DUKE COGEMA
STONE & WEBSTER

Mixed Oxide Fuel Fabrication Facility

Criticality Code Validation
Part II

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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 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.

Five design AOAs are established to cover the range of processes and fissile materials in the MFFF. The five AOAs 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 [17]. 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 [18].

The report concludes that the upper safety limit (USL) for the third design AOA (i.e., PuO_2 powder) is 0.9325, and the USL for the fourth design AOA (i.e., MOX powder) is 0.9305. The USL accounts for the computational bias, uncertainties, and a 0.05 administrative margin, and a conservative treatment 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 CSAS26 sequence of the SCALE 4.4 and SCALE 4.4a code packages [1] with the 238 energy group cross-section library 238GROUPNDF5 for nuclear criticality safety calculations of the MFFF.

1.3 APPLICABILITY

Five design areas of applicability (AOAs) are established to cover the range of processes and fissile materials in the MFFF. The five AOAs are as follows:

- 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 4.4 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.

Recent KENO-VI updates published in Scale Newsletter Number 24 (July 2001), available at the SCALE web site, have not been applied to the version of SCALE 4.4 and SCALE 4.4a used for calculations. Comparison between patched and unpatched SCALE 4.4a versions do not indicate statistically significant differences [16].

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 3-1 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.*" Five AOAs are established for the MFFF: (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 five 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 [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 3.5).

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 ($\Delta\beta$) 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 7.1 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:

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

3.3 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 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

As stated in Section 3.1, both methods assume that the distribution of data points is normal; therefore, data that does not follow a normal distribution is examined on an individual basis. The data is evaluated to determine potential reasons why the data does not follow a normal distribution. This analysis can be performed by visually examining a plot of the data or by evaluating the χ^2 values for the data. If the evaluation indicates that the data is acceptable, a lower limit is taken that encompasses all the data including experimental and computational uncertainties. An administrative margin is then applied to the lower limit to determine the USL.

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:

$$\sigma_i = \sqrt{\sigma_{e,i}^2 + \sigma_{s,i}^2} \qquad \text{(Eq. 3.21)}$$

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:

$$k_{eff}\,(\text{normalized}) = k_{eff}\,(\text{calculated}) \,/\, k_{eff}\,(\text{experimental}) \qquad \text{(Eq. 3.22)}$$

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.

3.7 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)
- ^{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 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.

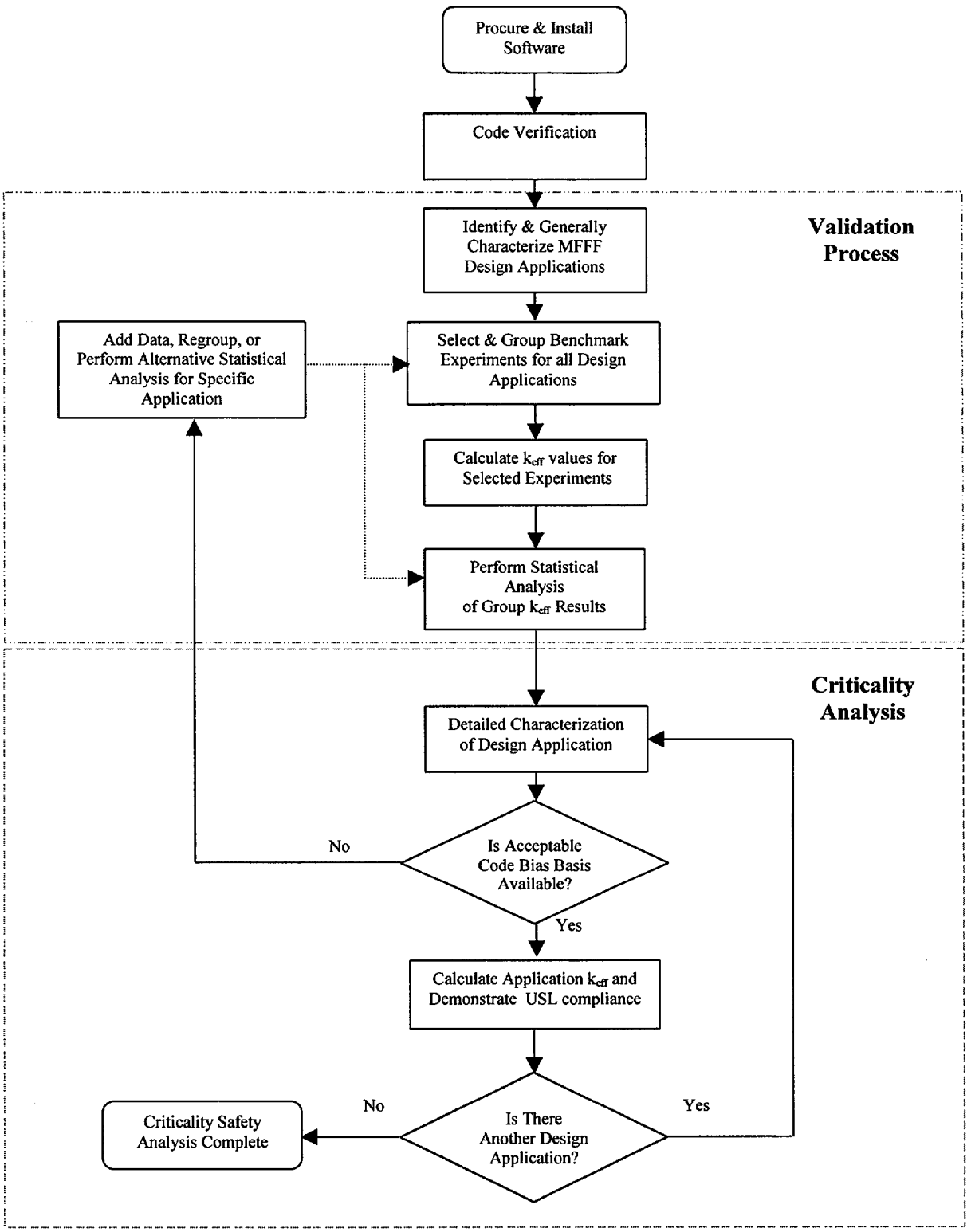

Figure 3-1 Overview of the Criticality Analysis Process of the MFFF

Table 3-1 Characteristics of the Five 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

4. MFFF DESIGN APPLICATION CLASSIFICATION

This section describes the characteristics of the established AOAs based on the various fuel configurations encountered in the MFFF. Five AOAs are established for the MFFF (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 (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 [eV]
AP: Decanning						
PuO_2 dosing hopper	Water	PuO_2 powder	4% ^{240}Pu	7.0	1.67	12500 to 13500
AP: Dissolution						
Electrolyzer	Water/concrete	PuO_2 powder	4% ^{240}Pu	7.0	1.67	200 to 25000
Filter glove box	Water/concrete	PuO_2 powder	4% ^{240}Pu	7.0	1.67	696
Tanks in cell	Cd/water/concrete	PuO_2 powder	4% ^{240}Pu	7.0	1.67	10000 to 50000
AP: Oxalic Precipitation Conversion						
Furnace GB	Water/concrete	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	100 to 200
PuO_2 powder sampling GB	Water	PuO_2 powder	4% ^{240}Pu	3.5	5.97	50 to 500[2]
Sampling GB	Water	PuO_2 powder	4% ^{240}Pu	3.5	5.97	50 to 500[2]
Sample storage GB	Water/concrete	PuO_2 powder	4% ^{240}Pu	3.5	5.97	50 to 500[2]
Cylindrical condenser	Water/concrete	PuO_2 powder	4% ^{240}Pu	3.5	5.97	50 to 500[2)]
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	Borated concrete reflected array	PuO_2 powder	4% ^{240}Pu	3.5	5.97	46.5
Primary dosing unit	Water/concrete	PuO_2 powder	4% ^{240}Pu	3.5	1.58	1572
PuO_2 decanning unit	Water/concrete	PuO_2 powder	4% ^{240}Pu	3.5	0.3	12 to 1340
Jar store unit	Concrete reflected array	PuO_2 Powder[1]	4% ^{240}Pu	3.5	1.58	0.5 to 371
Laboratory	Water	PuO_2 Powder	4% ^{240}Pu	11.46	900	0.05[2]
Waste store	Water/concrete	PuO_2 Powder	4% ^{240}Pu	11.46	1300	0.05
Waste units	Water	PuO_2 Powder	4% ^{240}Pu	11.46	700-1900	0.05[2]
Range of Design Application	**Various**	**PuO_2 powder**	**4% ^{240}Pu**	**3.5 – 11.46**	**0.3 to 1900**	**0.05 to 65000**

[1] The jar store unit contains only MOX powder, cf. Table 4-2. Nevertheless PuO_2 powder can appear as a part of non-homogenized MOX components in abnormal situations.
[2] Expected range of EALF-values.

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/Pu**	**EALF [eV]**
MP: Powder area							
Primary dosing unit	Water	MOX powder	6.3 – 22%	4% ^{240}Pu	4.1	7.2	25.3
Ball milling units	Water	MOX powder	6.3 – 22%	4% ^{240}Pu	5.5	1.6 – 7.8	20 – 54
Jar store unit	Water/ concrete	MOX powder	6.3 – 22%	4% ^{240}Pu	5.5	1.6	0.8 – 31
Final dosing unit	Water	MOX powder	6.3 – 22%	4% ^{240}Pu	5.5	7.2 – 25.2	5.8 – 57.6
Final mix homogenization and press station unit	Water	MOX powder	6.3 – 22%	4% ^{240}Pu	5.5	4.2 – 291	2.8 – 8.24
Scrap processing unit	Water	MOX powder	6.3%	4% ^{240}Pu	5.5	14.8 – 15.2	20 – 94
Auxiliary powder unit	Water	MOX powder	6.3 – 22%	4% ^{240}Pu	5.5	4.2 – 15.2	20 – 317
Expected Range of Application	**Various**	**MOX powder**	**6.3–22 %**	**4% ^{240}Pu**	**4.1 – 5.5**	**1.6 – 291**	**0.8 – 317**

5. BENCHMARK EXPERIMENTS

5.1 AOA (3) PuO_2 POWDER MIXTURE

Two benchmarks of thirty two experiments with PuO_2-polysterene compacts and three benchmarks of fourteen experiments with plutonium metal are selected from the ICSBEP Handbook [6] to cover the AOA for PuO_2 powder. These experiments cover a suitable range of H/Pu ratios, EALF values, geometries, and reflectors which correspond to the AOA. Table 5-1 lists the experiments along with a description and key parameters.

Table 5-2 provides a comparison of the key AOA parameters for the critical experiments and design applications. The experiments involving plutonium metal are chosen to cover the range of the EALF values for the MFFF application from dry powder (normal situation) to moderated powder (abnormal situations).

5.2 AOA (4) MOX POWDER MIXTURE

One set of mixed U/Pu benchmark experiments was selected from the Neutronics Benchmark for the Utilization of Mixed-Oxide Fuel [8] to represent the AOA of MOX powder. These experiments include fourteen critical experiments performed with MOX powder and polystyrene mixtures with various Pu content and moderating ratios H/(U+Pu). Table 5-3 lists the benchmark along with a description and key parameters. Table 5-4 provides a comparison of the AOA key parameters for the critical experiments and design applications.

Table 5-1 Critical Experiments Selected for AOA(3)

Experiment*	H/Pu	EALF [eV]	Reflector/ Geometrical Form	^{240}Pu [wt. %]	Description
PU-COMP-MIXED-001	5.0 – 49.6	1.548 – 175000	Bare rectangular parallelepipeds	2.2 – 18.35	PuO_2- polystyrene compacts
PU-COMP-MIXED-002	0.04 – 49.6	0.685 – 4900	Plexiglas-reflected rectangular parallelepipeds	2.2 – 18.35	PuO_2- polystyrene compacts
PU-MET-FAST-016	0	7760 – 11700	Array of plutonium metal cylinders in water	5.97	Cylinders of plutonium metal sealed in an aluminum can with a steel lid
PU-MET-FAST-017	0	93500 – 410000	Array of plutonium metal cylinders in water	5.97	Cylinders of plutonium metal sealed in an aluminum can with a steel lid
PU-MET-FAST-037	0	23400 – 146000	Array of plutonium metal in water	5.97	Cylinders of plutonium contained in a steamless aluminum cans

* From [6]

Table 5-2 AOA (3) Comparison of Key Parameters

Parameter	Design application (cf. Table 4-1)	Benchmarks (cf. Table 5-1)
Geometric shape	Parallelepipeds Arrays of cylinders Spheres	(a)[1] Parallelepipeds (b)[2] Arrays of cylinders
Absorber/reflector	Water, Cd, Borated concrete	(a) Plexiglas, air (b) Air/ water
Chemical form	PuO_2 powder	(a) PuO_2 in polystyrene (C_8H_8) (b) Pu-metal in air/ water
Isotopic composition	4 wt. % ^{240}Pu	(a) 2.2 wt. % to 18.35 wt. % ^{240}Pu (b) 5.97 wt. % ^{240}Pu
H/Pu	0.3 to 1900	(a) 0.04 to 49.6 (b) 0[3]
EALF [eV]	0.05 to 65000	(a) 0.685 to 4900 (b) 7760 to 410000

[1] PU-COMP-MIXED experiments
[2] PU-MET-FAST experiments
[3] metal system, no hydrogen present

Table 5-3 Critical Experiments Selected for AOA(4)

Experiment	H/(U+Pu)	EALF	Reflector	Pu content (wt.%)	Description
MIX-COMP-INTER-001	2.8 – 7.3	0.63 – 41.71	Plexiglas	8.1 – 29.3	Rectangular parallelepipeds, Compacts of UO_2+PuO_2 +Polystyrene

Table 5-4 AOA (4) Comparison of Key Parameters

Parameter	Design application (cf. Table 4-2)	Benchmark (cf. Table 5-4)
Geometrical shape	Various configurations	Parallelepipeds (arrays of square compacts)
Absorber/reflector	Water, concrete	Plexiglas
Chemical form	MOX powder	MOX powder in polystyrene
$PuO_2/(PuO_2+UO_2)$ composition	6.3 – 22 wt. %	8.1 – 29.3 wt.%
Isotopic composition	4% ^{240}Pu	11.5 % ^{240}Pu
H/(U+Pu)	0.1 – 64	2.8 – 7.3
H/Pu	1.6 – 291	9.5 – 90.9
EALF [eV]	0.8 – 317	0.63 – 41.71

6. ANALYSIS OF VALIDATION RESULTS

6.1 DESIGN APPLICATION (3) – PuO_2 POWDER

Five sets of benchmarks (cf. Table 5-1) are modeled with CSAS26/KENO VI using the 238 group library 238GROUPNDF5. These experiments can be grouped as follows based on experimental EALF ranges and material properties:

- Group 1: Thirty-two experiments with PuO_2 powders, dry and low moderated (arrays of PuO_2-oxide-polystyrene compacts, bare and plexiglas reflected),
- Group 2: Fourteen experiments with metal cylinders bare or in water (arrays of water reflected Pu-metal cylinders sealed in an aluminum can with a steel lid).

Two benchmark sets, PU-COMP-MIXED-001 and PU-COMP-MIXED-002 are used for Group 1. From the benchmark set PU-COMP-MIXED-001, only three of five cases are chosen, because one experiment (case 1) is well outside the design application EALF range, cf. Table 4-1 and the other experiment (case 4) is not adequately described (the PuO_2-polystyrene composition is indicated in [8] as "not reported"). The selection of the Pu-metal experiments for Group 2 in addition to the PuO_2-polystyrene experiments of Group 1 is necessary to cover the full range of the EALF values anticipated in the PuO_2 powder applications, cf. Table 4-1.

The calculated k_{eff} values for the two groups of AOA(3) are presented in Attachment 1. Figure 6-1 shows the distribution of calculated k_{eff} values for the first group of experiments calculated with SCALE 4.4 on the Sun workstation and with SCALE 4.4a on the PC platform. Similarly, Figure 6-2 shows the distribution of the calculated k_{eff} values for the second group of experiments.

The k_{eff} values of the two groups are analyzed statistically using the USLSTATS computer code[2]. For Group 1, the EALF ranges from 0.69 eV to 4.9×10^3 eV. For Group 2 the benchmark range of EALF goes from 7.8×10^3 eV to 4.1×10^5 eV (cf. Tables A2-2a and A2-2b). However, since the maximum anticipated design application EALF, from Table 5-2, is only 6.5×10^4 eV, the limiting USL values are evaluated at a bounding EALF of 7.0×10^4 eV for Group 2 based on the linear USL relationships generated by USLSTATS.

The gap in the EALF range between Groups 1 and 2 is small in comparison with the range of applicability of AOA(3). Since the USL value is determined as the minimum of the two values evaluated separately for each experimental group, design applications with EALF values falling between the two groups (i.e., in the range from 4.9×10^3 to 7.8×10^3 eV) do not represent an extension of the area of applicability.

Table 6-1 through Table 6-4 summarize the statistical results of the USLSTATS program for both groups (PuO_2-polysterene and Pu-metal). It can be noted that the range of EALF obtained

[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., $k_{eff}\neq1.000$). Therefore, all calculated k_{eff} values are normalized to the handbook values (cf. Section 3.5).

with these experiments covers the EALF values of AOA(3), cf. Table 4-1. Figure 6-3 through Figure 6-5 show the results graphically.

6.1.1 USL with EALF and H/Pu ratio

Figure 6-3 and Figure 6-4 show the k_{eff} values calculated on the Sun and PC platforms and the values of USL-1 and USL-2 versus the trending parameters EALF and H/Pu, respectively. The k_{eff} values calculated for Group 2 (experiments with plutonium metal) are shown in Figure 6-6. The corresponding USLSTATS output listings are included in Attachment 5 for PC values and in Attachment 6 for Sun values.

Table 6-1 and Table 6-2 show that, for the AOA(3) Group 1 the minimum USL-1 with a 0.05 administrative margin is 0.9325(a)/0.9328(b)[3]. The minimum USL-2 found for the PuO_2 systems is 0.9528(a)/0.9534(b).

Table 6-3 and Table 6-4 show that, for the AOA(3) Group 2 the minimum USL-1 with a 0.05 administrative margin is 0.9353(a)/0.9358(b). The minimum USL-2 found for the Pu-metal systems is 0.9580(a)/0.9595(b). These values are obtained by evaluating the linear relationship for the USL–1 and USL–2 parameters, as determined by USLSTATS and shown in Attachments 5 and 6, at an EALF value of 7×10^4 eV which bounds the maximum design application value from Table 5-2 of 6.5×10^4 eV.

For the full set of experiments, the most limiting minimum margin of subcriticality Δk_m=0.0298(a)/0.0294(b) calculated with the USL-2 method indicates that the administrative margin (Δk_m=0.05) applied to the USL-1 value is adequate for the AOA(3) as long as the EALF and H/Pu ratio fall within this range of applicability [4].

It is shown that the two versions of SCALE running on different hardware platforms have no statistically significant differences. Thus an administrative margin of 0.05 plus bias and uncertainties to provide a USL of 0.9325 is justified for both SCALE 4.4 and SCALE4.4a.

6.1.2 USL with ^{240}Pu Content in Plutonium

With the thirty-two experiments of Group 1 from PU-COMP-MIXED-001 and PU-COMP-MIXED-002, the effect of the ^{240}Pu/Pu ratio on the calculational bias is also studied. The ^{240}Pu content in the PuO_2 powder used in the experiments varies from 2.20 wt. % to 18.35 wt. %.

Figure 6-5 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, for SCALE 4.4 on the Sun platform and SCALE 4.4a on the PC platform. These figures show that the bias (k_{eff}–1.0) is positive and remains constant with an increase in ^{240}Pu content. The maximum considered ^{240}Pu content (18.35%) in the experiments is bounding for the MFFF design value of 4%.

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[3] Results for the Sun platform with SCALE 4.4 are tagged "(a)". Those for the PC platform with SCALE 4.4a are tagged "(b)".

[4] 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.

Table 6-1 and Table 6-2, corresponding to the calculations from SCALE 4.4 on the Sun platform and SCALE 4.4a on the PC platform, shows that the minimum USL-1 with a 0.05 administrative margin is 0.9339(a)/0.9338(b). The minimum USL-2 for this set of experiments is 0.9566(a)/0.9561(b). The minimum margin to subcriticality Δk_m=0.0274(a)/0.0277(b), calculated using the USL-2 method, indicates that the administrative margin (Δk_m=0.05) applied to the USL-1 value is adequate for the AOA(3) application.

