               1.00824
 Minimum value of k                               0.99480
 Variance of fit, s(k,X)^2                       3.5025E-06
 Within variance, s(w)^2                         1.7752E-05
 Pooled variance, s(p)^2                         2.1254E-05
 Pooled std. deviation, s(p)                     4.6103E-03
 C(alpha,rho)*s(p)                               2.0310E-02
 student-t @ (n-2,1-gamma)                       1.66558E+00
 Confidence band width, W                        8.2357E-03
 Minimum margin of subcriticality, C*s(p)-W      1.2074E-02

 Upper subcritical limits: (  85.030     <= X <=    210.18     )
 ***** *********** *******

 USL Method 1 (Confidence Band with
 Administrative Margin)        USL1 = 0.9418 (  85.030    < X <  210.18    )

 USL Method 2 (Single-Sided Uniform
 Width Closed Interval Approach)    USL2 = 0.9797 (  85.030    < X <  210.18    )


 USLs Evaluated Over Range of Parameter X:
 **** ********* **** ***** ** ********* **

 X:  8.50E+1  1.03E+2  1.21E+2  1.39E+2  1.57E+2  1.74E+2  1.92E+2  2.10E+2
     ----------------------------------------------------------------------
USL-1:   0.9418   0.9418   0.9418   0.9418   0.9418   0.9418   0.9418   0.9418
USL-2:   0.9797   0.9797   0.9797   0.9797   0.9797   0.9797   0.9797   0.9797
     ----------------------------------------------------------------------

  ***************************************************************************
                              Thus spake USLSTATS
                                     Finis.
```