Draft FCSS Interim Staff Guidance-10, Revision 1
Justification for Minimum Margin of Subcriticality for Safety

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Issue

Technical justification for the selection of the minimum margin of subcriticality for safety for fuel cycle facilities, as required by 10 CFR 70.61(d)

Introduction

10 CFR 70.61(d) requires, in part, that licensees or applicants (henceforth to be referred to as "licensees") demonstrate that "under normal and credible abnormal conditions, all nuclear processes are subcritical, including use of an approved margin of subcriticality for safety." There are a variety of methods that may be used to demonstrate subcriticality, including use of industry standards, handbooks, hand calculations, and computer methods. Subcriticality is assured, in part, by providing margin between actual and expected critical conditions. This interim staff guidance (ISG), however, only applies to margin used in those methods that rely on calculation of k_{eff}, including deterministic and probabilistic computer methods. The use of other methods (e.g., use of endorsed industry standards, widely accepted handbooks, certain hand calculations), containing varying amounts of margin, is outside the scope of this ISG.

For methods relying on calculation of k_{eff}, margin may be provided either in terms of limits on physical parameters of the system (of which k_{eff} is a function), or in terms of limits on k_{eff} directly, or both. For the purposes of this ISG, the term *margin of safety* will be used to refer to the margin to criticality in terms of system parameters, and the term *margin of subcriticality* (MoS) will refer to the margin to criticality in terms of k_{eff}. A common approach to ensuring subcriticality is to determine a maximum k_{eff} limit below which the licensee's calculations must fall. This limit will be referred to in this ISG as the *Upper Subcritical Limit* (USL). Licensees using calculational methods perform validation studies, in which critical experiments similar to actual or anticipated facility calculations are chosen and then analyzed to determine the bias and uncertainty in the bias. The bias is a measure of the systematic differences between calculational method results and experimental data. The uncertainty in the bias is a measure of both the accuracy and precision of the calculations and the uncertainty in the experimental data. A USL is then established that includes allowances for bias and bias uncertainty as well as an additional margin, to be referred to in this ISG as the *minimum margin of subcriticality* (MMS). The MMS is variously referred to in the nuclear industry as *minimum subcritical margin*, *administrative margin*, and *arbitrary margin*, and the term MMS should be regarded as synonymous with those terms. The term MMS will be used throughout this ISG, and has been chosen for consistency with the rule. The MMS is an allowance for any unknown errors or uncertainties in the method of calculating k_{eff} that may exist beyond those which have been accounted for explicitly in calculating the bias and its uncertainty.

There is little guidance in the fuel facility Standard Review Plans (SRPs) as to what constitutes sufficient technical justification for the MMS. NUREG-1520, “Standard Review Plan for the Review of a License Application for a Fuel Cycle Facility,” Section 5.4.3.4.4, states that this margin must include, among other uncertainties, “adequate allowance for uncertainty in the methodology, data, and bias to assure subcriticality.” However, there has been almost no guidance on how to determine an appropriate MMS. Partly due to the lack of historical guidance, and partly due to differences between facilities’ processes and methods of calculation, there have been significantly different MMS values approved for the various fuel cycle facilities over time. In addition, the different ways licensees have of defining margins and calculating k_{eff} limits have made a consistent approach to reviewing k_{eff} limits difficult. Recent licensing experience has highlighted the need for further guidance to clarify what constitutes an acceptable justification for the MMS.

The MMS can have a substantial effect on facility operations (e.g., storage capacity, throughput) and there has, therefore, been considerable recent interest in decreasing margin in k_{eff} below what has been licensed previously. In addition, the increasing sophistication of computer codes and the ready availability of computing resources means that there has been a gradual move towards more realistic (often resulting in less conservative) modeling of process systems. These two factors–the increasing interest in reducing the MMS and the reduction in modeling conservatism–make technical justification of the MMS more risk-significant than it has been in the past. In general, consistent with a risk-informed approach to regulation, a smaller MMS requires a more substantial technical justification.

This ISG is only applicable to fuel enrichment and fabrication facilities licensed under 10 CFR Part 70.