6.1.3 Summary of USL for AOA(3) PuO_2 Powder

The minimum USL for AOA(3) is 0.9325. This value includes a 0.05 administrative margin and consideration for calculational bias and allowance for uncertainties. The 0.05 administrative margin is more than adequate since an adequate number of representative benchmark experiments cover the two ranges of applicability for the design conditions. This 0.05 administrative margin is further justified by comparison with the minimum margin to subcriticality of 0.0298, obtained with the USL-2 method.

The calculated USL values for AOA(3) are summarized in Table 6-1 through Table 6-4. Note that the USLSTATS results indicate that the data does not pass the normal distribution test for the two groups of experimental data. (See the USLSTATS outputs in Attachments 5 and 6). The non-normality of the data can be observed in Figure 6-1 and Figure 6-2. 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 trending results shown in Figure 6-3 through Figure 6-6, it is apparent that the minimum normalized k_{eff} value is bounded by a value of 0.99. With the application of a 0.05 administrative margin, the graphical analysis of the data indicates that a USL of 0.9400 is adequate. Hence, since the USLSTATS methodology determines a more conservative USL, the USLSTATS result is used.

6.2 DESIGN APPLICATION (4) – MOX POWDER

Fourteen experiments are evaluated for this design application. The calculated k_{eff} values are presented in Attachment 3. The distribution of the calculated k_{eff} values for the set of experiments used for AOA(4) (MOX powder) is shown in Figure 6-7. The results are analyzed statistically using the USLSTATS computer code. The experiments are analyzed as a full set for trends. Figure 6-8 through Figure 6-11 show the results graphically and Table 6-5 and Table 6-6 summarize the statistical results for the Sun and the PC platforms, respectively.

6.2.1 USL with EALF, H/Pu and H/(U+Pu) ratio

Figure 6-8 shows the calculated k_{eff}-values and the values of USL-1 and USL-2 versus the trending parameter EALF for SCALE 4.4 on the Sun platform and SCALE 4.4a on the PC platform. Figure 6-9 shows the calculated k_{eff} values and the values of USL-1 and USL-2 versus the trending parameter H/(U+Pu) for SCALE 4.4 on the Sun platform and SCALE 4.4a on the PC, respectively. Figure 6-10 shows the calculated k_{eff} values and the values of USL-1 and USL-2 versus the trending parameter H/Pu for SCALE 4.4 on the Sun platform and SCALE 4.4a on the PC respectively. Table 6-5 and Table 6-6 show that the minimum USL-1 with a 0.05 administrative margin is 0.9305(a)/0.9309(b) for trending with EALF, H/Pu and H/(U+Pu)

(EALF from 0.63 to 41.71 eV, H/Pu from 9.5 to 90.9 and H/(U+Pu) ratio from 2.8 to 7.3). The minimum USL-2 for the experiments is 0.9539(a)/0.9531(b).

With a minimum margin of subcriticality (Δk_m) for the EALF, H/Pu and H/(U+Pu) ratio of 0.0270(a)/0.0274(b), 0.0215(a)/0.0215(b) and 0.0226(a)/0.0227(b) calculated using the USL-2 method, the 0.05 administrative margin is justified. Thus, the administrative margin of 0.05 plus bias and uncertainties to provide a USL-1 of 0.9305 is justified.

6.2.2 USL with PuO_2 content in MOX

The fourteen experiments are also analyzed as a function of Pu content in order to evaluate the effect of Pu content on the calculational bias. These 14 experiments cover a range from 8.1 wt. % to 29.3 wt. % in Pu containing 11.5 wt. % of ^{240}Pu. Figure 6-11 shows the calculated k_{eff} values and the parameters for the determination of USL-1 and USL-2 based on trending with Pu content for SCALE 4.4 on the Sun platform and SCALE 4.4a on the PC. These figures show that the k_{eff}, USL-1, and USL-2 values decrease with an increase in the Pu content. Hence, application of the USL computed here to design applications down to 6.3 wt. % Pu content is acceptable with no additional AOA margin required.

Table 6-5 and Table 6-6 show that the minimum USL-1 with a 0.05 administrative margin is 0.9315(a)/0.9312(b). The minimum USL-2 for this set of experiments is 0.9545(a)/0.9537(b). The minimum margin to subcriticality Δk_m=0.0270(a)/0.0275(b), calculated using the USL-2 method, indicates that the administrative margin (Δk_m=0.05) applied to the USL-1 value is adequate for the AOA(4) application. Thus, an administrative margin of 0.05 plus bias and uncertainties to provide a USL of 0.9315 is justified.

6.2.3 Summary of USL for AOA(4) MOX powder

The minimum USL for the AOA(4) systems is 0.9305. This value includes a 0.05 administrative margin and consideration for calculational bias and allowance for uncertainties. This 0.05 administrative margin is further justified by comparison with the maximum calculated minimum margin of subcriticality of 0.0275, obtained using the USL-2 method.

Note that the USLSTATS results indicate that the data does not pass the normal distribution test. (See the USLSTATS outputs in Attachments 5 and 6). The non-normality of the data can be observed in Figure 6-7 and is related to the differences in the number of cases evaluated at each of the three Pu contents. By performing a graphical analysis of the trending results shown in Figure 6-8 through Figure 6-11, it is apparent that the minimum normalized k_{eff} value is bounded by a value of 0.98. With the application of a 0.05 administrative margin, the graphical analysis of the data indicates that a USL of 0.93 is adequate. Hence, since this value is essentially the same as the USLSTATS result of 0.9305, the USLSTATS result is reported here for consistency.

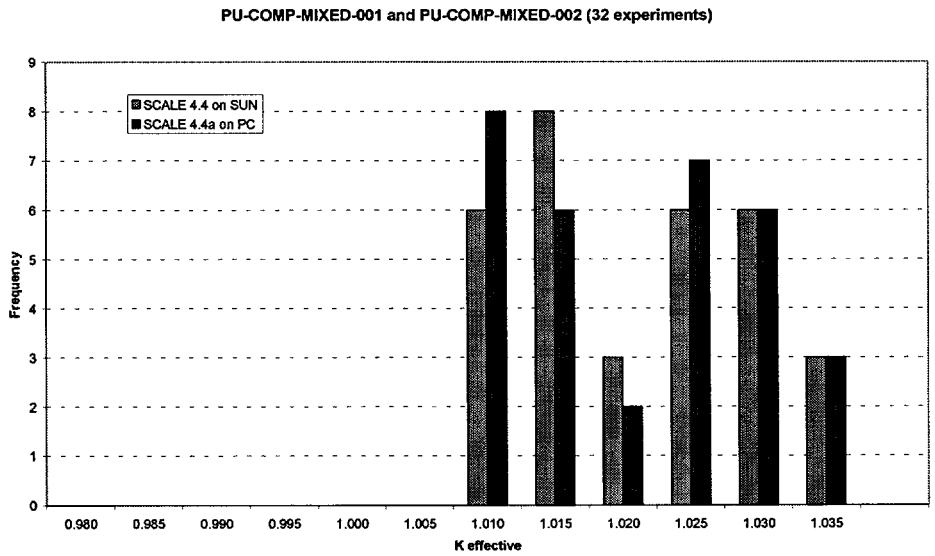


Figure 6-1 Histogram of k_{eff} Occurrences of AOA(3) Group 1

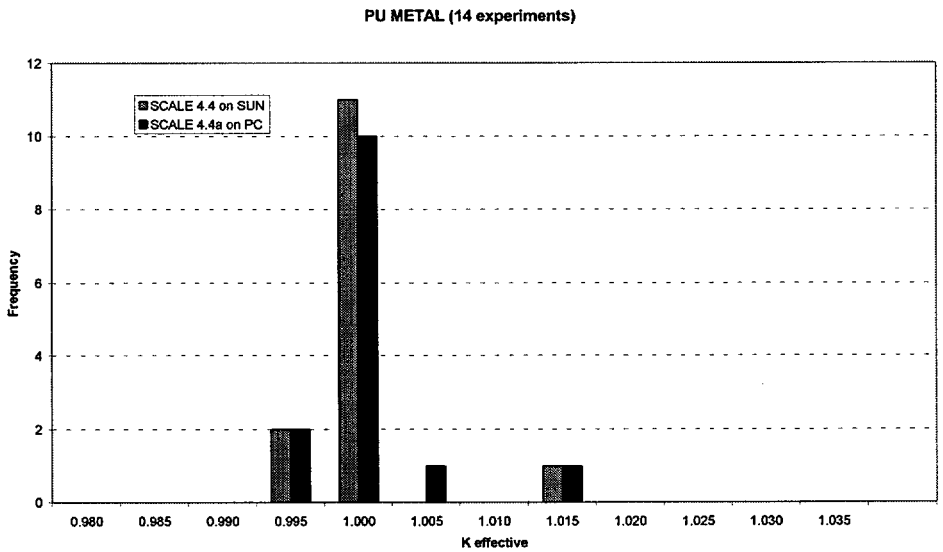
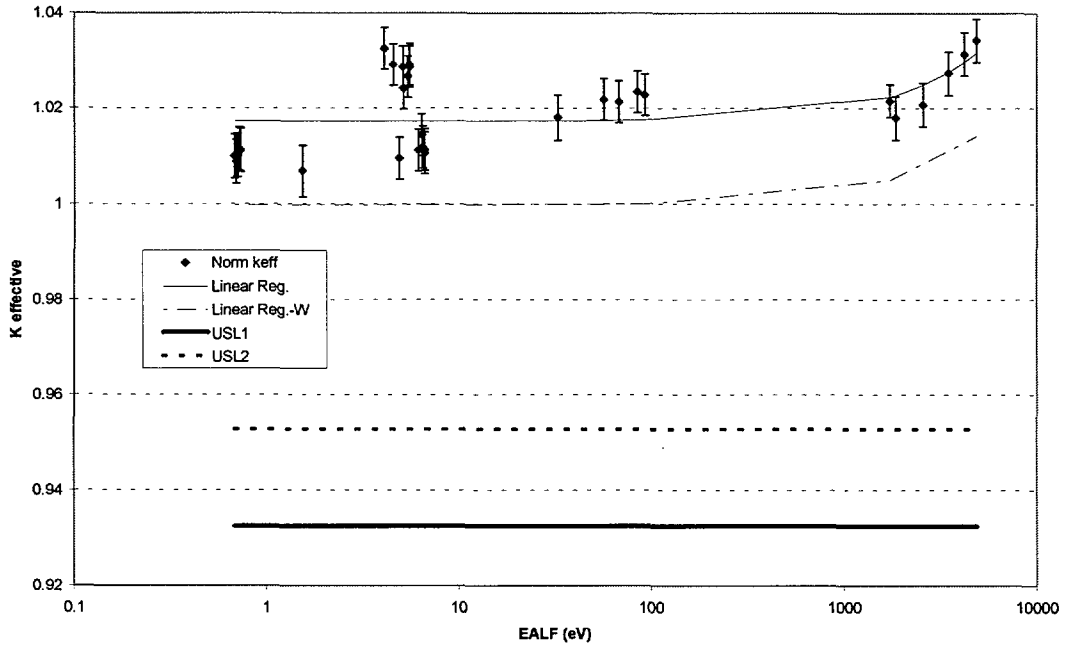
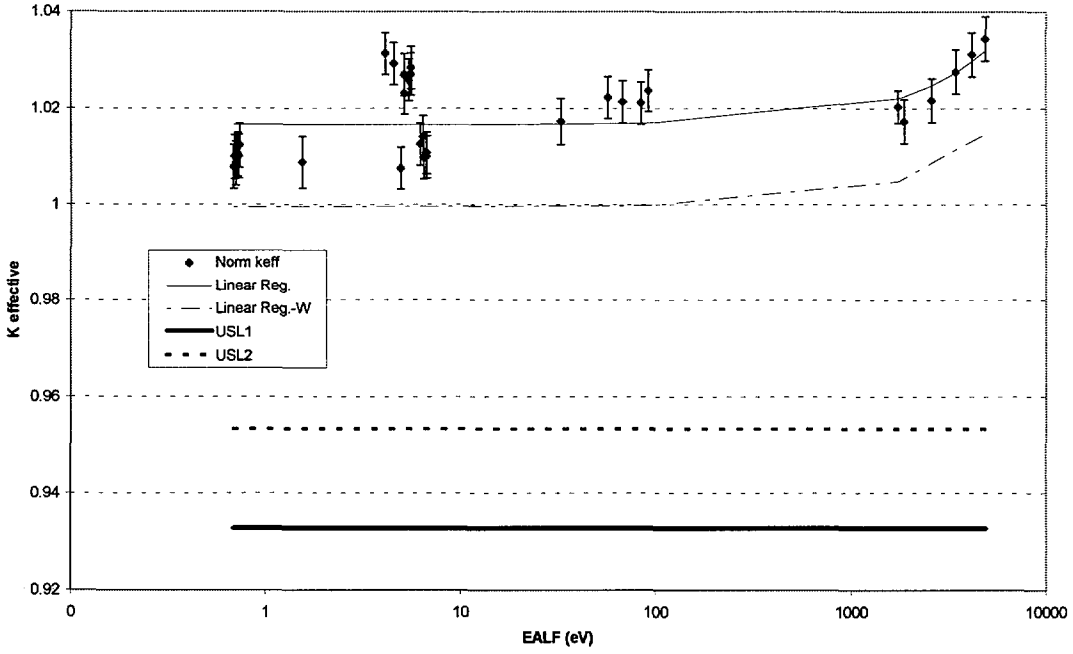


Figure 6-2 Histogram of k_{eff} Occurrences of AOA(3) Group 2

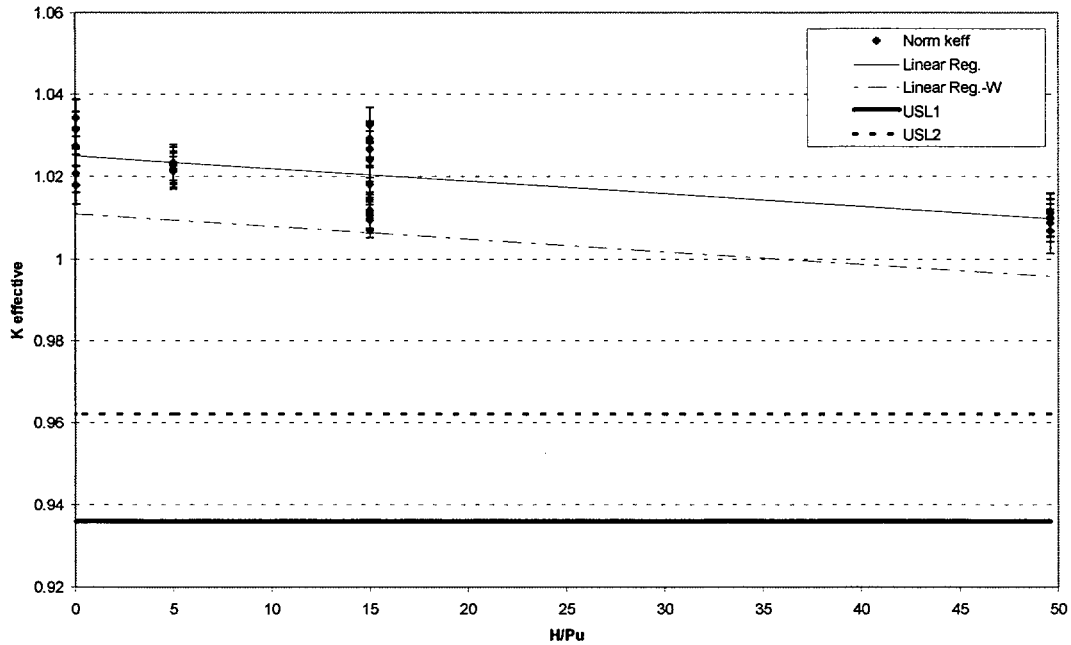


(a) Sun Platform (SCALE 4.4)

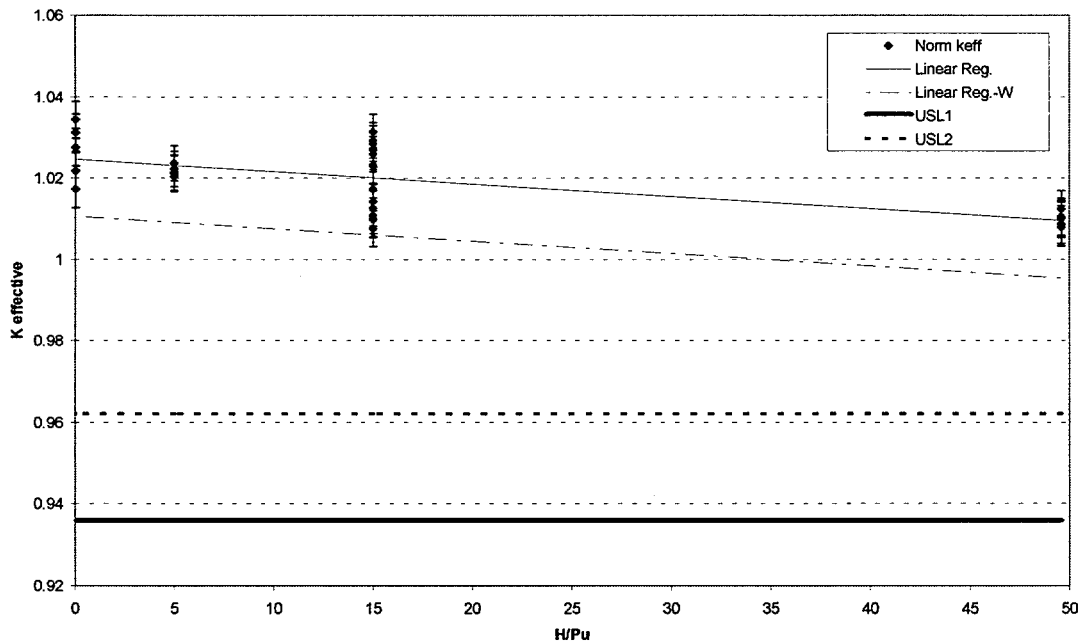


(b) PC Platform (SCALE 4.4a)

Figure 6-3 AOA(3) k_{eff} as Function of EALF (Group 1: Pu-Comp-Mixed)

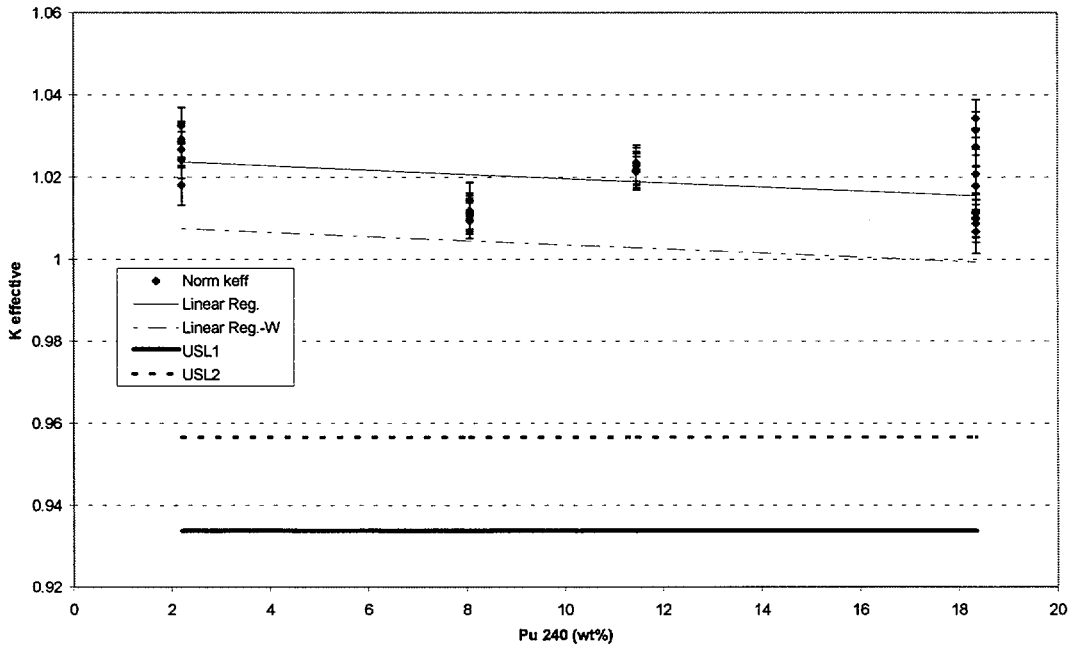


(a) Sun Platform (SCALE 4.4)

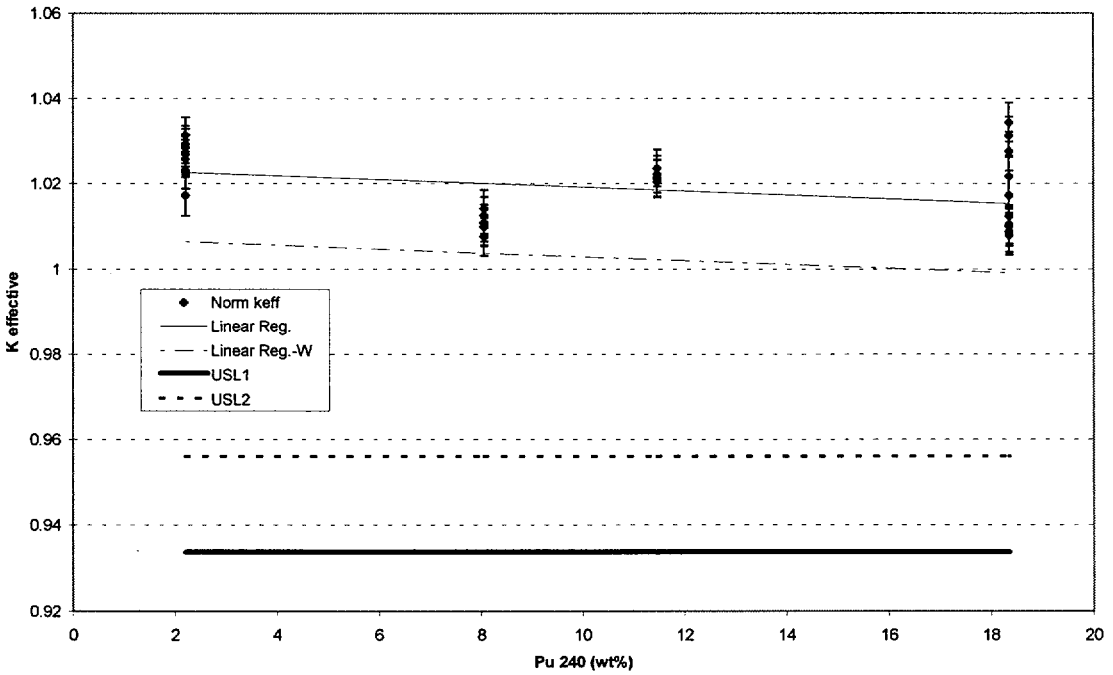


(b) PC Platform (SCALE 4.4a)

Figure 6-4 AOA(3) k_{eff} as Function of H/Pu (Group 1: Pu-Comp-Mixed)

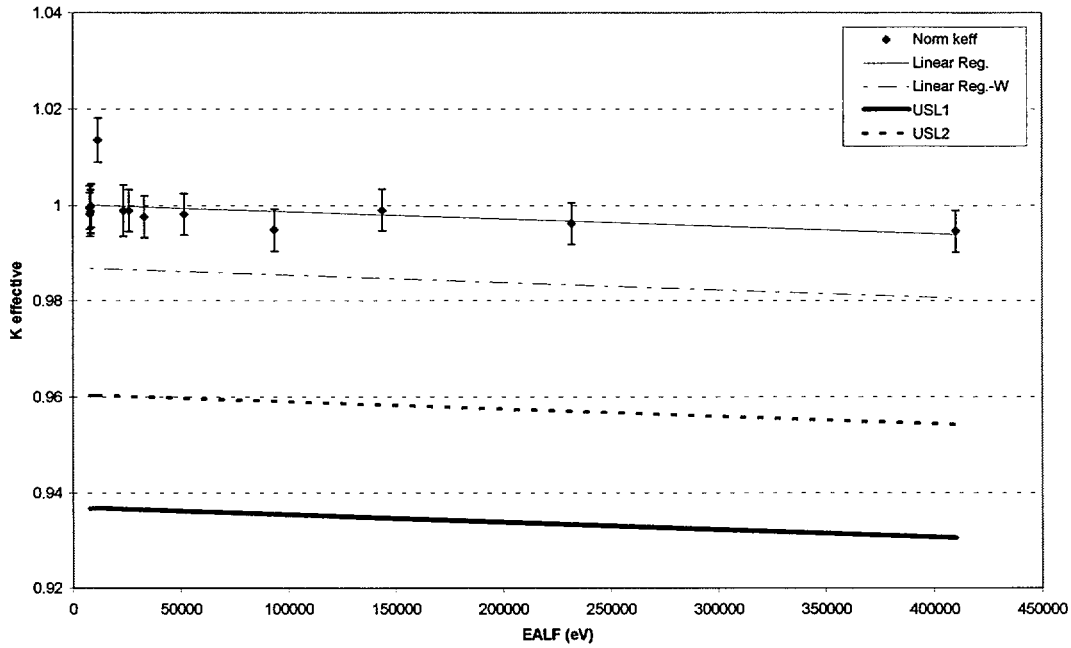


(a) Sun Platform (SCALE 4.4)

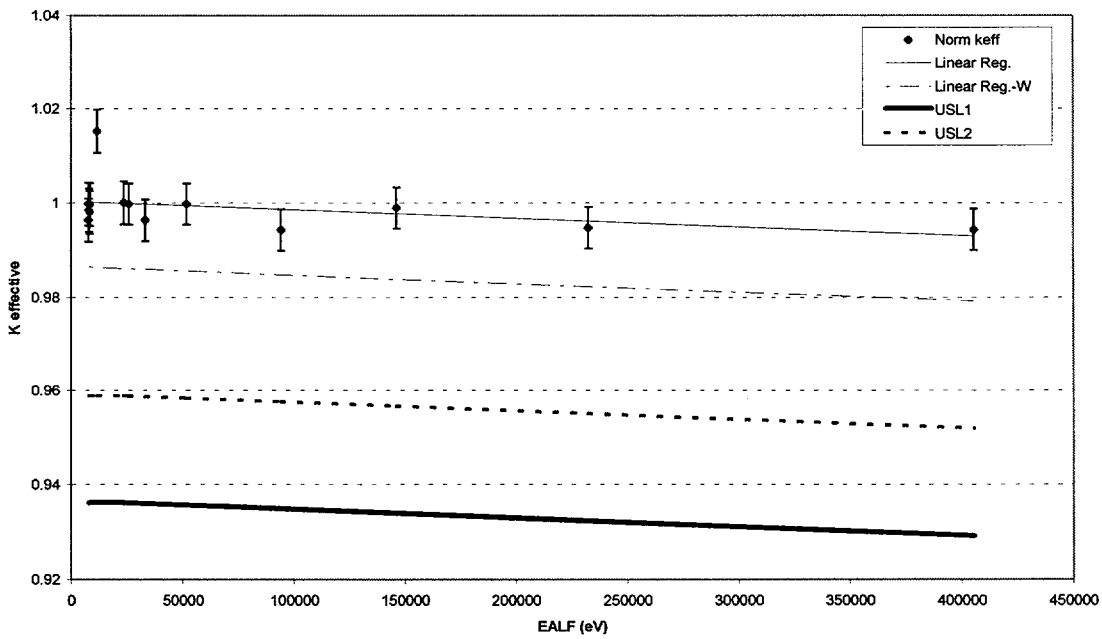


(b) PC Platform (SCALE 4.4a)

Figure 6-5 AOA(3) k_{eff} as Function of ^{240}Pu content (Group 1: Pu-Comp-Mixed)



(a) Sun Platform (SCALE 4.4)



(b) PC Platform (SCALE 4.4a)

Figure 6-6 AOA(3) k_{eff} as Function of EALF (Group 2: Pu-Met-Fast-016-017-037)

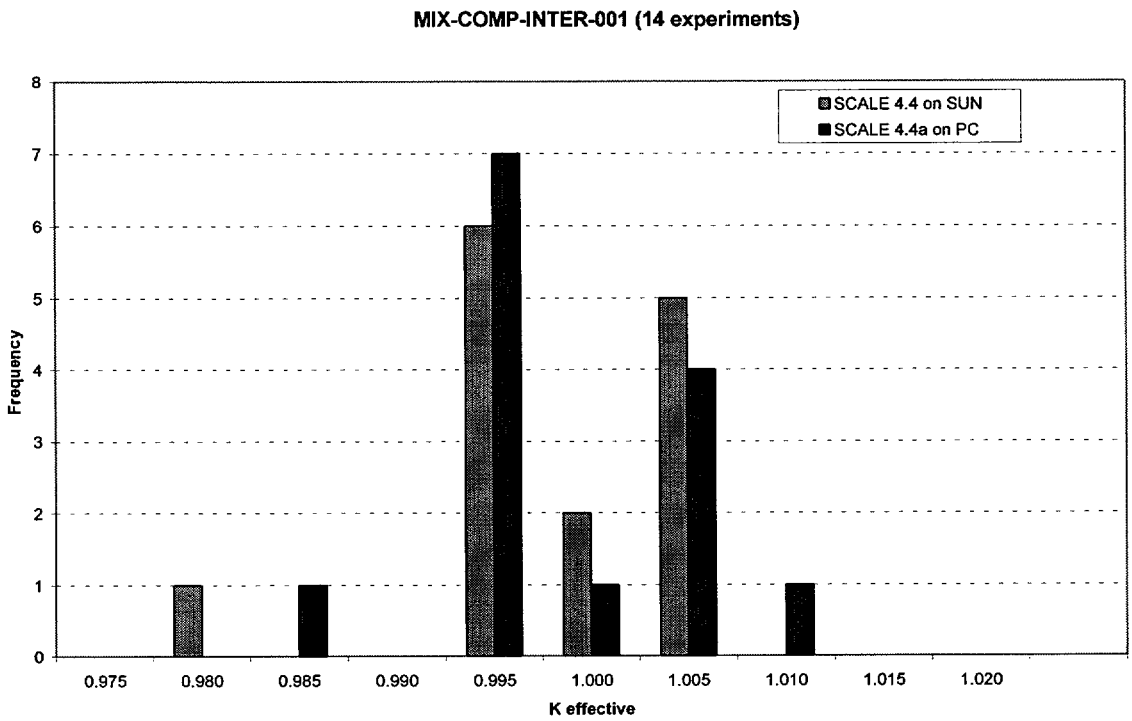
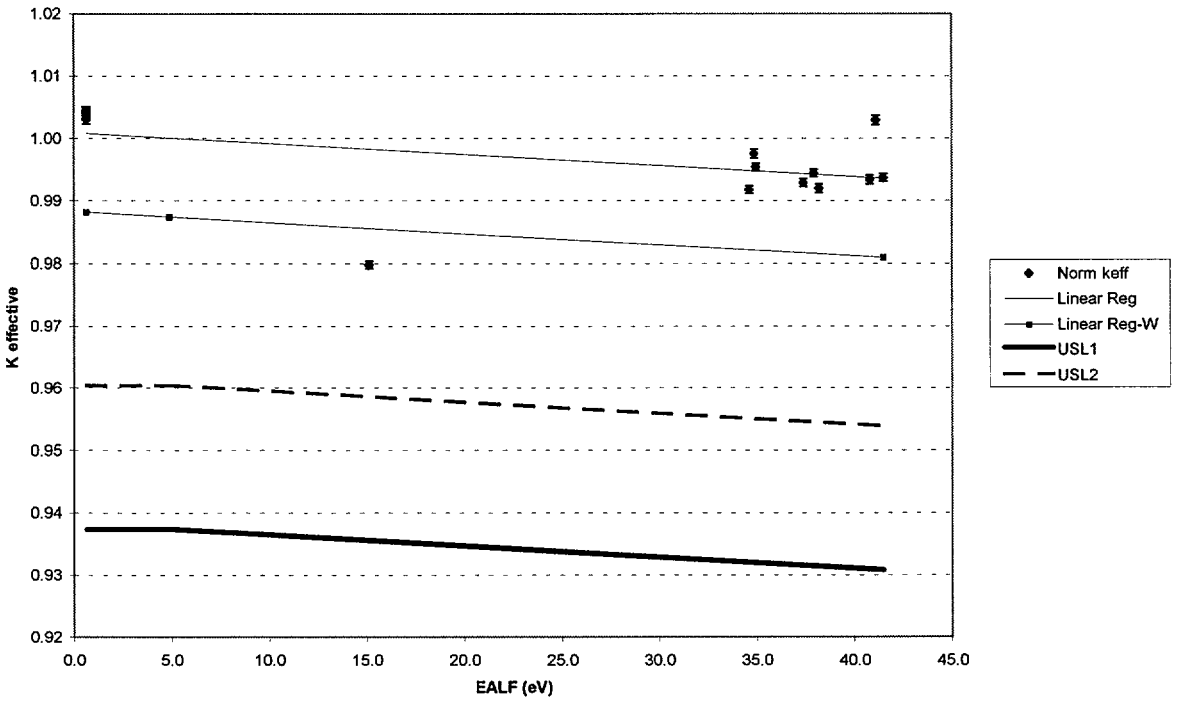
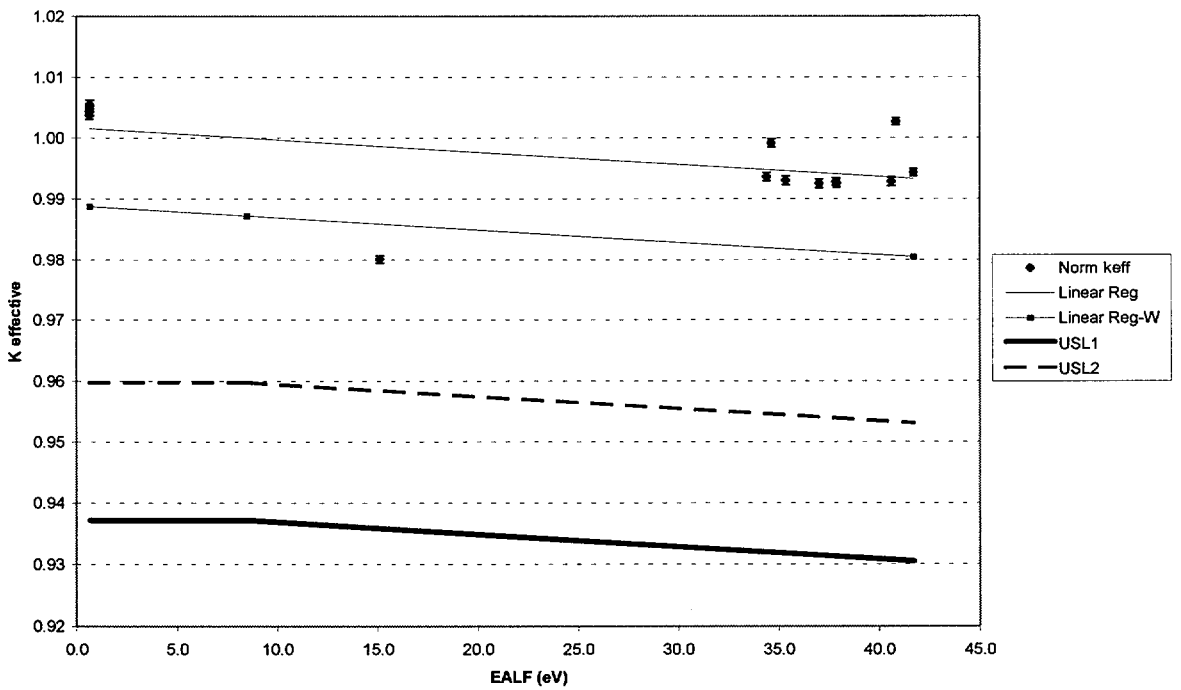


Figure 6-7 Histogram of k_{eff} Occurrences for AOA(4)

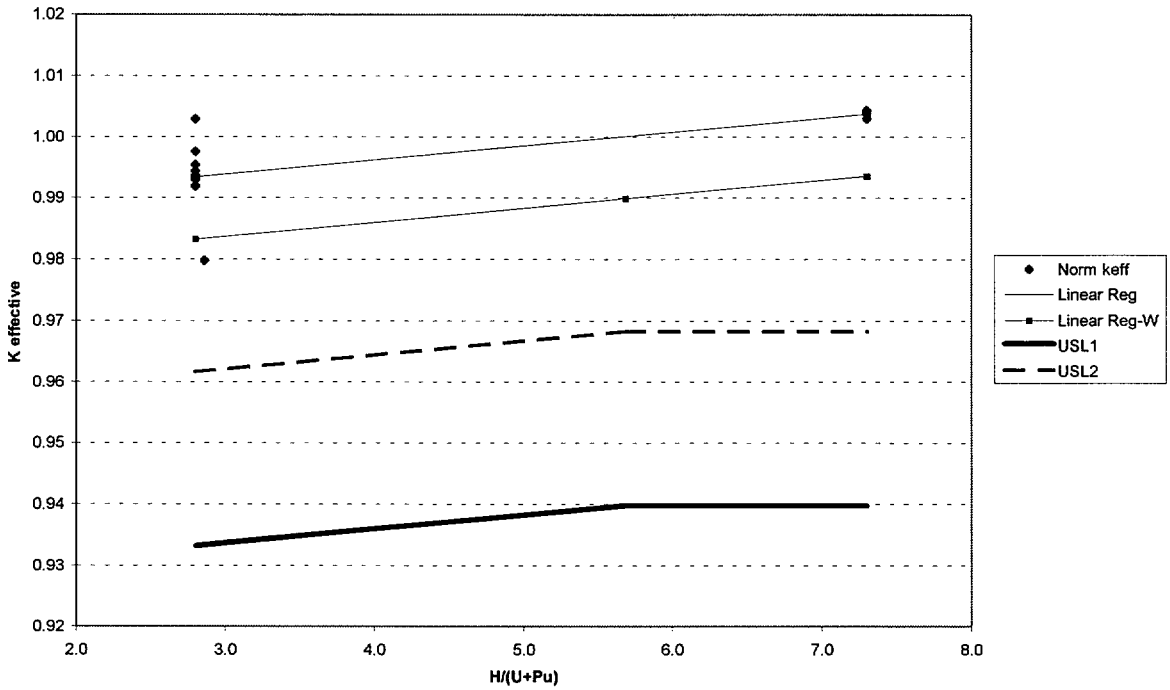


(a) Sun Platform (SCALE 4.4)

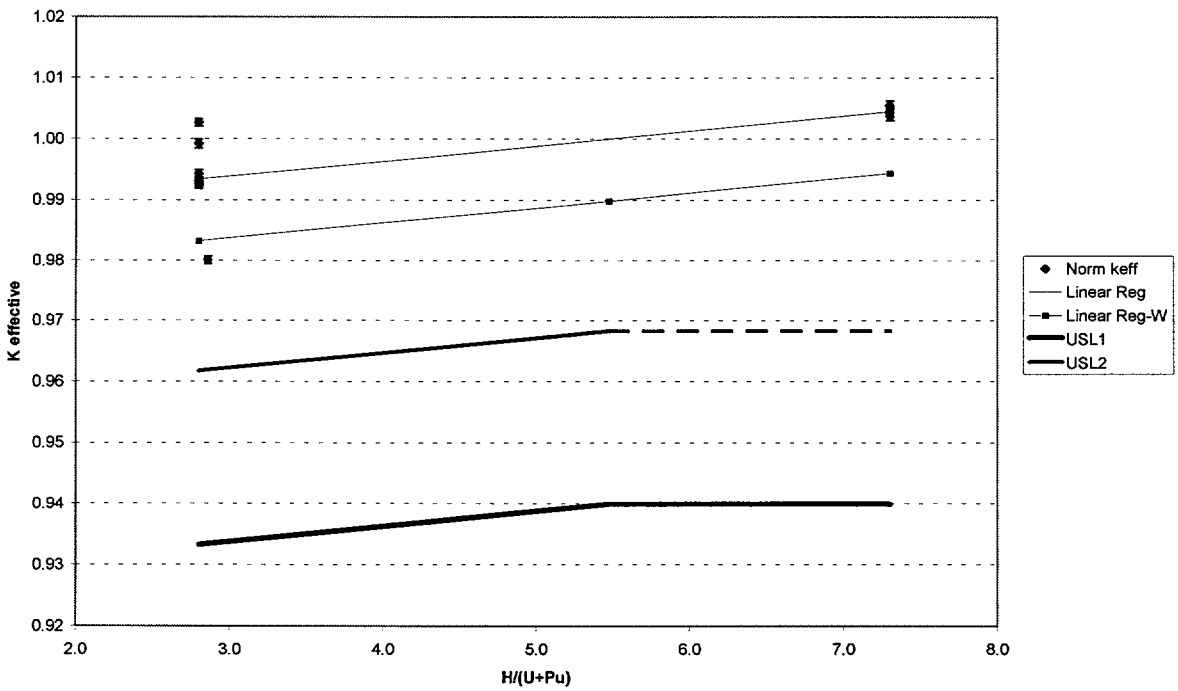


(b) PC Platform (SCALE 4.4a)