Discussion

This guidance is applicable to evaluating the MMS in methods of evaluation that rely on calculation of k_{eff}. The k_{eff} value of a fissionable system depends, in general, on a large number of physical variables. The factors that can affect the calculated value of k_{eff} may be broadly divided into the following categories: (1) the geometric configuration; (2) the material composition; and (3) the neutron distribution. The geometric form and material composition of the system determine–together with the underlying nuclear data (e.g., ν, χ(E), cross section data)–the spatial and energy distribution of neutrons in the system (flux and energy spectrum). An error in the nuclear data or the geometric or material modeling of these systems can produce an error in the neutron flux and energy spectrum, and thus in the calculated value of k_{eff}. The bias associated with a single system is defined as the difference between the calculated and physical values of k_{eff}, by the following equation:

$$\beta = k_{calc} - k_{physical}$$

Thus, determining the bias requires knowing both the calculated and physical k_{eff} values of the system. The bias associated with a single critical experiment can be known with a high degree of confidence, because the physical (experimental) value is known *a priori* ($k_{physical}$. 1). However, for calculations performed to demonstrate subcriticality of facility processes (to be referred to as “applications”), this is not generally the case. The bias associated with such an application (i.e., not a known critical configuration) is not typically known with this same high degree of confidence, because the actual physical k_{eff} of the system is usually not known. In

practice, the bias is determined as the average calculated k_{eff} for a set of experiments that cover different aspects of the licensee's applications. The bias and its uncertainty must be estimated by calculating the bias associated with a set of critical experiments having geometric forms, material compositions, and neutron spectra similar to those of the application. Because of the large number of factors that can affect the bias, and the finite number of critical experiments available, staff should recognize that this is only an estimate of the true bias of the system. The experiments analyzed cannot cover all possible combinations of conditions or sources of error that may be present in the applications to be evaluated. The effect on k_{eff} of geometric, material, or spectral differences between critical experiments and applications cannot be known with precision. Therefore, an additional margin (MMS) must be applied to allow for the effects of any unknown uncertainties that may exist in the calculated value of k_{eff} beyond those accounted for in the calculation of the bias and its uncertainty. As the MMS decreases, there needs to be a greater level of assurance that the various sources of bias and uncertainty have been taken into account, and that the bias and uncertainty are known with a high degree of accuracy. In general, the more similar the critical experiments are to the applications, the more confidence there is in the estimate of the bias and the less MMS is needed.

In determining an appropriate MMS, the reviewer should consider the specific conditions and process characteristics present at the facility in question. However, the MMS should not be reduced below 0.02. The nuclear cross sections are not generally known to better than - 1-2%, and thus it is not possible to have a greater level of assurance in the calculated results than this. Moreover, errors in the criticality codes have been discovered over time that have produced k_{eff} differences of roughly this same magnitude of 1-2% (e.g., Information Notice 2005-13, "Potential Non-Conservative Error in Modeling Geometric Regions in the KENO-V.a Criticality Code").

Staff should recognize the important distinction between ensuring that processes are safe and ensuring that they are adequately subcritical. The value of k_{eff} is a direct indication of the degree of subcriticality of the system, but is not fully indicative of the degree of safety. A system that is very subcritical (i.e., with k_{eff} «1) may have a small margin of safety if a small change in a process parameter can result in criticality. An example of this would be a UO_2 powder storage vessel, which is subcritical when dry, but may require only the addition of water for criticality. Similarly, a system with a small MoS (i.e., with k_{eff} - 1) may have a very large margin of safety if it cannot credibly become critical. An example of this would be a natural uranium system in light water, which may have a k_{eff} value close to 1 but will never exceed 1. Because of this, a distinction should be made between the *margin of subcriticality* and the *margin of safety*. Although a variety of terms are in use in the nuclear industry, the term *margin of subcriticality* will be taken to mean the difference between the actual (physical) value of k_{eff} and the value of k_{eff} at which the system is expected to be critical. The term *margin of safety* will be taken to mean the difference between the actual value of a parameter and the value of the parameter at which the system is expected to be critical. The appropriate MMS depends only on the confidence that applications calculated to be subcritical will be subcritical. It does not depend on other aspects of the process (e.g., safety of the process or the ability to control parameters within certain bounds) that may need to be reviewed as part of an overall licensing review.

There are a variety of different approaches that a licensee could choose in justifying the MMS. Some of these approaches and means of reviewing them are described in the following sections, in no particular preferential order. Many of these approaches consist of qualitative

arguments, and therefore there will be some degree of subjectivity in determining the adequacy of the MMS. Because the MMS is an allowance for unknown (or difficult to identify or quantify) errors, the reviewer must ultimately exercise his or her best judgement in determining whether a specific MMS is justified. Thus, the topics listed below should be regarded as factors the reviewer should take into consideration in exercising that judgement, rather than any kind of prescriptive checklist.