Figure 6-8 AOA(4) k_{eff} as Function of EALF

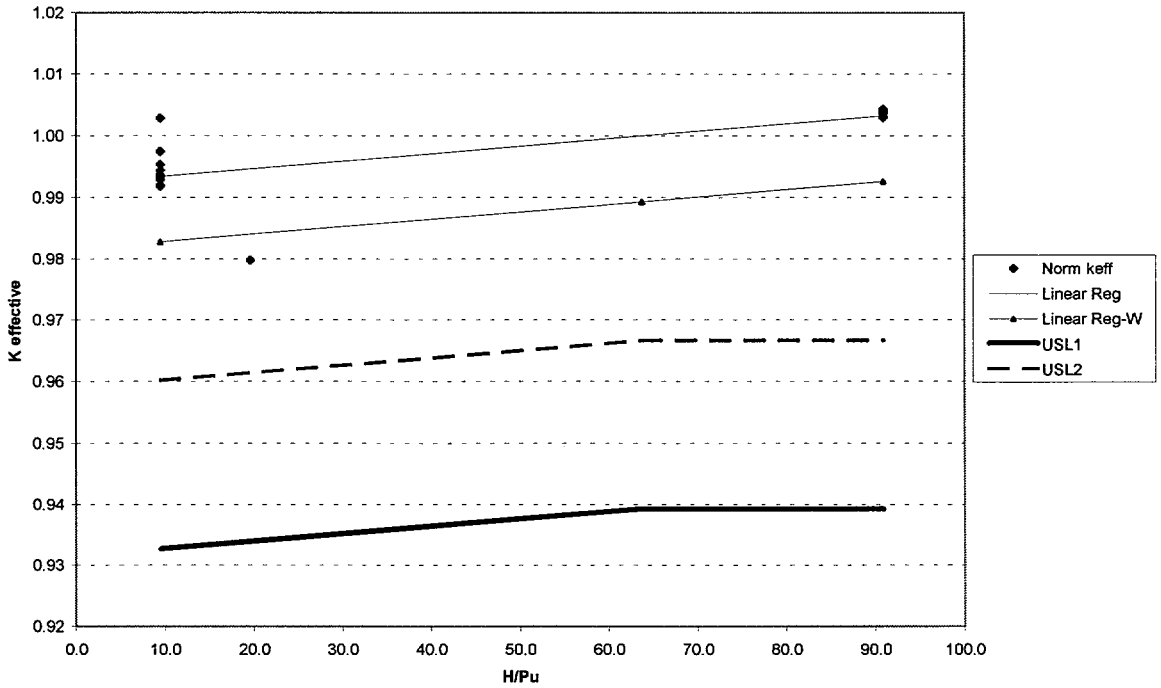


(a) Sun Platform (SCALE 4.4)

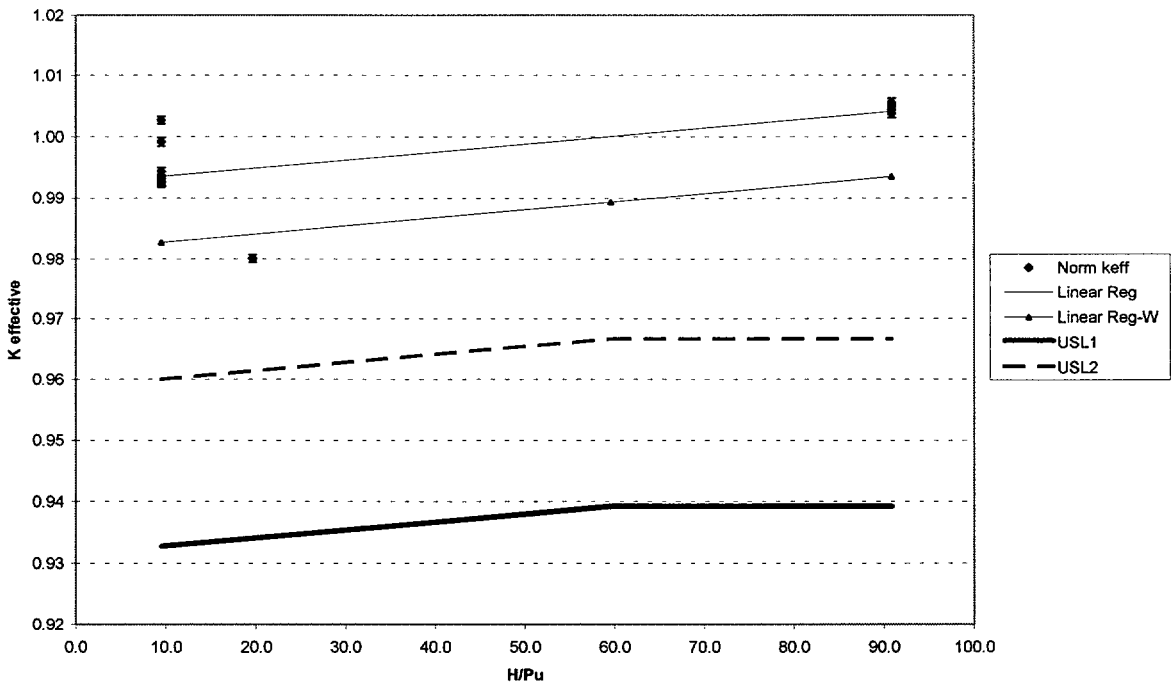


(b) PC Platform (SCALE 4.4a)

Figure 6-9 AOA(4) k_{eff} as Function of H/(U+Pu)

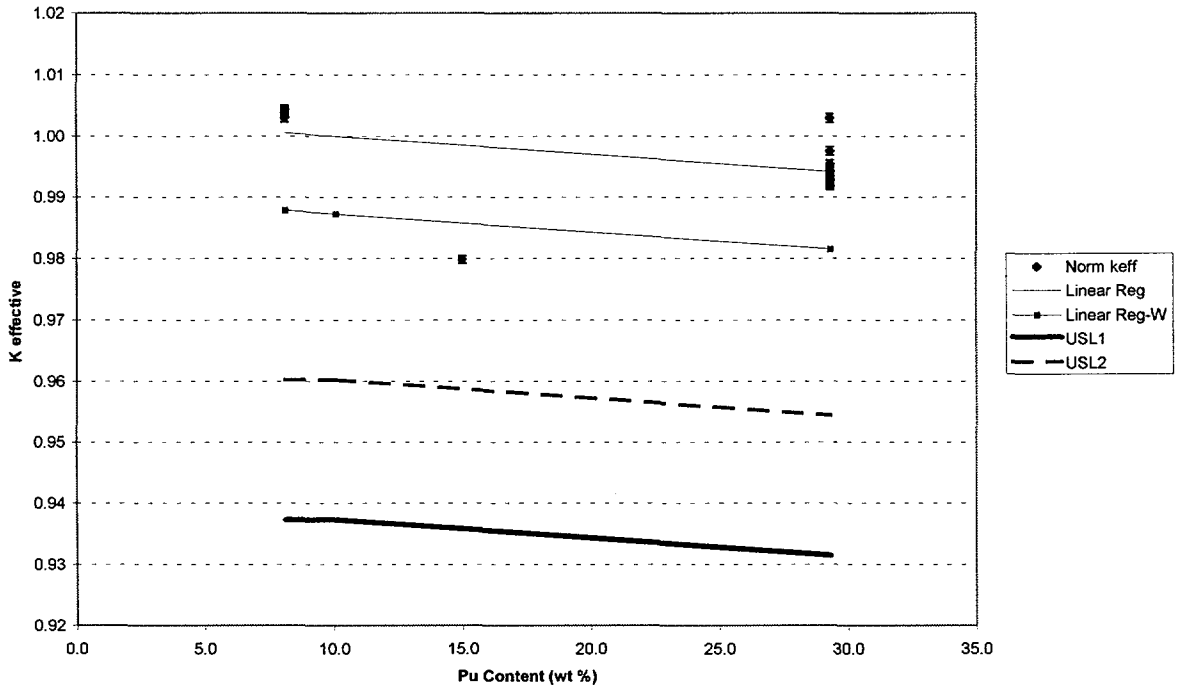


(a) Sun Platform (SCALE 4.4)

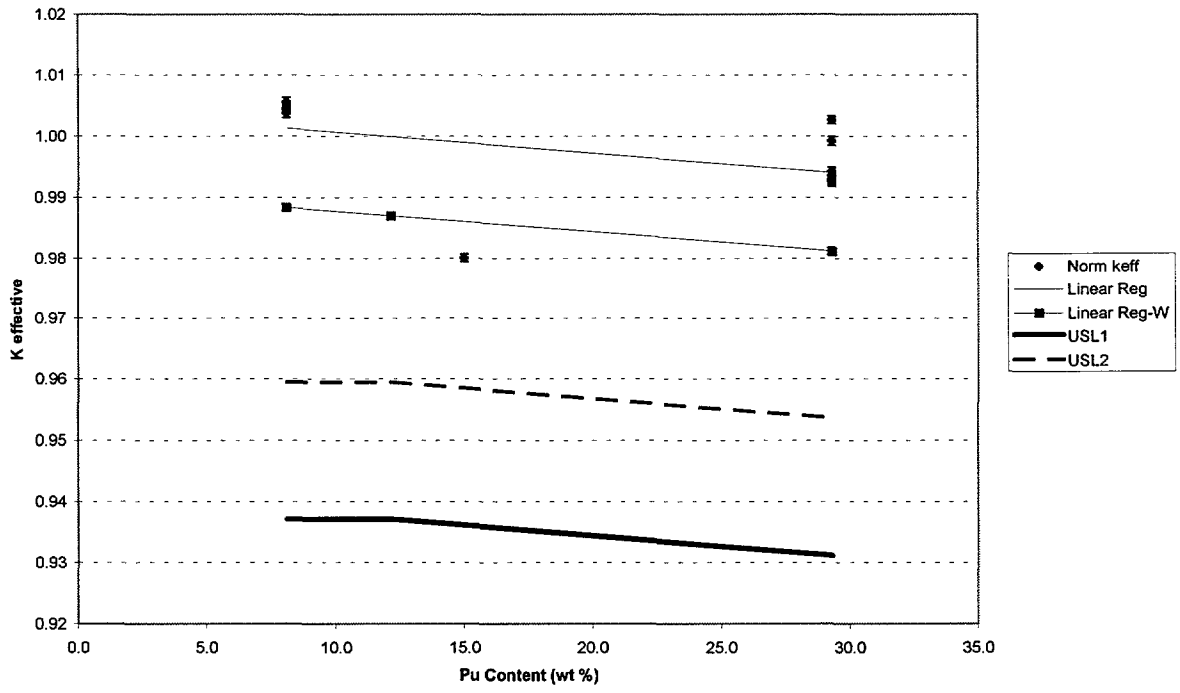


(b) PC Platform (SCALE 4.4a)

Figure 6-10 AOA(4) k_{eff} as Function of H/Pu



(a) Sun Platform (SCALE 4.4)



(b) PC Platform (SCALE 4.4a)

Figure 6-11 AOA(4) k_{eff} as Function of Pu content

Table 6-1 Summary of USL Calculations from SCALE 4.4 on Sun platform AOA(3), 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 (Δk_m=0.05)	Min USL_2	Min Δk_m (USL_2)
EALF [eV]	32	0.69 – 4900	1.0172+(2.9407E-06)*X	1.0190	0.9325	0.9528	0.0298
H/Pu	32	0.04 – 49.60	1.0250+(-3.0590E-04)*X	1.0190	0.9360	0.9621	0.0239
^{240}Pu [wt. %]	32	2.20 – 18.35	1.0247+(-5.0472E-04)*X	1.0190	0.9339	0.9566	0.0274

Table 6-2 Summary of USL Calculations from SCALE 4.4a on PC Platform AOA(3), 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 (Δk_m=0.05)	Min USL_2	Min Δk_m (USL_2)
EALF [eV]	32	0.69 – 4900	1.0167+(3.1025E-06)*X	1.0186	0.9328	0.9534	0.0294
H/Pu	32	0.04 – 49.60	1.0246+(-3.0367E-04)*X	1.0186	0.9360	0.9621	0.0239
^{240}Pu [wt. %]	32	2.20 – 18.35	1.0237+(-4.5199E-04)*X	1.0186	0.9338	0.9561	0.0277

Table 6-3 Summary of USL Calculations with SCALE 4.4 on Sun Platform AOA(3), Group 2: PU-MET-FAST-016, -017, -037

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)
EALF [eV]	14	7.8×10^3 – 7.0×10^4	1.0002+(-1.5416E-08)*X	0.9990	0.9358[1]	0.9595[1]	0.0263

[1] Evaluated at EALF of 7×10^4 eV which bounds the maximum design application EALF from Table 5-2.

Table 6-4 Summary of USL Calculations with SCALE 4.4a on PC Platform AOA(3), Group 2: PU-MET-FAST-016, -017, -037

Correlated parameter (X)	No 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)
EALF [eV]	14	7.9×10^3 – 7.0×10^4	1.0004+(-1.8120E-08)*X	0.9991	0.9353[1]	0.9580[1]	0.0273

[1] Evaluated at EALF of 7×10^4 eV which bounds the maximum design application EALF from Table 5-2.

Table 6-5 Summary of USL Calculations with SCALE 4.4 on Sun platform for AOA(4): MIX-COMP-INTER-001

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)
EALF [eV]	14	0.63 – 41.49	1.0009+(-1.7610E-04)*X	0.9963	0.9309	0.9539	0.0270
H/(U+Pu)	14	2.8 – 7.3	0.9870+(2.2933E-03)*X	0.9963	0.9332	0.9617	0.0215
H/Pu	14	9.5 – 90.9	0.9923+(1.2090E-04)*X	0.9963	0.9328	0.9602	0.0226
Pu [wt. %]	14	8.1 – 29.3	1.0030+(-3.0103E-04)*X	0.9963	0.9315	0.9545	0.0270

Table 6-6 Summary of USL Calculations with SCALE 4.4a on PC platform AOA(4): MIX-COMP-INTER-001

Correlated parameter (X)	No 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)
EALF [eV]	14	0.63 – 41.71	1.0017+(-2.0089E-04)*X	0.9966	0.9305	0.9531	0.0274
H/(U+Pu)	14	2.8 – 7.3	0.9864+(2.4816E-03)*X	0.9966	0.9332	0.9617	0.0215
H/Pu	14	9.5 – 90.9	0.9922+(1.3153E-04)*X	0.9966	0.9327	0.9601	0.0227
Pu [wt. %]	14	8.1 – 29.3	1.0041+(-3.4124E-04)*X	0.9966	0.9312	0.9537	0.0275

7. CONCLUSIONS

The SCALE 4.4 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. It has been validated for two of the five design applications: (3) PuO_2 powder and (4) MOX powder.

The comparison of the USL for the two SCALE versions SCALE4.4 and SCALE4.4a show that the differences are small and within the statistical uncertainties. Therefore the lowest USL for each of the two AOAs is used as a bounding limit for both SCALE versions.

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

- Design application (3) PuO_2 powder USL(AOA3) = 0.9325
- Design application (4) MOX powder USL(AOA4) = 0.9305

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(3). For the AOA(4) an extrapolation outside the range of applicability may be necessary, cf. Table 5-4. ANSI/ANS-8.1 [2] allows 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 [21], 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 [21] 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) [20], 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

[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.

(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 [19]. 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	Most Limiting USL-2 Minimum Margin of Subcriticality	Administrative Margin	Factor By Which Admin Margin Exceeds Recommended Value
AOA(3)	0.0298	0.050	1.7
AOA(4)	0.0275	0.050	1.8

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] Comparison of original and patched versions of Scale4.4a, Document in preparation.

[17] 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

[18] 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.

[19] 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.

[20] 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.

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

ATTACHMENT NUMBER 1

ICSBEP BENCHMARKS FOR AOA(3)

ICSBEP PUO_2 POWDER BENCHMARKS

The following lines present for each ICSBEP the reasons for which the benchmark were selected or not.

PU-COMP-MIX-001 Only Cases 2, 3, and 5 are selected. Case 1 has an EALF value well outside the design application range. Case 4 is not adequately described (see Section 6.1). The input files are obtained directly from the Handbook and translated to CSAS26 input files 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 obtained directly from the Handbook and translated to CSAS26 input files using the c5toc6 program. The 27 group library is replaced by the 238 group library.

PU-MET-FAST-016 All the experiments are selected. The input files are obtained directly from the Handbook and translated to CSAS26 input files using the c5toc6 program. The 27 group library is replaced by the 238 group library.

PU-MET-FAST-017 Three of the six experiments are selected. The selected experiments are the ones which present the lowest EALF values, in agreement with the expected range of application for the design application. The input files are obtained directly from the Handbook and translated to CSAS26 input files using the c5toc6 program. The 27 group library is replaced by the 238 group library.

PU-MET-FAST-037 Five of the sixteen experiments are selected. Only seven out of all experiments have their input files in the Handbook. They are translated using the c5toc6 program to CSAS26 input files, and the 27 group library is replaced by the 238 group library. The last two experiments are not selected because the EALF value is outside the range of application.