The reviewer should also bear in mind that the licensee is not required to use any or all of these approaches, but may choose an approach that is applicable to its facility or a particular process within its facility. While it may be desirable and convenient to have a single k_{eff} limit or MMS value (and single corresponding justification) across an entire facility, it is not necessary for this to be the case. The MMS may be easier to justify for one process than for another, or for a limited application versus generically for the entire facility. The reviewer should expect to see various combinations of these approaches, or entirely different approaches, used, depending on the nature of the licensee's processes and methods of calculation. Any approach used must ultimately lead to a determination that there is adequate assurance of subcriticality.

(1) Conservatism in the Calculational Models

The margin in k_{eff} produced by the licensee's modeling practices, together with the MMS, provide the margin between actual conditions and expected critical conditions. In terms of the subcriticality criterion taken from ANSI/ANS-8.17-1984 (R1997), "Criticality Safety Criteria for theHandling, Storage, and Transportation of LWR Fuel Outside Reactors" (as explained in Appendix A):

$$MoS \geq \Delta k_m + \Delta k_{sa}$$

where Δk_m is the MMS and Δk_{sa} is the margin in k_{eff} due to conservative modeling of the system (i.e., conservative values of system parameters).

Two different applications for which the sums on the right hand side of the equation above are equal to each other are equally subcritical. Assurance of subcriticality may thus be provided by specifying a margin in k_{eff} (Δk_m), or specifying conservative modeling practices (Δk_{sa}), or some combination thereof. This principle will be particularly useful to the reviewer evaluating a proposed reduction in the currently approved MMS; the review of such a reduction should prove straightforward in cases in which the overall combination of modeling conservatism and MMS has not changed. Because of this straightforward quantitative relationship, any modeling conservatism that has not been previously credited should be considered before examining other factors. Cases in which the overall MoS has decreased may still be acceptable, but would have to be justified by other means.

In evaluating justification for the MMS relying on conservatism in the model, the reviewer should consider only that conservatism in excess of any manufacturing tolerances, uncertainties in system parameters, or credible process variations. That is, the conservatism should consist of conservatism beyond the worst-case normal or abnormal conditions, as appropriate, including allowance for any tolerances. Examples of this added conservatism may include assuming optimum concentration in solution processes, neglecting neutron absorbers in structural materials, or requiring minimum reflector conditions (e.g., at least a 1-inch, tight-fitting reflector around process equipment). These technical practices used to perform criticality calculations generally result in conservatism of at least several percent in k_{eff}. To credit this as part of the

justification for the MMS, the reviewer should have assurance that the modeling practices described will result in a predictable and dependable amount of conservatism in k_{eff}. In some cases, the conservatism may be process-dependent, in which case it may be relied on as justification for the MMS for a particular process. However, only modeling practices that result in a global conservatism across the entire facility should be relied on as justification for a site-wide MMS. Ensuring predictable and dependable conservatism includes verifying that this conservatism will be maintained over the facility lifetime, such as through the use of license commitments or conditions.

If the licensee has a program that establishes operating limits (to ensure that subcritical limits are not exceeded) below subcritical limits determined in nuclear criticality safety evaluations, the margin provided by this (optional) practice may be credited as part of the conservatism. In such cases, the reviewer should credit only the difference between operating and subcritical limits that exceeds any tolerances or process variation, and should ensure that operating limits will be maintained over the facility lifetime, through the use of license commitments or conditions.

Some questions that the reviewer may ask in evaluating the use of modeling conservatism as justification for the MMS include:

- How much margin in k_{eff} is provided due to conservatism in modeling practices?
- How much of this margin exceeds allowance for tolerances and process variations?
- Is this margin specific to a particular process or does it apply to all facility processes?
- What provides assurance that this margin will be maintained over the facility lifetime?

(2) Validation Methodology and Results

Assurance of subcriticality for methods that rely on the calculation of k_{eff} requires that those methods be appropriately validated. One of the goals of validation is to determine the method's bias and the uncertainty in the bias. After this has been done, an additional margin (MMS) is specified to account or any additional uncertainties that may exist. The appropriate MMS depends, in part, on the degree of confidence in the validation results. Having a high degree of confidence in the bias and bias uncertainty requires both that there be sufficient (for the statistical method used) applicable benchmark-quality experiments and that there be a rigorous validation methodology. If either the data or the methodology is deficient, a high degree of confidence in the results cannot be attained, and a larger MMS may need to be employed than would otherwise be acceptable. Therefore, although validation and determining the MMS are separate exercises, they are related. The more confidence one has in the validation results, the less additional margin (MMS) is needed. The less confidence one has in the validation resutls, the more MMS is needed.