ATTACHMENT NUMBER 2

CRITICALITY CALCULATION RESULTS FOR AOA(3)

Table A2-1a: SCALE 4.4 calculations on Sun platform

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	1.0215	0.0009	1.73E+03	1503	1000	3
Case 3	15	2.2	0.999	0.0047	1.0170	0.0008	3.27E+01	1503	1000	130
Case 5	49.6	18.35	0.9989	0.0053	1.0057	0.0007	1.55E+00	1503	1000	17
PU-COMP-MIXED-002										
Case 1	0.04	18.35	0.999	0.0045	1.0332	0.0007	4.90E+03	1503	1000	42
Case 2	0.04	18.35	0.999	0.0045	1.0303	0.0007	4.24E+03	1503	1000	65
Case 3	0.04	18.35	0.999	0.0045	1.0263	0.0008	3.50E+03	1503	1000	8
Case 4	0.04	18.35	0.999	0.0045	1.0197	0.0008	2.57E+03	1503	1000	46
Case 5	0.04	18.35	0.999	0.0045	1.0169	0.0008	1.85E+03	1503	1000	34
Case 6	5	11.46	1	0.0043	1.0228	0.0007	9.29E+01	1503	1000	18
Case 7	5	11.46	1	0.0043	1.0234	0.0007	8.52E+01	1503	1000	3
Case 8	5	11.46	1	0.0043	1.0213	0.0007	6.81E+01	1503	1000	12
Case 9	5	11.46	1	0.0043	1.0218	0.0007	5.68E+01	1503	1000	4
Case 10	15	2.2	1	0.0043	1.0325	0.0008	4.12E+00	1503	1000	4
Case 11	15	2.2	1	0.0043	1.0291	0.0007	4.58E+00	1503	1000	5
Case 12	15	2.2	1	0.0043	1.0286	0.0008	5.14E+00	1503	1000	46
Case 13	15	2.2	1	0.0043	1.0266	0.0007	5.44E+00	1503	1000	12
Case 14	15	2.2	1	0.0043	1.0291	0.0008	5.55E+00	1503	1000	34
Case 15	15	2.2	1	0.0043	1.0287	0.0008	5.56E+00	1503	1000	63
Case 16	15	2.2	1	0.0043	1.0241	0.0007	5.17E+00	1503	1000	76
Case 17	15	8.06	0.9988	0.0043	1.0083	0.0008	4.91E+00	1503	1000	74
Case 18	15	8.06	0.9988	0.0043	1.0100	0.0007	6.17E+00	1503	1000	4
Case 19	15	8.06	0.9988	0.0043	1.0106	0.0008	6.48E+00	1503	1000	33
Case 20	15	8.06	0.9988	0.0043	1.0101	0.0007	6.63E+00	1503	1000	17
Case 21	15	8.06	0.9988	0.0043	1.0094	0.0007	6.65E+00	1503	1000	46
Case 22	15	8.06	0.9988	0.0043	1.0132	0.0008	6.42E+00	1503	1000	39
Case 23	49.6	18.35	1	0.0045	1.0099	0.0008	6.85E-01	1503	1000	154
Case 24	49.6	18.35	1	0.0045	1.0088	0.0008	6.96E-01	1503	1000	9
Case 25	49.6	18.35	1	0.0045	1.0101	0.0008	7.02E-01	1503	1000	38
Case 26	49.6	18.35	1	0.0045	1.0101	0.0007	7.11E-01	1503	1000	16
Case 27	49.6	18.35	1	0.0045	1.0113	0.0007	7.25E-01	1503	1000	51
Case 28	49.6	18.35	1	0.0045	1.0115	0.0007	7.26E-01	1503	1000	108
Case 29	49.6	18.35	1	0.0045	1.0112	0.0007	7.37E-01	1503	1000	21

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

Table A2-1b: 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 A2-2a: SCALE 4.4 calculations on Sun platform

Experiment	Exp. k_{eff}	Exp. Uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF	GEN	NPG	NSK
PU-MET-FAST-016								
Case 1	0.9974	0.0042	1.0109	0.0009	1.16E+04	1000	1500	5
Case 2	1.0000	0.0038	0.9999	0.0007	8.48E+03	1000	1500	48
Case 3	1.0000	0.0033	0.9987	0.0007	8.24E+03	1000	1500	56
Case 4	1.0000	0.0030	0.9986	0.0007	8.05E+03	1000	1500	16
Case 5	1.0000	0.0034	0.9981	0.0008	7.94E+03	1000	1500	30
Case 6	1.0000	0.0032	0.9995	0.0007	7.76E+03	1000	1500	16
PU-MET-FAST-017								
Case 202	0.9979	0.0011	0.9925	0.0008	4.10E+05	1503	1000	20
Case 203	0.9988	0.0011	0.9950	0.0007	2.32E+05	1503	1000	22
Case 205	1.0051	0.0011	0.9999	0.0008	9.35E+04	1503	1000	21
PU-MET-FAST-037								
Case 1	1.0000	0.0044	0.9990	0.0008	1.43E+05	1503	1000	42
Case 5	1.0000	0.0037	0.9981	0.0007	5.15E+04	1503	1000	36
Case 7	1.0000	0.0038	0.9976	0.0007	3.30E+04	1503	1000	21
Case 10	1.0000	0.0034	0.9989	0.0007	2.59E+04	1503	1000	10
Case 12	1.0000	0.0040	0.9989	0.0007	2.34E+04	1503	1000	13

Table A2-2b: SCALE 4.4a calculations on PC

Experiment	Exp. k_{eff}	Exp. Uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF	GEN	NPG	NSK
PU-MET-FAST-016								
Case 1	0.9974	0.0042	1.0128	0.0007	1.17E+04	1000	1500	27
Case 2	1.0000	0.0038	0.9997	0.0007	8.52E+03	1000	1500	8
Case 3	1.0000	0.0033	0.9981	0.0007	8.34E+03	1000	1500	14
Case 4	1.0000	0.0030	0.9985	0.0007	8.05E+03	1000	1500	7
Case 5	1.0000	0.0034	0.9964	0.0008	7.87E+03	1000	1500	30
Case 6	1.0000	0.0032	0.9998	0.0008	7.91E+03	1000	1500	15
PU-MET-FAST-017								
Case 202	0.9979	0.0011	0.9923	0.0007	4.05E+05	1503	1000	16
Case 203	0.9988	0.0011	0.9936	0.0007	2.32E+05	1503	1000	16
Case 205	1.0051	0.0011	0.9994	0.0008	9.41E+04	1503	1000	17
PU-MET-FAST-037								
Case 1	1.0000	0.0044	0.9990	0.0008	1.46E+05	1503	1000	4
Case 5	1.0000	0.0037	0.9992	0.0007	5.17E+04	1503	1000	39
Case 7	1.0000	0.0038	0.9964	0.0008	3.33E+04	1503	1000	19
Case 10	1.0000	0.0034	0.9998	0.0007	2.59E+04	1503	1000	7
Case 12	1.0000	0.0040	1.0001	0.0008	2.36E+04	1503	1000	39

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

ATTACHMENT NUMBER 3

ICSBEP BENCHMARKS FOR AOA(4)

ICSBEP MOX POWDER BENCHMARKS

The following lines present for each ICSBEP the reasons for which the benchmark were selected or not. It also discuss on where the original inputs were obtained.

MIX-COMP-INTER-001 All the experiments are selected. The input files are directly issued from the document 0 and translated in a CSAS26 input file using the c5toc6 program. The 44 group library is replaced by the 238 group library.

ATTACHMENT NUMBER 4

CRITICALITY CALCULATION RESULTS FOR AOA(4)

Table A4-1a: SCALE 4.4 calculations on Sun platform

Experiment No.	H (U+Pu)	Pu Content	Exp. k_{eff}	Exp. Uncertainty	CSAS26 238GROUP K_{eff}	σ	EALF	GEN	NPG	NSK
MIX-COMP-INTER-001										
Case 1	7.33	8.10%	1	-	1.0030	0.0007	6.461E-01	1503	1000	62
Case 2	7.33	8.10%	1	-	1.0040	0.0007	6.421E-01	1503	1000	6
Case 3	7.33	8.10%	1	-	1.0037	0.0007	6.399E-01	1503	1000	23
Case 4	7.33	8.10%	1	-	1.0043	0.0007	6.319E-01	1503	1000	7
Case 5	2.86	14.64%	1	-	0.9798	0.0006	1.513E+01	1503	1000	19
Case 6	2.77	29.33%	1	-	0.9937	0.0006	4.149E+01	1503	1000	22
Case 7	2.77	29.33%	1	-	0.9934	0.0007	4.080E+01	1503	1000	81
Case 8	2.77	29.33%	1	-	1.0029	0.0007	4.110E+01	1503	1000	41
Case 9	2.77	29.33%	1	-	0.9944	0.0006	3.794E+01	1503	1000	38
Case 10	2.77	29.33%	1	-	0.9920	0.0007	3.820E+01	1503	1000	27
Case 11	2.77	29.33%	1	-	0.9929	0.0006	3.740E+01	1503	1000	23
Case 12	2.77	29.33%	1	-	0.9954	0.0006	3.496E+01	1503	1000	11
Case 13	2.77	29.33%	1	-	0.9918	0.0006	3.462E+01	1503	1000	95
Case 14	2.77	29.33%	1	-	0.9975	0.0007	3.487E+01	1503	1000	3

Table A4-1b: SCALE 4.4a calculations on PC

Experiment No.	H (U+Pu)	Pu Content	Exp. k_{eff}	Exp. Uncertainty	CSAS26 238GROUP k_{eff}	σ	EALF	GEN	NPG	NSK
MIX-COMP-INTER-001										
Case 1	7.33	8.10%	1	-	1.0056	0.0007	6.448E-01	1503	1000	49
Case 2	7.33	8.10%	1	-	1.0045	0.0008	6.420E-01	1503	1000	5
Case 3	7.33	8.10%	1	-	1.0044	0.0007	6.385E-01	1503	1000	34
Case 4	7.33	8.10%	1	-	1.0038	0.0007	6.321E-01	1503	1000	39
Case 5	2.86	14.64%	1	-	0.9801	0.0006	1.510E+01	1503	1000	28
Case 6	2.77	29.33%	1	-	0.9943	0.0006	4.171E+01	1503	1000	17
Case 7	2.77	29.33%	1	-	0.9928	0.0007	4.062E+01	1503	1000	11
Case 8	2.77	29.33%	1	-	1.0027	0.0006	4.084E+01	1503	1000	10
Case 9	2.77	29.33%	1	-	0.9928	0.0006	3.786E+01	1503	1000	10
Case 10	2.77	29.33%	1	-	0.9926	0.0007	3.790E+01	1503	1000	22
Case 11	2.77	29.33%	1	-	0.9925	0.0007	3.703E+01	1503	1000	63
Case 12	2.77	29.33%	1	-	0.9930	0.0007	3.536E+01	1503	1000	4
Case 13	2.77	29.33%	1	-	0.9936	0.0007	3.440E+01	1503	1000	18
Case 14	2.77	29.33%	1	-	0.9992	0.0007	3.463E+01	1503	1000	47

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

ATTACHMENT NUMBER 5

OUTPUT LISTING OF USLSTATS V1.0 PROGRAM

Figure A5-1 USLSTATS output listing for AOA(3) 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 variable - x	dependent variable - y	deviation in y	independent variable - x	dependent variable - y	deviation 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(3) 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 variable - x	dependent variable - y	deviation in y	independent variable - x	dependent variable - y	deviation 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(3) 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

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   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 variable - x	dependent variable - y	deviation in y	independent variable - x	dependent variable - y	deviation 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(3) Group 2: Pu-metal – k_{eff} versus EALF as trending parameter, SCALE 4.4a on PC

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

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   Input to statistical treatment from file:ealf.in

Title: Pu-Met-Fast-016-017-037 EALF

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =   14
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05


   independent     dependent       deviation
   variable - x    variable - y      in y

    1.46252E+05     9.99000E-01     4.47214E-03
    5.16868E+04     9.99200E-01     3.76563E-03
    3.33091E+04     9.96400E-01     3.88330E-03
    2.59583E+04     9.99800E-01     3.47131E-03
    2.36436E+04     1.00010E+00     4.07922E-03
    4.05334E+05     9.94189E-01     3.08058E-03
    2.32397E+05     9.96090E-01     3.08058E-03
    9.41425E+04     9.92551E-01     3.10484E-03
    1.16389E+04     1.01444E+00     4.25793E-03
    8.51817E+03     9.99700E-01     3.86394E-03
    8.33903E+03     9.98100E-01     3.37343E-03
    8.05156E+03     9.98500E-01     3.08058E-03
    7.94207E+03     9.98800E-01     3.47131E-03
    7.90634E+03     9.99800E-01     3.29849E-03


   WARNING *** the test for normal may be unreliable due to insufficient data.
   chi = 18.1429 (upper bound = 9.49). The data tests NOT normal


         Output from statistical treatment

   Pu-Met-Fast-016-017-037 EALF

    Number of data points (n)                          14
    Linear regression, k(X)                           1.0004 + (-1.8120E-08)*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                                 7906.3400
    Maximum value of X                                **********
    Average value of X                                76079.95500
    Average value of k                                  0.99905
    Minimum value of k                                  0.99255
    Variance of fit, s(k,X)^2                          2.2130E-05
    Within variance, s(w)^2                            1.3102E-05
    Pooled variance, s(p)^2                            3.5232E-05
    Pooled std. deviation, s(p)                        5.9357E-03
    C(alpha,rho)*s(p)                                  4.1089E-02
    student-t @ (n-2,1-gamma)                          1.78200E+00
    Confidence band width, W                           1.3783E-02
    Minimum margin of subcriticality, C*s(p)-W         2.7306E-02

    Upper subcritical limits: (  7906.3     <= X <=  4.05334E+05)
    ***** *********** *******

    USL Method 1 (Confidence Band with
```

```
Administrative Margin)            USL1 = 0.9366 + (-1.8120E-08)*X (X >    23527.   )
                                       = 0.9362                   (X <= *******)

USL Method 2 (Single-Sided Uniform
Width Closed Interval Approach)   USL2 = 0.9593 + (-1.8120E-08)*X (X >    23527.   )
                                       = 0.9589                   (X <= *******)


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

X:  7.91E+3  6.47E+4  1.21E+5  1.78E+5  2.35E+5  2.92E+5  3.49E+5  4.05E+5
   ---------------------------------------------------------------------------
USL-1:   0.9362   0.9355   0.9344   0.9334   0.9324   0.9314   0.9303   0.9293
USL-2:   0.9589   0.9582   0.9571   0.9561   0.9551   0.9540   0.9530   0.9520
   ---------------------------------------------------------------------------

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

Figure A5-5: USLSTATS output listing for AOA(4): MOX 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

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                     Oak Ridge National Laboratory
*****************************************************************************


   Input to statistical treatment from file:ealf.in

Title: Mix-Comp-Inter-001 EALF

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =   14
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05


   independent     dependent       deviation
   variable - x    variable - y      in y

    6.44773E-01     1.00560E+00     7.00000E-04
    6.42027E-01     1.00450E+00     8.00000E-04
    6.38514E-01     1.00440E+00     7.00000E-04
    6.32093E-01     1.00380E+00     7.00000E-04
    1.51007E+01     9.80100E-01     6.00000E-04
    4.17097E+01     9.94300E-01     6.00000E-04
    4.06188E+01     9.92800E-01     7.00000E-04
    4.08443E+01     1.00270E+00     6.00000E-04
    3.78626E+01     9.92800E-01     6.00000E-04
    3.78956E+01     9.92600E-01     7.00000E-04
    3.70255E+01     9.92500E-01     7.00000E-04
    3.53607E+01     9.93000E-01     7.00000E-04
    3.43960E+01     9.93600E-01     7.00000E-04
    3.46318E+01     9.99200E-01     7.00000E-04


   WARNING *** the test for normal may be unreliable due to insufficient data.
   chi = 13.1429 (upper bound = 9.49). The data tests NOT normal


         Output from statistical treatment

   Mix-Comp-Inter-001 EALF

    Number of data points (n)                          14
    Linear regression, k(X)                           1.0017 + (-2.0089E-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                                    0.6321
    Maximum value of X                                   41.7097
    Average value of X                                   25.57165
    Average value of k                                  0.99656
    Minimum value of k                                  0.98010
    Variance of fit, s(k,X)^2                          4.1629E-05
    Within variance, s(w)^2                            4.6357E-07
    Pooled variance, s(p)^2                            4.2093E-05
    Pooled std. deviation, s(p)                        6.4879E-03
    C(alpha,rho)*s(p)                                  4.0215E-02
    student-t @ (n-2,1-gamma)                          1.78200E+00
    Confidence band width, W                           1.2805E-02
    Minimum margin of subcriticality, C*s(p)-W         2.7410E-02

    Upper subcritical limits: ( 0.63209     <= X <=   41.710     )
    ***** *********** *******

    USL Method 1 (Confidence Band with
```

```
Administrative Margin)            USL1 = 0.9389 + (-2.0089E-04)*X (X >    8.4695   )
                                       = 0.9372                   (X <=   8.470)

USL Method 2 (Single-Sided Uniform
Width Closed Interval Approach)   USL2 = 0.9615 + (-2.0089E-04)*X (X >    8.4695   )
                                       = 0.9598                   (X <=   8.470)


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

X:  6.32E-1  6.50E+0  1.24E+1  1.82E+1  2.41E+1  3.00E+1  3.58E+1  4.17E+1
    ---------------------------------------------------------------------
USL-1:   0.9372   0.9372   0.9364   0.9352   0.9341   0.9329   0.9317   0.9305
USL-2:   0.9598   0.9598   0.9590   0.9578   0.9566   0.9555   0.9543   0.9531
    ---------------------------------------------------------------------

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

Figure A5-6: USLSTATS output listing for AOA(4): MOX 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

 ******************************************************************************
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                     Oak Ridge National Laboratory
 ******************************************************************************


   Input to statistical treatment from file:hpu.in

Title: Mix-Comp-Inter-001 H/Pu

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =   14
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05


   independent     dependent       deviation
   variable - x    variable - y      in y

    9.09000E+01     1.00560E+00     7.00000E-04
    9.09000E+01     1.00450E+00     8.00000E-04
    9.09000E+01     1.00440E+00     7.00000E-04
    9.09000E+01     1.00380E+00     7.00000E-04
    1.96000E+01     9.80100E-01     6.00000E-04
    9.47000E+00     9.94300E-01     6.00000E-04
    9.47000E+00     9.92800E-01     7.00000E-04
    9.47000E+00     1.00270E+00     6.00000E-04
    9.47000E+00     9.92800E-01     6.00000E-04
    9.47000E+00     9.92600E-01     7.00000E-04
    9.47000E+00     9.92500E-01     7.00000E-04
    9.47000E+00     9.93000E-01     7.00000E-04
    9.47000E+00     9.93600E-01     7.00000E-04
    9.47000E+00     9.99200E-01     7.00000E-04


   WARNING *** the test for normal may be unreliable due to insufficient data.
   chi = 13.1429 (upper bound = 9.49). The data tests NOT normal


         Output from statistical treatment

   Mix-Comp-Inter-001 H/Pu

    Number of data points (n)                          14
    Linear regression, k(X)                           0.9922 + ( 1.3153E-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                                    9.4700
    Maximum value of X                                   90.9000
    Average value of X                                   33.45929
    Average value of k                                  0.99656
    Minimum value of k                                  0.98010
    Variance of fit, s(k,X)^2                          2.8331E-05
    Within variance, s(w)^2                            4.6357E-07
    Pooled variance, s(p)^2                            2.8794E-05
    Pooled std. deviation, s(p)                        5.3660E-03
    C(alpha,rho)*s(p)                                  3.3341E-02
    student-t @ (n-2,1-gamma)                          1.78200E+00
    Confidence band width, W                           1.0687E-02
    Minimum margin of subcriticality, C*s(p)-W         2.2654E-02

    Upper subcritical limits: (  9.4700     <= X <=   90.900    )
    ***** *********** *******

    USL Method 1 (Confidence Band with
```

```
Administrative Margin)            USL1 = 0.9315 + ( 1.3153E-04)*X (X <    59.580   )
                                       = 0.9393                   (X >=  59.580)

USL Method 2 (Single-Sided Uniform
Width Closed Interval Approach)   USL2 = 0.9588 + ( 1.3153E-04)*X (X <    59.580   )
                                       = 0.9667                   (X >=  59.580)


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

X:  9.47E+0  2.11E+1  3.27E+1  4.44E+1  5.60E+1  6.76E+1  7.93E+1  9.09E+1
    ---------------------------------------------------------------------------
USL-1:   0.9327   0.9343   0.9358   0.9373   0.9388   0.9393   0.9393   0.9393
USL-2:   0.9601   0.9616   0.9631   0.9647   0.9662   0.9667   0.9667   0.9667
    ---------------------------------------------------------------------------

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

Figure A5-7: USLSTATS output listing for AOA(4): MOX powder – k_{eff} versus H/(U+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:hupu.in

Title: Mix-Comp-Inter-001 H/(U+Pu)

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =   14
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05


   independent     dependent       deviation
   variable - x    variable - y      in y

    7.30000E+00     1.00560E+00     7.00000E-04
    7.30000E+00     1.00450E+00     8.00000E-04
    7.30000E+00     1.00440E+00     7.00000E-04
    7.30000E+00     1.00380E+00     7.00000E-04
    2.86000E+00     9.80100E-01     6.00000E-04
    2.80000E+00     9.94300E-01     6.00000E-04
    2.80000E+00     9.92800E-01     7.00000E-04
    2.80000E+00     1.00270E+00     6.00000E-04
    2.80000E+00     9.92800E-01     6.00000E-04
    2.80000E+00     9.92600E-01     7.00000E-04
    2.80000E+00     9.92500E-01     7.00000E-04
    2.80000E+00     9.93000E-01     7.00000E-04
    2.80000E+00     9.93600E-01     7.00000E-04
    2.80000E+00     9.99200E-01     7.00000E-04


   WARNING *** the test for normal may be unreliable due to insufficient data.
   chi = 13.1429 (upper bound = 9.49). The data tests NOT normal


         Output from statistical treatment

   Mix-Comp-Inter-001 H/(U+Pu)

    Number of data points (n)                          14
    Linear regression, k(X)                           0.9864 + ( 2.4816E-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                                    2.8000
    Maximum value of X                                    7.3000
    Average value of X                                    4.09000
    Average value of k                                   0.99656
    Minimum value of k                                   0.98010
    Variance of fit, s(k,X)^2                          2.5488E-05
    Within variance, s(w)^2                            4.6357E-07
    Pooled variance, s(p)^2                            2.5951E-05
    Pooled std. deviation, s(p)                        5.0942E-03
    C(alpha,rho)*s(p)                                  3.1664E-02
    student-t @ (n-2,1-gamma)                          1.78200E+00
    Confidence band width, W                           1.0149E-02
    Minimum margin of subcriticality, C*s(p)-W         2.1514E-02

    Upper subcritical limits: (  2.8000     <= X <=   7.3000    )
    ***** *********** *******

    USL Method 1 (Confidence Band with
```

```
Administrative Margin)            USL1 = 0.9263 + ( 2.4816E-03)*X (X <    5.4745   )
                                       = 0.9399                   (X >=   5.474)

USL Method 2 (Single-Sided Uniform
Width Closed Interval Approach)   USL2 = 0.9548 + ( 2.4816E-03)*X (X <    5.4745   )
                                       = 0.9683                   (X >=   5.474)


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

X:  2.80E+0  3.44E+0  4.09E+0  4.73E+0  5.37E+0  6.01E+0  6.66E+0  7.30E+0
   ---------------------------------------------------------------------------
USL-1:   0.9332   0.9348   0.9364   0.9380   0.9396   0.9399   0.9399   0.9399
USL-2:   0.9617   0.9633   0.9649   0.9665   0.9681   0.9683   0.9683   0.9683
   ---------------------------------------------------------------------------

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

Figure A5-8: USLSTATS output listing for AOA(4): MOX powder – 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:%pu.in

Title: Mix-Comp-Inter-001 %Pu

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =   14
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05


   independent     dependent       deviation
   variable - x    variable - y      in y

    8.10000E+00     1.00560E+00     7.00000E-04
    8.10000E+00     1.00450E+00     8.00000E-04
    8.10000E+00     1.00440E+00     7.00000E-04
    8.10000E+00     1.00380E+00     7.00000E-04
    1.50000E+01     9.80100E-01     6.00000E-04
    2.93000E+01     9.94300E-01     6.00000E-04
    2.93000E+01     9.92800E-01     7.00000E-04
    2.93000E+01     1.00270E+00     6.00000E-04
    2.93000E+01     9.92800E-01     6.00000E-04
    2.93000E+01     9.92600E-01     7.00000E-04
    2.93000E+01     9.92500E-01     7.00000E-04
    2.93000E+01     9.93000E-01     7.00000E-04
    2.93000E+01     9.93600E-01     7.00000E-04
    2.93000E+01     9.99200E-01     7.00000E-04


   WARNING *** the test for normal may be unreliable due to insufficient data.
   chi = 13.1429 (upper bound = 9.49). The data tests NOT normal


         Output from statistical treatment

   Mix-Comp-Inter-001 %Pu

    Number of data points (n)                          14
    Linear regression, k(X)                           1.0041 + (-3.4124E-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                                    8.1000
    Maximum value of X                                   29.3000
    Average value of X                                   22.22143
    Average value of k                                  0.99656
    Minimum value of k                                  0.98010
    Variance of fit, s(k,X)^2                          4.2481E-05
    Within variance, s(w)^2                            4.6357E-07
    Pooled variance, s(p)^2                            4.2944E-05
    Pooled std. deviation, s(p)                        6.5532E-03
    C(alpha,rho)*s(p)                                  4.0452E-02
    student-t @ (n-2,1-gamma)                          1.78200E+00
    Confidence band width, W                           1.2924E-02
    Minimum margin of subcriticality, C*s(p)-W         2.7528E-02

    Upper subcritical limits: (  8.1000     <= X <=   29.300    )
    ***** *********** *******

    USL Method 1 (Confidence Band with
```

```
Administrative Margin)            USL1 = 0.9412 + (-3.4124E-04)*X (X >    12.153   )
                                       = 0.9371                   (X <=  12.153)

USL Method 2 (Single-Sided Uniform
Width Closed Interval Approach)   USL2 = 0.9637 + (-3.4124E-04)*X (X >    12.153   )
                                       = 0.9595                   (X <=  12.153)


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

X:  8.10E+0  1.11E+1  1.42E+1  1.72E+1  2.02E+1  2.32E+1  2.63E+1  2.93E+1
    ---------------------------------------------------------------------
USL-1:   0.9371   0.9371   0.9364   0.9354   0.9343   0.9333   0.9322   0.9312
USL-2:   0.9595   0.9595   0.9588   0.9578   0.9568   0.9558   0.9547   0.9537
    ---------------------------------------------------------------------

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

ATTACHMENT NUMBER 6

OUTPUT LISTING OF USLSTATS V1.0 PROGRAM

FOR SUN CALCULATIONS

Figure A6-1: USLSTATS output listing for AOA(3) Group 1: PuO_2 powder – 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: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 variable - x	dependent variable - y	deviation in y	independent variable - x	dependent variable - y	deviation in y
4.90168E+03	1.03423E+00	4.65296E-03	4.90900E+00	1.00951E+00	4.47214E-03
4.24025E+03	1.03133E+00	4.65296E-03	6.16800E+00	1.01121E+00	4.45533E-03
3.49705E+03	1.02733E+00	4.66905E-03	6.47600E+00	1.01181E+00	4.47214E-03
2.57277E+03	1.02072E+00	4.66905E-03	6.63300E+00	1.01131E+00	4.45533E-03
1.85490E+03	1.01792E+00	4.66905E-03	6.64900E+00	1.01061E+00	4.45533E-03
9.28990E+01	1.02280E+00	4.45533E-03	6.41900E+00	1.01442E+00	4.47214E-03
8.52420E+01	1.02340E+00	4.45533E-03	6.85000E-01	1.00990E+00	4.66905E-03
6.80920E+01	1.02130E+00	4.45533E-03	6.96000E-01	1.00880E+00	4.66905E-03
5.68370E+01	1.02180E+00	4.45533E-03	7.02000E-01	1.01010E+00	4.66905E-03
4.12300E+00	1.03250E+00	4.47214E-03	7.11000E-01	1.01010E+00	4.65296E-03
4.57600E+00	1.02910E+00	4.45533E-03	7.25000E-01	1.01130E+00	4.65296E-03
5.14000E+00	1.02860E+00	4.47214E-03	7.26000E-01	1.01150E+00	4.65296E-03
5.44100E+00	1.02660E+00	4.45533E-03	7.37000E-01	1.01120E+00	4.65296E-03
5.55400E+00	1.02910E+00	4.47214E-03	1.73418E+03	1.02150E+00	3.42053E-03
5.56400E+00	1.02870E+00	4.47214E-03	3.27300E+01	1.01802E+00	4.76760E-03
5.17000E+00	1.02410E+00	4.45533E-03	1.54800E+00	1.00681E+00	5.34603E-03

```
   WARNING *** the test for normal may be unreliable due to insufficient data.
   chi = 14.2500 (upper bound = 9.49). The data tests NOT normal


        Output from statistical treatment

   PuO2 powder EALF

    Number of data points (n)                          32
    Linear regression, k(X)                            1.0172 + ( 2.9407E-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                                    0.6850
    Maximum value of X                                 4901.6800
    Average value of X                                  600.49944
    Average value of k                                  1.01899
    Minimum value of k                                  1.00681
    Variance of fit, s(k,X)^2                          5.6955E-05
    Within variance, s(w)^2                            2.0694E-05
    Pooled variance, s(p)^2                            7.7649E-05
    Pooled std. deviation, s(p)                        8.8119E-03
    C(alpha,rho)*s(p)                                  4.7246E-02
    student-t @ (n-2,1-gamma)                          1.69700E+00
    Confidence band width, W                           1.7457E-02
    Minimum margin of subcriticality, C*s(p)-W         2.9788E-02

    Upper subcritical limits: ( 0.68500     <= X <=   4901.7    )
    ***** *********** *******
```

```
USL Method 1 (Confidence Band with
Administrative Margin)            USL1 = 0.9325 ( 0.68500   < X <  4901.7   )

USL Method 2 (Single-Sided Uniform
Width Closed Interval Approach)   USL2 = 0.9528 ( 0.68500   < X <  4901.7   )


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

X:  6.85E-1  7.01E+2  1.40E+3  2.10E+3  2.80E+3  3.50E+3  4.20E+3  4.90E+3
    ---------------------------------------------------------------------
USL-1:   0.9325   0.9325   0.9325   0.9325   0.9325   0.9325   0.9325   0.9325
USL-2:   0.9528   0.9528   0.9528   0.9528   0.9528   0.9528   0.9528   0.9528
    ---------------------------------------------------------------------

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

Figure A6-2: USLSTATS output listing for AOA(3) Group 1: PuO_2 powder – 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: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 variable - x	dependent variable - y	deviation in y	independent variable - x	dependent variable - y	deviation in y
4.00000E-02	1.03423E+00	4.65296E-03	1.50000E+01	1.00951E+00	4.47214E-03
4.00000E-02	1.03133E+00	4.65296E-03	1.50000E+01	1.01121E+00	4.45533E-03
4.00000E-02	1.02733E+00	4.66905E-03	1.50000E+01	1.01181E+00	4.47214E-03
4.00000E-02	1.02072E+00	4.66905E-03	1.50000E+01	1.01131E+00	4.45533E-03
4.00000E-02	1.01792E+00	4.66905E-03	1.50000E+01	1.01061E+00	4.45533E-03
5.00000E+00	1.02280E+00	4.45533E-03	1.50000E+01	1.01442E+00	4.47214E-03
5.00000E+00	1.02340E+00	4.45533E-03	4.96000E+01	1.00990E+00	4.66905E-03
5.00000E+00	1.02130E+00	4.45533E-03	4.96000E+01	1.00880E+00	4.66905E-03
5.00000E+00	1.02180E+00	4.45533E-03	4.96000E+01	1.01010E+00	4.66905E-03
1.50000E+01	1.03250E+00	4.47214E-03	4.96000E+01	1.01010E+00	4.65296E-03
1.50000E+01	1.02910E+00	4.45533E-03	4.96000E+01	1.01130E+00	4.65296E-03
1.50000E+01	1.02860E+00	4.47214E-03	4.96000E+01	1.01150E+00	4.65296E-03
1.50000E+01	1.02660E+00	4.45533E-03	4.96000E+01	1.01120E+00	4.65296E-03
1.50000E+01	1.02910E+00	4.47214E-03	5.00000E+00	1.02150E+00	3.42053E-03
1.50000E+01	1.02870E+00	4.47214E-03	1.50000E+01	1.01802E+00	4.76760E-03
1.50000E+01	1.02410E+00	4.45533E-03	4.96000E+01	1.00681E+00	5.34603E-03

```
   WARNING *** the test for normal may be unreliable due to insufficient data.
   chi = 14.2500 (upper bound = 9.49). The data tests NOT normal