Any review of a licensing action involving the MMS should involve examination of the licensee's validation methodology and results. While there is no clear quantifiable relationship between the validation and MMS (as exists with modeling conservatism), several aspects of validation should be considered before making a qualitative determination of the adequacy of the MMS.

There are four factors that the reviewer should consider in evaluating the validation: (1) the

similarity of benchmark experiments to actual applications; (2) sufficiency of the data (including the number and quality of experiments); (3) adequacy of the validation methodology; and (4) conservatism in the calculation of the bias and its uncertainty. These factors are discussed in more detail below.

Similarity of Benchmark Experiments

Because the bias and its uncertainty must be estimated based on critical experiments having similar geometric form, material composition, and neutronic behavior to specific applications, the degree of similarity between the critical experiments and applications is a key consideration in determining the appropriateness of the MMS. The more closely critical experiments represent the characteristics of applications being validated, the more confidence the reviewer has in the estimate of the bias and the bias uncertainty for those applications.

The reviewer must understand both the critical experiments and applications in sufficient detail to ascertain the degree of similarity between them. Validation reports generally contain a description of critical experiments (including source references). The reviewer may need to consult these references to understand the physical characteristics of the experiments. In addition, the reviewer may need to consult process descriptions, nuclear criticality safety evaluations, drawings, tables, input files, or other information to understand the physical characteristics of applications. The reviewer must consider the full spectrum of normal and abnormal conditions that may have to be modeled when evaluating the similarity of the benchmarks to applications.

In evaluating the similarity of experiments to applications, the reviewer must recognize that some parameters are more significant than others to accurately calculate k_{eff}. The parameters that have the greatest effect on the calculated k_{eff} of the system are those that are most important to match when choosing critical experiments. Because of this, there is a close relationship between similarity of benchmarks to applications and system sensitivity. Historically, certain parameters have been used to trend the bias because these are the parameters that have been found to have the greatest effect on the bias. These parameters include the moderator-to-fuel ratio (e.g., H/U, H/X, v^m/v^f), isotopic abundance (e.g., uranium-235 (^{235}U), plutonium-239 (^{239}Pu), or overall Pu-to-uranium ratio), and parameters that characterize the neutron energy spectrum (e.g., energy of average lethargy causing fission (EALF), average energy group (AEG)). Other parameters, such as material density or overall geometric shape, are generally considered to be of less importance. The reviewer should consider all important system characteristics that can reasonably be supposed to affect the bias. For example, the critical experiments should include any materials that can have an appreciable effect on the calculated k_{eff}, so that the effect due to the cross sections of those materials is included in the bias. Furthermore, these materials should have at least the same reactivity worth in the experiments (which may be evidenced by having similar number densities) as in the applications. Otherwise, the effect of any bias from the underlying cross sections or the assumed material composition may be masked in the applications. It is also important that the materials be present in a statistically significant number of experiments having similar neutron spectra to the application. Conversely, materials that do not have an appreciable effect on the bias may be neglected and would not have to be represented in the critical experiments.

Merely having critical experiments that are representative of applications is the minimum acceptance criterion, and does not alone justify having any particular value of the MMS. There are some situations, however, in which there is an unusually high degree of similarity between

the critical experiments and applications, and in these cases, this fact may be credited as justification for having a smaller MMS than would otherwise be acceptable. If the critical experiments have geometric forms, material compositions, and neutron spectra that are nearly indistinguishable from those of the applications, this may be justification for reducing the MMS. For example, justification for having a small MMS for finished fuel assemblies could include selecting critical experiments consisting of fuel assemblies in water, where the fuel has nearly the same pellet diameter, pellet density, cladding materials, pitch, absorber content, enrichment, and neutron energy spectrum as the licensee's fuel. In this case, the validation should be very specific to this type of system, because including other types of benchmark experiments could mask variations in the bias. Therefore, this type of justification is generally easiest when the area of applicability (AOA) is very narrowly defined. The reviewer should pay particular attention to abnormal conditions. In this example, damage to the fuel or partial flooding may significantly affect the applicability of the critical experiments.

There are several tools available to the reviewer to ascertain the degree of similarity between critical experiments and applications. Some of these are listed below:

1. NUREG/CR-6698, "Guide to Validation of Nuclear Criticality Safety Calculational Method," Table 2.3, contains a set of screening criteria for determining benchmark applicability. As is stated in the NUREG, these criteria were arrived at by consensus among experienced nuclear criticality safety specialists and may be considered to be conservative. The reviewer should consider agreement on all screening criteria to be justification for demonstrating a very high degree of benchmark similarity. (Agreement on the most significant screening criteria for a particular system should be considered as demonstration of an acceptable degree of benchmark similarity.) Less conservative (i.e., broader) screening criteria may also be acceptable, if appropriately justified.