        Output from statistical treatment

   PuO2 powder H/Pu

    Number of data points (n)                          32
    Linear regression, k(X)                            1.0250 + (-3.0590E-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                                   1.01899
    Minimum value of k                                   1.00681
    Variance of fit, s(k,X)^2                          4.0364E-05
    Within variance, s(w)^2                            2.0694E-05
    Pooled variance, s(p)^2                            6.1059E-05
    Pooled std. deviation, s(p)                        7.8140E-03
    C(alpha,rho)*s(p)                                  3.7935E-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         2.3924E-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 A6-3: USLSTATS output listing for AOA(3) Group 1: PuO_2 powder – k_{eff} versus ^{240}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:%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 variable - x	dependent variable - y	deviation in y	independent variable - x	dependent variable - y	deviation in y
1.83500E+01	1.03423E+00	4.65296E-03	8.06000E+00	1.00951E+00	4.47214E-03
1.83500E+01	1.03133E+00	4.65296E-03	8.06000E+00	1.01121E+00	4.45533E-03
1.83500E+01	1.02733E+00	4.66905E-03	8.06000E+00	1.01181E+00	4.47214E-03
1.83500E+01	1.02072E+00	4.66905E-03	8.06000E+00	1.01131E+00	4.45533E-03
1.83500E+01	1.01792E+00	4.66905E-03	8.06000E+00	1.01061E+00	4.45533E-03
1.14600E+01	1.02280E+00	4.45533E-03	8.06000E+00	1.01442E+00	4.47214E-03
1.14600E+01	1.02340E+00	4.45533E-03	1.83500E+01	1.00990E+00	4.66905E-03
1.14600E+01	1.02130E+00	4.45533E-03	1.83500E+01	1.00880E+00	4.66905E-03
1.14600E+01	1.02180E+00	4.45533E-03	1.83500E+01	1.01010E+00	4.66905E-03
2.20000E+00	1.03250E+00	4.47214E-03	1.83500E+01	1.01010E+00	4.65296E-03
2.20000E+00	1.02910E+00	4.45533E-03	1.83500E+01	1.01130E+00	4.65296E-03
2.20000E+00	1.02860E+00	4.47214E-03	1.83500E+01	1.01150E+00	4.65296E-03
2.20000E+00	1.02660E+00	4.45533E-03	1.83500E+01	1.01120E+00	4.65296E-03
2.20000E+00	1.02910E+00	4.47214E-03	1.14600E+01	1.02150E+00	3.42053E-03
2.20000E+00	1.02870E+00	4.47214E-03	2.20000E+00	1.01802E+00	4.76760E-03
2.20000E+00	1.02410E+00	4.45533E-03	1.83500E+01	1.00681E+00	5.34603E-03

```
   WARNING *** the test for normal may be unreliable due to insufficient data.
   chi = 14.2500 (upper bound = 9.49). The data tests NOT normal


        Output from statistical treatment

   PuO2 powder %Pu

    Number of data points (n)                          32
    Linear regression, k(X)                           1.0247 + (-5.0472E-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                                   1.01899
    Minimum value of k                                   1.00681
    Variance of fit, s(k,X)^2                          6.1388E-05
    Within variance, s(w)^2                            2.0694E-05
    Pooled variance, s(p)^2                            8.2082E-05
    Pooled std. deviation, s(p)                        9.0599E-03
    C(alpha,rho)*s(p)                                  4.3433E-02
    student-t @ (n-2,1-gamma)                          1.69700E+00
    Confidence band width, W                           1.6064E-02
    Minimum margin of subcriticality, C*s(p)-W         2.7369E-02

    Upper subcritical limits: (  2.2000     <= X <=   18.350    )
    ***** *********** *******
```

```
USL Method 1 (Confidence Band with
Administrative Margin)            USL1 = 0.9339 (  2.2000   < X <  18.350   )

USL Method 2 (Single-Sided Uniform
Width Closed Interval Approach)   USL2 = 0.9566 (  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:   0.9339   0.9339   0.9339   0.9339   0.9339   0.9339   0.9339   0.9339
USL-2:   0.9566   0.9566   0.9566   0.9566   0.9566   0.9566   0.9566   0.9566
    ---------------------------------------------------------------------

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

Figure A6-4: USLSTATS output listing for AOA(3) Group 2: Pu-metal – 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:ealf.in

Title: Pu-Met-Fast-001-017-037 EALF

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =   14
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05


   independent     dependent       deviation
   variable - x    variable - y      in y

    1.43715E+05     9.99000E-01     4.47214E-03
    5.15477E+04     9.98100E-01     3.76563E-03
    3.30872E+04     9.97600E-01     3.86394E-03
    2.59307E+04     9.98900E-01     3.47131E-03
    2.34008E+04     9.98900E-01     4.06079E-03
    4.10071E+05     9.94389E-01     3.10484E-03
    2.31754E+05     9.97494E-01     3.08058E-03
    9.34987E+04     9.93048E-01     3.10484E-03
    1.16544E+04     1.01354E+00     4.29535E-03
    8.47947E+03     9.99900E-01     3.86394E-03
    8.24009E+03     9.98700E-01     3.37343E-03
    8.04721E+03     9.98600E-01     3.08058E-03
    7.94148E+03     9.98100E-01     3.49285E-03
    7.76291E+03     9.99500E-01     3.27567E-03


   WARNING *** the test for normal may be unreliable due to insufficient data.
   chi = 18.1429 (upper bound = 9.49). The data tests NOT normal


         Output from statistical treatment

   Pu-Met-Fast-001-017-037 EALF

    Number of data points (n)                          14
    Linear regression, k(X)                           1.0002 + (-1.5416E-08)*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                                 7762.9100
    Maximum value of X                                **********
    Average value of X                                76080.76143
    Average value of k                                  0.99898
    Minimum value of k                                  0.99305
    Variance of fit, s(k,X)^2                          1.9449E-05
    Within variance, s(w)^2                            1.3114E-05
    Pooled variance, s(p)^2                            3.2563E-05
    Pooled std. deviation, s(p)                        5.7064E-03
    C(alpha,rho)*s(p)                                  3.9564E-02
    student-t @ (n-2,1-gamma)                          1.78200E+00
    Confidence band width, W                           1.3284E-02
    Minimum margin of subcriticality, C*s(p)-W         2.6281E-02

    Upper subcritical limits: (  7762.9     <= X <=  4.10071E+05)
    ***** *********** *******

    USL Method 1 (Confidence Band with
```

```
Administrative Margin)            USL1 = 0.9369 + (-1.5416E-08)*X (X >    10131.   )
                                       = 0.9367                   (X <= *******)

USL Method 2 (Single-Sided Uniform
Width Closed Interval Approach)   USL2 = 0.9606 + (-1.5416E-08)*X (X >    10131.   )
                                       = 0.9604                   (X <= *******)


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

X:  7.76E+3  6.52E+4  1.23E+5  1.80E+5  2.38E+5  2.95E+5  3.53E+5  4.10E+5
    ---------------------------------------------------------------------
USL-1:   0.9367   0.9359   0.9350   0.9341   0.9332   0.9323   0.9314   0.9306
USL-2:   0.9604   0.9596   0.9587   0.9578   0.9569   0.9560   0.9552   0.9543
    ---------------------------------------------------------------------

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

Figure A6-5: USLSTATS output listing for AOA(4): MOX powder – 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:ealf.in

Title: Mix-Comp-Inter-001 EALF

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =   14
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05


   independent     dependent       deviation
   variable - x    variable - y      in y

    6.46084E-01     1.00300E+00     7.00000E-04
    6.42067E-01     1.00400E+00     7.00000E-04
    6.39871E-01     1.00370E+00     7.00000E-04
    6.31923E-01     1.00430E+00     7.00000E-04
    1.51268E+01     9.79800E-01     6.00000E-04
    4.14854E+01     9.93700E-01     6.00000E-04
    4.08017E+01     9.93400E-01     7.00000E-04
    4.11007E+01     1.00290E+00     7.00000E-04
    3.79347E+01     9.94400E-01     6.00000E-04
    3.81990E+01     9.92000E-01     7.00000E-04
    3.73957E+01     9.92900E-01     6.00000E-04
    3.49596E+01     9.95400E-01     6.00000E-04
    3.46195E+01     9.91800E-01     6.00000E-04
    3.48684E+01     9.97500E-01     7.00000E-04


   WARNING *** the test for normal may be unreliable due to insufficient data.
   chi =  9.5714 (upper bound = 9.49). The data tests NOT normal


         Output from statistical treatment

   Mix-Comp-Inter-001 EALF

    Number of data points (n)                          14
    Linear regression, k(X)                           1.0009 + (-1.7610E-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                                    0.6319
    Maximum value of X                                   41.4854
    Average value of X                                   25.64653
    Average value of k                                  0.99634
    Minimum value of k                                  0.97980
    Variance of fit, s(k,X)^2                          4.0423E-05
    Within variance, s(w)^2                            4.3429E-07
    Pooled variance, s(p)^2                            4.0857E-05
    Pooled std. deviation, s(p)                        6.3919E-03
    C(alpha,rho)*s(p)                                  3.9620E-02
    student-t @ (n-2,1-gamma)                          1.78200E+00
    Confidence band width, W                           1.2616E-02
    Minimum margin of subcriticality, C*s(p)-W         2.7004E-02

    Upper subcritical limits: ( 0.63192     <= X <=   41.485    )
    ***** *********** *******

    USL Method 1 (Confidence Band with
```

```
Administrative Margin)            USL1 = 0.9382 + (-1.7610E-04)*X (X >    4.8791   )
                                       = 0.9374                   (X <=   4.879)

USL Method 2 (Single-Sided Uniform
Width Closed Interval Approach)   USL2 = 0.9612 + (-1.7610E-04)*X (X >    4.8791   )
                                       = 0.9604                   (X <=   4.879)


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

X:  6.32E-1  6.47E+0  1.23E+1  1.81E+1  2.40E+1  2.98E+1  3.56E+1  4.15E+1
    ---------------------------------------------------------------------
USL-1:   0.9374   0.9371   0.9361   0.9351   0.9340   0.9330   0.9320   0.9309
USL-2:   0.9604   0.9601   0.9591   0.9581   0.9570   0.9560   0.9550   0.9539
    ---------------------------------------------------------------------

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

Figure A6-6: USLSTATS output listing for AOA(4): MOX powder – 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:hpu.in

Title: Mix-Comp-Inter-001 H/Pu

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =   14
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05


   independent     dependent       deviation
   variable - x    variable - y      in y

    9.09000E+01     1.00300E+00     7.00000E-04
    9.09000E+01     1.00400E+00     7.00000E-04
    9.09000E+01     1.00370E+00     7.00000E-04
    9.09000E+01     1.00430E+00     7.00000E-04
    1.96000E+01     9.79800E-01     6.00000E-04
    9.47000E+00     9.93700E-01     6.00000E-04
    9.47000E+00     9.93400E-01     7.00000E-04
    9.47000E+00     1.00290E+00     7.00000E-04
    9.47000E+00     9.94400E-01     6.00000E-04
    9.47000E+00     9.92000E-01     7.00000E-04
    9.47000E+00     9.92900E-01     6.00000E-04
    9.47000E+00     9.95400E-01     6.00000E-04
    9.47000E+00     9.91800E-01     6.00000E-04
    9.47000E+00     9.97500E-01     7.00000E-04


   WARNING *** the test for normal may be unreliable due to insufficient data.
   chi =  9.5714 (upper bound = 9.49). The data tests NOT normal


         Output from statistical treatment

   Mix-Comp-Inter-001 H/Pu

    Number of data points (n)                          14
    Linear regression, k(X)                           0.9923 + ( 1.2090E-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                                    9.4700
    Maximum value of X                                   90.9000
    Average value of X                                   33.45929
    Average value of k                                  0.99634
    Minimum value of k                                  0.97980
    Variance of fit, s(k,X)^2                          2.8218E-05
    Within variance, s(w)^2                            4.3429E-07
    Pooled variance, s(p)^2                            2.8652E-05
    Pooled std. deviation, s(p)                        5.3528E-03
    C(alpha,rho)*s(p)                                  3.3259E-02
    student-t @ (n-2,1-gamma)                          1.78200E+00
    Confidence band width, W                           1.0661E-02
    Minimum margin of subcriticality, C*s(p)-W         2.2598E-02

    Upper subcritical limits: (  9.4700     <= X <=   90.900    )
    ***** *********** *******

    USL Method 1 (Confidence Band with
```

```
Administrative Margin)            USL1 = 0.9316 + ( 1.2090E-04)*X (X <    63.708   )
                                       = 0.9393                   (X >=  63.708)

USL Method 2 (Single-Sided Uniform
Width Closed Interval Approach)   USL2 = 0.9590 + ( 1.2090E-04)*X (X <    63.708   )
                                       = 0.9667                   (X >=  63.708)


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

X:  9.47E+0  2.11E+1  3.27E+1  4.44E+1  5.60E+1  6.76E+1  7.93E+1  9.09E+1
    ---------------------------------------------------------------------
USL-1:   0.9328   0.9342   0.9356   0.9370   0.9384   0.9393   0.9393   0.9393
USL-2:   0.9602   0.9616   0.9630   0.9644   0.9658   0.9667   0.9667   0.9667
    ---------------------------------------------------------------------

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

Figure A6-7: USLSTATS output listing for AOA(4): MOX powder – k_{eff} versus H/(U+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:hupu.in

Title: Mix-Comp-Inter-001 H/(U+Pu)

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =   14
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05


   independent     dependent       deviation
   variable - x    variable - y      in y

    7.30000E+00     1.00300E+00     7.00000E-04
    7.30000E+00     1.00400E+00     7.00000E-04
    7.30000E+00     1.00370E+00     7.00000E-04
    7.30000E+00     1.00430E+00     7.00000E-04
    2.86000E+00     9.79800E-01     6.00000E-04
    2.80000E+00     9.93700E-01     6.00000E-04
    2.80000E+00     9.93400E-01     7.00000E-04
    2.80000E+00     1.00290E+00     7.00000E-04
    2.80000E+00     9.94400E-01     6.00000E-04
    2.80000E+00     9.92000E-01     7.00000E-04
    2.80000E+00     9.92900E-01     6.00000E-04
    2.80000E+00     9.95400E-01     6.00000E-04
    2.80000E+00     9.91800E-01     6.00000E-04
    2.80000E+00     9.97500E-01     7.00000E-04


   WARNING *** the test for normal may be unreliable due to insufficient data.
   chi =  9.5714 (upper bound = 9.49). The data tests NOT normal


         Output from statistical treatment

   Mix-Comp-Inter-001 H/(U+Pu)

    Number of data points (n)                          14
    Linear regression, k(X)                           0.9870 + ( 2.2933E-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                                    2.8000
    Maximum value of X                                    7.3000
    Average value of X                                    4.09000
    Average value of k                                  0.99634
    Minimum value of k                                  0.97980
    Variance of fit, s(k,X)^2                          2.5548E-05
    Within variance, s(w)^2                            4.3429E-07
    Pooled variance, s(p)^2                            2.5982E-05
    Pooled std. deviation, s(p)                        5.0972E-03
    C(alpha,rho)*s(p)                                  3.1682E-02
    student-t @ (n-2,1-gamma)                          1.78200E+00
    Confidence band width, W                           1.0155E-02
    Minimum margin of subcriticality, C*s(p)-W         2.1527E-02

    Upper subcritical limits: (  2.8000     <= X <=   7.3000    )
    ***** *********** *******

    USL Method 1 (Confidence Band with
```

```
Administrative Margin)            USL1 = 0.9268 + ( 2.2933E-03)*X (X <    5.6847   )
                                       = 0.9398                   (X >=   5.685)

USL Method 2 (Single-Sided Uniform
Width Closed Interval Approach)   USL2 = 0.9553 + ( 2.2933E-03)*X (X <    5.6847   )
                                       = 0.9683                   (X >=   5.685)


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

X:  2.80E+0  3.44E+0  4.09E+0  4.73E+0  5.37E+0  6.01E+0  6.66E+0  7.30E+0
   ---------------------------------------------------------------------
USL-1:   0.9332   0.9347   0.9362   0.9377   0.9391   0.9398   0.9398   0.9398
USL-2:   0.9617   0.9632   0.9647   0.9661   0.9676   0.9683   0.9683   0.9683
   ---------------------------------------------------------------------

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

Figure A6-8: USLSTATS output listing for AOA(4): MOX powder – 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:%pu.in

Title: Mix-Comp-Inter-001 %Pu

   Proportion of the population = .999
   Confidence of fit            = .950
   Confidence on proportion     = .950
   Number of observations       =   14
   Minimum value of closed band =    0.00
   Maximum value of closed band =    0.00
   Administrative margin        =    0.05


   independent     dependent       deviation
   variable - x    variable - y      in y

    8.10000E+00     1.00300E+00     7.00000E-04
    8.10000E+00     1.00400E+00     7.00000E-04
    8.10000E+00     1.00370E+00     7.00000E-04
    8.10000E+00     1.00430E+00     7.00000E-04
    1.50000E+01     9.79800E-01     6.00000E-04
    2.93000E+01     9.93700E-01     6.00000E-04
    2.93000E+01     9.93400E-01     7.00000E-04
    2.93000E+01     1.00290E+00     7.00000E-04
    2.93000E+01     9.94400E-01     6.00000E-04
    2.93000E+01     9.92000E-01     7.00000E-04
    2.93000E+01     9.92900E-01     6.00000E-04
    2.93000E+01     9.95400E-01     6.00000E-04
    2.93000E+01     9.91800E-01     6.00000E-04
    2.93000E+01     9.97500E-01     7.00000E-04


   WARNING *** the test for normal may be unreliable due to insufficient data.
   chi =  9.5714 (upper bound = 9.49). The data tests NOT normal


         Output from statistical treatment

   Mix-Comp-Inter-001 %Pu

    Number of data points (n)                          14
    Linear regression, k(X)                           1.0030 + (-3.0103E-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                                    8.1000
    Maximum value of X                                   29.3000
    Average value of X                                   22.22143
    Average value of k                                  0.99634
    Minimum value of k                                  0.97980
    Variance of fit, s(k,X)^2                          4.1015E-05
    Within variance, s(w)^2                            4.3429E-07
    Pooled variance, s(p)^2                            4.1450E-05
    Pooled std. deviation, s(p)                        6.4381E-03
    C(alpha,rho)*s(p)                                  3.9742E-02
    student-t @ (n-2,1-gamma)                          1.78200E+00
    Confidence band width, W                           1.2697E-02
    Minimum margin of subcriticality, C*s(p)-W         2.7045E-02

    Upper subcritical limits: (  8.1000     <= X <=   29.300    )
    ***** *********** *******

    USL Method 1 (Confidence Band with
```

```
Administrative Margin)            USL1 = 0.9403 + (-3.0103E-04)*X (X >    10.072   )
                                       = 0.9373                   (X <=  10.072)

USL Method 2 (Single-Sided Uniform
Width Closed Interval Approach)   USL2 = 0.9633 + (-3.0103E-04)*X (X >    10.072   )
                                       = 0.9603                   (X <=  10.072)


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

X:  8.10E+0  1.11E+1  1.42E+1  1.72E+1  2.02E+1  2.32E+1  2.63E+1  2.93E+1
    ---------------------------------------------------------------------
USL-1:   0.9373   0.9370   0.9361   0.9352   0.9343   0.9334   0.9324   0.9315
USL-2:   0.9603   0.9599   0.9590   0.9581   0.9572   0.9563   0.9554   0.9545
    ---------------------------------------------------------------------

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

ATTACHMENT NUMBER 7

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 C has no label
 Volume Serial Number is 2555-10E7

Directory of C:\Cases

.               <DIR>        10-10-01 11:19a .
..              <DIR>        10-10-01 11:19a ..
PC              <DIR>        10-29-01  3:29p PC
SUN             <DIR>        10-29-01  3:30p Sun
         0 file(s)               0 bytes

Directory of C:\Cases\PC

.               <DIR>        10-29-01  3:29p .
..              <DIR>        10-29-01  3:29p ..
AOA3            <DIR>        10-29-01  3:29p AoA3
AOA4            <DIR>        10-29-01  3:29p AoA4
         0 file(s)               0 bytes

Directory of C:\Cases\PC\AoA3

.               <DIR>        10-29-01  3:29p .
..              <DIR>        10-29-01  3:29p ..
PU-COM-1        <DIR>        10-29-01  3:29p pu-comp-mixed-002
PU-COM-2        <DIR>        10-29-01  3:30p pu-comp-mixed-001
PU-MET-1        <DIR>        10-29-01  3:29p Pu-Met-Fast-037
PU-MET-2        <DIR>        10-29-01  3:29p Pu-Met-Fast-017
PU-MET-3        <DIR>        10-29-01  3:29p Pu-Met-Fast-016
USL             <DIR>        10-29-01  3:29p usl
         0 file(s)               0 bytes

Directory of C:\Cases\PC\AoA3\pu-comp-mixed-002

.               <DIR>        10-29-01  3:29p .
..              <DIR>        10-29-01  3:29p ..
PU_COM-1            2,036  06-05-01  8:26a pu_comp_mix_a02
PU_COM-1 OUT      760,794  06-05-01  9:01a pu_comp_mix_a01.out
PU_COM-2 OUT      760,637  06-05-01  9:30a pu_comp_mix_a02.out
PU_COM-2            2,241  06-05-01  8:26a pu_comp_mix_a10
PU_COM-3 OUT      761,285  06-05-01  9:59a pu_comp_mix_a03.out
PU_COM-3            2,242  06-05-01  8:26a pu_comp_mix_a11
PU_COM-4 OUT      760,262  06-05-01 10:28a pu_comp_mix_a04.out
PU_COM-4            2,242  06-05-01  8:26a pu_comp_mix_a12
PU_COM-5 OUT      760,629  06-05-01 10:57a pu_comp_mix_a05.out
PU_COM-5            2,242  06-05-01  8:26a pu_comp_mix_a13
PU_COM-6 OUT      759,974  06-05-01 11:20a pu_comp_mix_a06.out
PU_COM-6            2,242  06-05-01  8:26a pu_comp_mix_a14
PU_COM-7 OUT      759,113  06-05-01 11:43a pu_comp_mix_a07.out
PU_COM-7            2,242  06-05-01  8:26a pu_comp_mix_a15
PU_COM-8 OUT      758,579  06-05-01 12:06p pu_comp_mix_a08.out
PU_COM-8            2,242  06-05-01  8:26a pu_comp_mix_a16
PU_COM-9 OUT      758,407  06-05-01 12:30p pu_comp_mix_a09.out
PU_COM-9            2,458  06-05-01  8:26a pu_comp_mix_a17
PU_CO-10 OUT      748,489  06-05-01 12:52p pu_comp_mix_a10.out
PU_CO-10            2,458  06-05-01  8:26a pu_comp_mix_a18
PU_CO-11 OUT      748,359  06-05-01  1:14p pu_comp_mix_a11.out
PU_CO-11            2,458  06-05-01  8:26a pu_comp_mix_a19
PU_CO-12            2,036  06-05-01  8:26a pu_comp_mix_a03
PU_CO-12 OUT      748,212  06-05-01  1:36p pu_comp_mix_a12.out
PU_CO-13 OUT      749,648  06-05-01  1:58p pu_comp_mix_a13.out
PU_CO-13            2,458  06-05-01  8:26a pu_comp_mix_a20
PU_CO-14 OUT      749,791  06-05-01  2:20p pu_comp_mix_a14.out
PU_CO-14            2,458  06-05-01  8:26a pu_comp_mix_a21
PU_CO-15 OUT      748,414  06-05-01  2:42p pu_comp_mix_a15.out
PU_CO-15            2,458  06-05-01  8:26a pu_comp_mix_a22
PU_CO-16 OUT      748,738  06-05-01  3:04p pu_comp_mix_a16.out
PU_CO-16            2,483  06-05-01  8:26a pu_comp_mix_a23
PU_CO-17 OUT      760,755  06-05-01  3:26p pu_comp_mix_a17.out
PU_CO-17            2,483  06-05-01  8:26a pu_comp_mix_a24
PU_CO-18 OUT      760,127  06-05-01  3:46p pu_comp_mix_a18.out
PU_CO-18            2,483  06-05-01  8:26a pu_comp_mix_a25
PU_CO-19 OUT      759,145  06-05-01  4:08p pu_comp_mix_a19.out
PU_CO-19            2,483  06-05-01  8:26a pu_comp_mix_a26
PU_CO-20 OUT      759,644  06-05-01  4:28p pu_comp_mix_a20.out
PU_CO-20            2,483  06-05-01  8:26a pu_comp_mix_a27
PU_CO-21 OUT      760,142  06-05-01  4:49p pu_comp_mix_a21.out
PU_CO-21            2,483  06-05-01  8:26a pu_comp_mix_a28
PU_CO-22 OUT      759,458  06-05-01  5:10p pu_comp_mix_a22.out
PU_CO-22            2,483  06-05-01  8:26a pu_comp_mix_a29
PU_CO-23            2,036  06-05-01  8:26a pu_comp_mix_a04
PU_CO-23 OUT      780,701  06-05-01  5:27p pu_comp_mix_a23.out
PU_CO-24 OUT      781,293  06-05-01  5:45p pu_comp_mix_a24.out
PU_CO-24            2,483  06-05-01  8:26a pu_comp_mix_a30
PU_CO-25            2,036  06-05-01  8:26a pu_comp_mix_a05
PU_CO-25 OUT      781,379  06-05-01  6:03p pu_comp_mix_a25.out
PU_CO-26            2,166  06-05-01  8:26a pu_comp_mix_a06
PU_CO-26 OUT      780,895  06-05-01  6:20p pu_comp_mix_a26.out
PU_CO-27            2,168  06-05-01  8:26a pu_comp_mix_a07
PU_CO-27 OUT      780,529  06-05-01  6:38p pu_comp_mix_a27.out
PU_CO-28            2,168  06-05-01  8:26a pu_comp_mix_a08
PU_CO-28 OUT      780,928  06-05-01  6:55p pu_comp_mix_a28.out
PU_CO-29            2,167  06-05-01  8:26a pu_comp_mix_a09
PU_CO-29 OUT      782,230  06-05-01  7:13p pu_comp_mix_a29.out
PU_CO-30 OUT      782,230  06-05-01  7:30p pu_comp_mix_a30.out
PU_CO-31            2,037  06-05-01  8:26a pu_comp_mix_a01
        60 file(s)     22,959,942 bytes

Directory of C:\Cases\PC\AoA3\pu-comp-mixed-001

.               <DIR>        10-29-01  3:30p .
..              <DIR>        10-29-01  3:30p ..
PU_COM-1 INP        2,710  07-18-01 12:54p pu_comp_mix_b1.inp
```

```
PU_COM~1 OUT       769,877  07-18-01  3:47p pu_comp_mix_b1.out
PU_COM~2 INP         2,639  07-18-01  1:39p pu_comp_mix_b2.inp
PU_COM~2 OUT       763,278  07-18-01  2:04p pu_comp_mix_b2.out
PU_COM~3 INP         2,585  07-18-01  1:40p pu_comp_mix_b3.inp
PU_COM~3 OUT       752,840  07-18-01  2:27p pu_comp_mix_b3.out
PU_COM~4 INP         2,684  07-18-01  1:40p pu_comp_mix_b4.inp
PU_COM~4 OUT       764,362  07-18-01  2:49p pu_comp_mix_b4.out
PU_COM~5 INP         2,852  07-18-01  1:41p pu_comp_mix_b5.inp
PU_COM~5 OUT       785,857  07-18-01  3:06p pu_comp_mix_b5.out
        10 file(s)      3,849,684 bytes

Directory of C:\Cases\PC\AoA3\Pu-Met-Fast-037

.              <DIR>        10-29-01  3:29p .
..             <DIR>        10-29-01  3:29p ..
PU-MET~1 INP        27,316  07-17-01  1:44p pu-met-fast-001-k6.inp
PU-MET~1 OUT       985,539  07-17-01  2:58p pu-met-fast-001-k6.out
PU-MET~2 INP        67,364  07-17-01  1:40p pu-met-fast-005-k6.inp
PU-MET~2 OUT     1,109,074  07-17-01  3:30p pu-met-fast-005-k6.out
PU-MET~3 INP        63,428  07-17-01  1:40p pu-met-fast-007-k6.inp
PU-MET~3 OUT     1,095,489  07-17-01  4:04p pu-met-fast-007-k6.out
PU-MET~4 INP        34,778  07-17-01  1:42p pu-met-fast-010-k6.inp
PU-MET~4 OUT     1,008,780  07-17-01  4:43p pu-met-fast-010-k6.out
PU-MET~5 INP        35,090  07-17-01  1:43p pu-met-fast-012-k6.inp
PU-MET~5 OUT     1,011,290  07-17-01  5:33p pu-met-fast-012-k6.out
        10 file(s)      5,438,148 bytes

Directory of C:\Cases\PC\AoA3\Pu-Met-Fast-017

.              <DIR>        10-29-01  3:29p .
..             <DIR>        10-29-01  3:29p ..
PU_MET~1 INP        46,527  07-18-01  2:33p pu_met_fast_017_202_k6.inp
PU_MET~1 OUT     1,464,213  07-18-01  4:56p pu_met_fast_017_202_k6.out
PU_MET~2 INP        46,527  07-18-01  2:34p pu_met_fast_017_203_k6.inp
PU_MET~2 OUT     1,463,914  07-18-01  5:50p pu_met_fast_017_203_k6.out
PU_MET~3 INP        43,985  07-18-01  2:33p pu_met_fast_017_205_k6.inp
PU_MET~3 OUT     1,455,533  07-18-01  6:43p pu_met_fast_017_205_k6.out
         6 file(s)      4,520,699 bytes

Directory of C:\Cases\PC\AoA3\Pu-Met-Fast-016

.              <DIR>        10-29-01  3:29p .
..             <DIR>        10-29-01  3:29p ..
PU-MET~1 IN         18,286  07-26-01 12:48p pu-met-fast-016-001-k6.in
PU-MET~1 OUT       826,651  07-20-01 10:24a pu-met-fast-016-001-k6.out
PU-MET~2 IN         16,773  07-26-01 12:48p pu-met-fast-016-002-k6.in
PU-MET~2 OUT       821,377  07-20-01 11:29a pu-met-fast-016-002-k6.out
PU-MET~3 IN         16,773  07-26-01 12:49p pu-met-fast-016-003-k6.in
PU-MET~3 OUT       822,537  07-20-01 12:35p pu-met-fast-016-003-k6.out
PU-MET~4 IN         16,855  07-26-01 12:49p pu-met-fast-016-004-k6.in
PU-MET~4 OUT       822,023  07-20-01  1:43p pu-met-fast-016-004-k6.out
PU-MET~5 IN         16,772  07-26-01 12:49p pu-met-fast-016-005-k6.in
PU-MET~5 OUT       821,981  07-20-01  2:53p pu-met-fast-016-005-k6.out
PU-MET~6 IN         16,780  07-26-01 12:49p pu-met-fast-016-006-k6.in
PU-MET~6 OUT       820,829  07-20-01  4:06p pu-met-fast-016-006-k6.out
        12 file(s)      5,037,637 bytes

Directory of C:\Cases\PC\AoA3\usl

.              <DIR>        10-29-01  3:29p .
..             <DIR>        10-29-01  3:29p ..
PU-MET~1       <DIR>        10-29-01  3:29p Pu-Met-Fast-016-017-037
PUO2PO~1       <DIR>        10-29-01  3:29p PuO2 powder
         0 file(s)              0 bytes

Directory of C:\Cases\PC\AoA3\usl\Pu-Met-Fast-016-017-037

.              <DIR>        10-29-01  3:29p .
..             <DIR>        10-29-01  3:29p ..
EALF     IN            638  09-07-01  2:33p EALF.in
EALF     OUT         4,388  09-07-01  3:35p EALF.OUT
         2 file(s)          5,026 bytes

Directory of C:\Cases\PC\AoA3\usl\PuO2 powder

%PU      IN          1,107  09-07-01  2:40p %Pu.in
%PU      OUT         5,305  09-07-01  3:36p %PU.OUT
.              <DIR>        10-29-01  3:29p .
..             <DIR>        10-29-01  3:29p ..
EALF     IN          1,236  09-07-01  2:40p EALF.in
EALF     OUT         5,305  09-07-01  3:36p EALF.OUT
HPU      IN          1,174  09-07-01  2:40p HPu.in
HPU      OUT         5,305  09-07-01  3:36p HPU.OUT
         6 file(s)         19,432 bytes

Directory of C:\Cases\PC\AoA4

.              <DIR>        10-29-01  3:29p .
..             <DIR>        10-29-01  3:29p ..
MIX-CO~1       <DIR>        10-29-01  3:29p mix-comp-inter-001
USL            <DIR>        10-29-01  3:29p usl
         0 file(s)              0 bytes

Directory of C:\Cases\PC\AoA4\mix-comp-inter-001

.              <DIR>        10-29-01  3:29p .
..             <DIR>        10-29-01  3:29p ..
CASEVI01 IN         7,130  10-16-01 12:09p casevi01.in
CASEVI01 OUT      926,621  10-16-01  1:59p casevi01.out
CASEVI02 IN         7,124  10-15-01  8:31a casevi02.in
CASEVI02 OUT      927,093  10-16-01  2:24p casevi02.out
CASEVI03 IN         7,130  10-15-01  8:32a casevi03.in
CASEVI03 OUT      930,277  10-16-01 12:58p casevi03.out
CASEVI04 IN         7,124  10-15-01  8:32a casevi04.in
CASEVI04 OUT      926,837  10-16-01  2:48p casevi04.out
CASEVI05 IN         7,126  10-16-01  2:24p casevi05.in
CASEVI05 OUT      934,327  10-16-01  3:11p casevi05.out
CASEVI06 IN         7,616  10-15-01  8:31a casevi06.in
CASEVI06 OUT      927,690  10-16-01  3:39p casevi06.out
CASEVI07 IN         7,622  10-15-01  8:32a casevi07.in
CASEVI07 OUT      927,936  10-16-01  4:07p casevi07.out
```

```
CASEVI08 IN          7,616  10-15-01  8:32a casevi08.in
CASEVI08 OUT       928,691  10-16-01  4:34p casevi08.out
CASEVI09 IN          7,632  10-15-01  8:32a casevi09.in
CASEVI09 OUT       928,357  10-16-01  5:02p casevi09.out
CASEVI10 IN          7,616  10-15-01  8:31a casevi10.in
CASEVI10 OUT       927,752  10-16-01  5:30p casevi10.out
CASEVI11 IN          7,616  10-15-01  8:31a casevi11.in
CASEVI11 OUT       927,296  10-16-01  5:58p casevi11.out
CASEVI12 IN          7,616  10-15-01  8:31a casevi12.in
CASEVI12 OUT       928,564  10-16-01  6:25p casevi12.out
CASEVI13 IN          7,632  10-15-01  8:31a casevi13.in
CASEVI13 OUT       928,728  10-16-01  6:53p casevi13.out
CASEVI14 IN          7,632  10-15-01  8:31a casevi14.in
CASEVI14 OUT       929,436  10-16-01  7:21p casevi14.out
        28 file(s)     13,103,837 bytes

Directory of C:\Cases\PC\AoA4\usl

%PU      IN            414  10-17-01  8:58a %Pu.in
%PU      OUT         4,388  10-17-01  8:59a %PU.OUT
.             <DIR>         10-29-01  3:29p .
..            <DIR>         10-29-01  3:29p ..
EALF     IN            471  10-17-01  8:58a EALF.in
EALF     OUT         4,388  10-17-01  8:59a EALF.OUT
HPU      IN            471  10-17-01  8:58a HPu.in
HPU      OUT         4,388  10-17-01  8:59a HPU.OUT
HUPU     IN            419  10-17-01  8:58a HUPu.in
HUPU     OUT         4,388  10-17-01  8:59a HUPU.OUT
         8 file(s)         19,327 bytes

Directory of C:\Cases\Sun

.             <DIR>         10-29-01  3:30p .
..            <DIR>         10-29-01  3:30p ..
AOA3          <DIR>         10-29-01  3:30p AoA3
AOA4          <DIR>         10-29-01  3:30p AoA4
         0 file(s)              0 bytes

Directory of C:\Cases\Sun\AoA3

.             <DIR>         10-29-01  3:30p .
..            <DIR>         10-29-01  3:30p ..
PU-COM-1      <DIR>         10-29-01  3:30p pu-comp-mixed-002
PU-COM-2      <DIR>         10-29-01  3:30p pu-comp-mixed-001
PU-MET-1      <DIR>         10-29-01  3:30p Pu-Met-Fast-037
PU-MET-2      <DIR>         10-29-01  3:30p Pu-Met-Fast-017
PU-MET-3      <DIR>         10-29-01  3:30p Pu-Met-Fast-016
USL           <DIR>         10-29-01  3:30p usl
         0 file(s)              0 bytes

Directory of C:\Cases\Sun\AoA3\pu-comp-mixed-002

.             <DIR>         10-29-01  3:30p .
..            <DIR>         10-29-01  3:30p ..
PU_COM-1             2,036  06-05-01  8:26a pu_comp_mix_a02
PU_COM-1 OUT       772,826  07-12-01  2:28p pu_comp_mix_a01.out
PU_COM-2 OUT       772,770  07-12-01  2:28p pu_comp_mix_a02.out
PU_COM-2             2,241  06-05-01  8:26a pu_comp_mix_a10
PU_COM-3 OUT       772,327  07-12-01  2:28p pu_comp_mix_a03.out
PU_COM-3             2,242  06-05-01  8:26a pu_comp_mix_a11
PU_COM-4 OUT       772,932  07-12-01  2:28p pu_comp_mix_a04.out
PU_COM-4             2,242  06-05-01  8:26a pu_comp_mix_a12
PU_COM-5 OUT       772,334  07-12-01  2:28p pu_comp_mix_a05.out
PU_COM-5             2,242  06-05-01  8:26a pu_comp_mix_a13
PU_COM-6 OUT       773,864  07-12-01  2:28p pu_comp_mix_a06.out
PU_COM-6             2,242  06-05-01  8:26a pu_comp_mix_a14
PU_COM-7 OUT       773,115  07-12-01  2:28p pu_comp_mix_a07.out
PU_COM-7             2,242  06-05-01  8:26a pu_comp_mix_a15
PU_COM-8 OUT       773,400  07-12-01  2:28p pu_comp_mix_a08.out
PU_COM-8             2,242  06-05-01  8:26a pu_comp_mix_a16
PU_COM-9 OUT       772,509  07-12-01  2:28p pu_comp_mix_a09.out
PU_COM-9             2,458  06-05-01  8:26a pu_comp_mix_a17
PU_CO-10 OUT       761,963  07-12-01  2:29p pu_comp_mix_a10.out
PU_CO-10             2,458  06-05-01  8:26a pu_comp_mix_a18
PU_CO-11 OUT       762,343  07-12-01  2:28p pu_comp_mix_a11.out
PU_CO-11             2,458  06-05-01  8:26a pu_comp_mix_a19
PU_CO-12             2,036  06-05-01  8:26a pu_comp_mix_a03
PU_CO-12 OUT       762,130  07-12-01  2:28p pu_comp_mix_a12.out
PU_CO-13 OUT       762,576  07-12-01  2:28p pu_comp_mix_a13.out
PU_CO-13             2,458  06-05-01  8:26a pu_comp_mix_a20
PU_CO-14 OUT       762,358  07-12-01  2:28p pu_comp_mix_a14.out
PU_CO-14             2,458  06-05-01  8:26a pu_comp_mix_a21
PU_CO-15 OUT       762,236  07-12-01  2:28p pu_comp_mix_a15.out
PU_CO-15             2,458  06-05-01  8:26a pu_comp_mix_a22
PU_CO-16 OUT       762,226  07-12-01  2:28p pu_comp_mix_a16.out
PU_CO-16             2,483  06-05-01  8:26a pu_comp_mix_a23
PU_CO-17 OUT       775,504  07-12-01  2:28p pu_comp_mix_a17.out
PU_CO-17             2,483  06-05-01  8:26a pu_comp_mix_a24
PU_CO-18 OUT       775,307  07-12-01  2:28p pu_comp_mix_a18.out
PU_CO-18             2,483  06-05-01  8:26a pu_comp_mix_a25
PU_CO-19 OUT       776,338  07-12-01  2:28p pu_comp_mix_a19.out
PU_CO-19             2,483  06-05-01  8:26a pu_comp_mix_a26
PU_CO-20 OUT       775,902  07-12-01  2:28p pu_comp_mix_a20.out
PU_CO-20             2,483  06-05-01  8:26a pu_comp_mix_a27
PU_CO-21 OUT       775,899  07-12-01  2:28p pu_comp_mix_a21.out
PU_CO-21             2,483  06-05-01  8:26a pu_comp_mix_a28
PU_CO-22 OUT       775,561  07-12-01  2:28p pu_comp_mix_a22.out
PU_CO-22             2,483  06-05-01  8:26a pu_comp_mix_a29
PU_CO-23             2,036  06-05-01  8:26a pu_comp_mix_a04
PU_CO-23 OUT       797,829  07-12-01  2:28p pu_comp_mix_a23.out
PU_CO-24 OUT       797,202  07-12-01  2:28p pu_comp_mix_a24.out
PU_CO-24             2,483  06-05-01  8:26a pu_comp_mix_a30
PU_CO-25             2,036  06-05-01  8:26a pu_comp_mix_a05
PU_CO-25 OUT       798,218  07-12-01  2:28p pu_comp_mix_a25.out
PU_CO-26             2,166  06-05-01  8:26a pu_comp_mix_a06
PU_CO-26 OUT       798,204  07-12-01  2:28p pu_comp_mix_a26.out
PU_CO-27             2,168  06-05-01  8:26a pu_comp_mix_a07
PU_CO-27 OUT       797,252  07-12-01  2:28p pu_comp_mix_a27.out
PU_CO-28             2,168  06-05-01  8:26a pu_comp_mix_a08
PU_CO-28 OUT       797,758  07-12-01  2:28p pu_comp_mix_a28.out
PU_CO-29             2,167  06-05-01  8:26a pu_comp_mix_a09
```

```
PU_CO~29 OUT       798,118  07-12-01  2:28p pu_comp_mix_a29.out
PU_CO~30 OUT       798,118  07-12-01  2:28p pu_comp_mix_a30.out
PU_CO~31             2,037  06-05-01  8:26a pu_comp_mix_a01
        60 file(s)     23,398,274 bytes

Directory of C:\Cases\Sun\AoA3\pu-comp-mixed-001

.              <DIR>        10-29-01  3:30p .
..             <DIR>        10-29-01  3:30p ..
PU_COM~1 INP         2,710  07-23-01  9:28a pu_comp_mix_b1.inp
PU_COM~1 OUT       780,977  07-23-01  9:28a pu_comp_mix_b1.out
PU_COM~2 INP         2,639  07-23-01  9:27a pu_comp_mix_b2.inp
PU_COM~2 OUT       779,666  07-23-01  9:28a pu_comp_mix_b2.out
PU_COM~3 INP         2,585  07-23-01  9:28a pu_comp_mix_b3.inp
PU_COM~3 OUT       769,988  07-23-01  9:28a pu_comp_mix_b3.out
PU_COM~4 INP         2,684  07-23-01  9:28a pu_comp_mix_b4.inp
PU_COM~4 OUT       781,813  07-23-01  9:27a pu_comp_mix_b4.out
PU_COM~5 INP         2,852  07-23-01  9:28a pu_comp_mix_b5.inp
PU_COM~5 OUT       804,564  07-23-01  9:28a pu_comp_mix_b5.out
        10 file(s)      3,930,478 bytes

Directory of C:\Cases\Sun\AoA3\Pu-Met-Fast-037

.              <DIR>        10-29-01  3:30p .
..             <DIR>        10-29-01  3:30p ..
PU-MET-1 INP        27,271  07-23-01  9:28a pu-met-fast-001-k6.inp
PU-MET-1 OUT       969,300  07-23-01  9:28a pu-met-fast-001-k6.out
PU-MET-2 INP        67,288  07-23-01  9:28a pu-met-fast-005-k6.inp
PU-MET-2 OUT     1,089,875  07-23-01  9:29a pu-met-fast-005-k6.out
PU-MET-3 INP        63,351  07-23-01  9:28a pu-met-fast-007-k6.inp
PU-MET-3 OUT     1,076,710  07-23-01  9:28a pu-met-fast-007-k6.out
PU-MET-4 INP        34,732  07-23-01  9:28a pu-met-fast-010-k6.inp
PU-MET-4 OUT       990,392  07-23-01  9:28a pu-met-fast-010-k6.out
PU-MET-5 INP        35,055  07-23-01  9:28a pu-met-fast-012-k6.inp
PU-MET-5 OUT       993,646  07-23-01  9:28a pu-met-fast-012-k6.out
        10 file(s)      5,347,620 bytes

Directory of C:\Cases\Sun\AoA3\Pu-Met-Fast-017

.              <DIR>        10-29-01  3:30p .
..             <DIR>        10-29-01  3:30p ..
PU_MET~1 INP        46,199  07-23-01  9:26a pu_met_fast_017_202_k6.inp
PU_MET~1 OUT     1,362,708  07-23-01  9:26a pu_met_fast_017_202_k6.out
PU_MET~2 INP        46,187  07-23-01  9:26a pu_met_fast_017_203_k6.inp
PU_MET~2 OUT     1,362,390  07-23-01  9:26a pu_met_fast_017_203_k6.out
PU_MET~3 INP        43,657  07-23-01  9:26a pu_met_fast_017_205_k6.inp
PU_MET~3 OUT     1,354,144  07-23-01  9:26a pu_met_fast_017_205_k6.out
         6 file(s)      4,215,285 bytes

Directory of C:\Cases\Sun\AoA3\Pu-Met-Fast-016

.              <DIR>        10-29-01  3:30p .
..             <DIR>        10-29-01  3:30p ..
PU-MET-1 IN         18,211  07-23-01  9:29a pu-met-fast-016-001-k6.in
PU-MET-1 OUT       806,684  07-23-01  9:30a pu-met-fast-016-001-k6.out
PU-MET-2 IN         16,698  07-23-01  9:29a pu-met-fast-016-002-k6.in
PU-MET-2 OUT       802,080  07-23-01  9:29a pu-met-fast-016-002-k6.out
PU-MET-3 IN         16,698  07-23-01  9:29a pu-met-fast-016-003-k6.in
PU-MET-3 OUT       802,292  07-23-01  9:29a pu-met-fast-016-003-k6.out
PU-MET-4 IN         16,780  07-23-01  9:29a pu-met-fast-016-004-k6.in
PU-MET-4 OUT       802,516  07-23-01  9:29a pu-met-fast-016-004-k6.out
PU-MET-5 IN         16,697  07-23-01  9:29a pu-met-fast-016-005-k6.in
PU-MET-5 OUT       802,747  07-23-01  9:30a pu-met-fast-016-005-k6.out
PU-MET-6 IN         16,705  07-23-01  9:29a pu-met-fast-016-006-k6.in
PU-MET-6 OUT       800,991  07-23-01  9:29a pu-met-fast-016-006-k6.out
        12 file(s)      4,919,099 bytes

Directory of C:\Cases\Sun\AoA3\usl

.              <DIR>        10-29-01  3:30p .
..             <DIR>        10-29-01  3:30p ..
PU-MET-1       <DIR>        10-29-01  3:30p Pu-Met-Fast-016-017-037
PUO2PO-1       <DIR>        10-29-01  3:30p PuO2 powder
         0 file(s)              0 bytes

Directory of C:\Cases\Sun\AoA3\usl\Pu-Met-Fast-016-017-037

.              <DIR>        10-29-01  3:30p .
..             <DIR>        10-29-01  3:30p ..
EALF     IN        641  09-07-01  2:45p EALF.in
EALF     OUT     4,388  09-07-01  3:33p EALF.OUT
         2 file(s)        5,029 bytes

Directory of C:\Cases\Sun\AoA3\usl\PuO2 powder

%PU      IN      1,107  09-07-01  3:31p %Pu.in
%PU      OUT     5,306  09-07-01  3:32p %PU.OUT
.              <DIR>        10-29-01  3:30p .
..             <DIR>        10-29-01  3:30p ..
EALF     IN      1,268  09-07-01  3:31p EALF.in
EALF     OUT     5,306  09-07-01  3:32p EALF.OUT
HPU      IN      1,176  09-07-01  3:31p HPu.in
HPU      OUT     5,306  09-07-01  3:32p HPU.OUT
         6 file(s)       19,469 bytes

Directory of C:\Cases\Sun\AoA4

.              <DIR>        10-29-01  3:30p .
..             <DIR>        10-29-01  3:30p ..
MIX-CO-1       <DIR>        10-29-01  3:30p mix-comp-inter-001
USL            <DIR>        10-29-01  3:30p usl
         0 file(s)              0 bytes

Directory of C:\Cases\Sun\AoA4\mix-comp-inter-001

.              <DIR>        10-29-01  3:30p .
..             <DIR>        10-29-01  3:30p ..
CASEVI01 OUT       965,377  10-18-01  7:26a casevi01.out
CASEVI02 OUT       965,600  10-18-01  7:26a casevi02.out
CASEVI03 OUT       964,361  10-18-01  7:26a casevi03.out
CASEVI04 OUT       964,707  10-18-01  7:26a casevi04.out
```

```
CASEVI05 OUT       958,575  10-18-01  7:26a casevi05.out
CASEVI06 OUT       935,660  10-18-01  7:26a casevi06.out
CASEVI07 OUT       933,955  10-18-01  7:26a casevi07.out
CASEVI08 OUT       937,192  10-18-01  7:26a casevi08.out
CASEVI09 OUT       933,123  10-18-01  7:26a casevi09.out
CASEVI10 OUT       932,847  10-18-01  7:26a casevi10.out
CASEVI11 OUT       927,413  10-18-01  7:26a casevi11.out
CASEVI12 OUT       930,919  10-18-01  7:26a casevi12.out
CASEVI13 OUT       929,449  10-18-01  7:26a casevi13.out
CASEVI14 OUT       933,598  10-18-01  7:26a casevi14.out
DIFFS                  311  10-29-01  9:53a diffs
        15 file(s)     13,213,087 bytes

Directory of C:\Cases\Sun\AoA4\us1

%PU      IN            414  10-18-01  8:55a %Pu.in
%PU      OUT         4,388  10-18-01  8:56a %PU.OUT
.              <DIR>        10-29-01  3:30p .
..             <DIR>        10-29-01  3:30p ..
EALF     IN            471  10-18-01  8:55a EALF.in
EALF     OUT         4,388  10-18-01  8:56a EALF.OUT
HPU      IN            471  10-18-01  8:55a HPu.in
HPU      OUT         4,388  10-18-01  8:56a HPU.OUT
HUPU     IN            419  10-18-01  8:55a HUPu.in
HUPU     OUT         4,388  10-18-01  8:56a HUPU.OUT
         8 file(s)          19,327 bytes

Total files listed:
       271 file(s)    110,021,400 bytes
        80 dir(s)       2,690.73 MB free
```