2. Analytical methods that systematically quantify the degree of similarity between a set of critical experiments and applications in pair-wise fashion may be used. One example of this is the TSUNAMI code in the SCALE 5 code package. One strength of TSUNAMI is that it calculates an overall correlation that is a quantitative measure of the degree of similarity between an experiment and an application. Another strength is that this code considers all the nuclear phenomena and underlying cross sections and weights them by their importance to the calculated k_{eff} (i.e., sensitivity of k_{eff} to the data). The NRC staff currently considers a correlation coefficient of c_k / 0.95 to be indicative of a very high degree of similarity. This is based on the staff's experience comparing the results from TSUNAMI to those from a more traditional screening criterion approach. Conversely, a correlation coefficient less than 0.90 should not be used as a demonstration of a high degree of benchmark similarity. Because of limited use of the code to date, these observations should be considered tentative and thus the reviewer should not use TSUNAMI as a "black box," or base conclusions of adequacy solely on its use. However, it may be used to test a licensee's statement that there is a high degree of similarity between experiments and applications.

3. Traditional parametric sensitivity studies may be employed to demonstrate that k_{eff} is highly sensitive or insensitive to a particular parameter. For example, if a 50% reduction in the ^{10}B cross section is needed to produce a 1% change in the system k_{eff}, then it can be concluded that the system is highly insensitive to the boron content, in the amount present. This is because a credible error in the ^{10}B cross section of a few percent will have a statistically insignificant effect on the bias. Therefore, in the amount present, the

boron content is not a parameter that is important to match in order to conclude that there is a high degree of similarity between benchmarks and applications.

4. Physical arguments may demonstrate that k_{eff} is highly sensitive or insensitive to a particular parameter. For example, the fact that oxygen and fluorine are almost transparent to thermal neutrons (i.e., cross sections are very low) may justify why experiments consisting of UO_2F_2 may be considered similar to UO_2 or UF_4 applications, provided that both experiments and applications occur in the thermal energy range.

The reviewer should ensure that all parameters which can measurably affect the bias are considered when assessing benchmark similarity. For example, comparison should not be based solely on agreement in the ^{235}U fission spectrum for systems in which the system k_{eff} is highly sensitive to ^{238}U fission, ^{10}B absorption, or ^{1}H scattering. A method such as TSUNAMI that considers the complete set of reactions and nuclides present can be used to rank the various system sensitivities, and to thus determine whether it is reasonable to rely on the fission spectrum alone in assessing the similarity of benchmarks to applications.

Some questions that the reviewer may ask in evaluating reliance on benchmark similarity as justification for the MMS include:

- Do the benchmarks cover all geometric forms, material compositions, and neutron energy spectra expected in applications?

- Are the materials present with at least the same reactivity worth as in applications?

- Do the licensee’s criteria for determining whether experiments are sufficiently similar to applications consider all nuclear reactions and nuclides that could affect the bias?

Sufficiency of the Data

Another aspect of evaluating the selected benchmarks for a specific MMS is ensuring that there is a sufficient number of benchmark quality experiments to determine the bias across the entire AOA. Having a sufficient number of benchmark-quality experiments means that: (1) there are enough (applicable) experiments to make a statistically meaningful calculation of the bias and its uncertainty; (2) the experiments somewhat evenly span the entire range of all the important parameters, without gaps requiring extrapolation or wide interpolation; and (3) the experiments are all benchmark-quality experiments. The number of benchmarks needed is dependent on the statistical method used to analyze the data. For example, some methods require a minimum number of data points to reliably determine whether the data are normally distributed. Merely having a large number of experiments is not sufficient to provide confidence in the validation result, if the experiments are not applicable to the application. The reviewer should particularly examine whether consideration of only the most applicable experiments would result in a larger negative bias (and thus a lower USL) than that determined based on the full set of experiments. The experiments should also be sufficiently well-characterized (including experimental parameters and their uncertainties) to be considered benchmark experiments. They should be drawn from established sources (such as from the International Handbook of Evaluated Criticality Safety Benchmark Experiments (IHECSBE), laboratory reports, or peer-reviewed journals).

Some questions that the reviewer may ask in evaluating the number and quality of benchmark

experiments as justification for the MMS include:

- Are the critical experiments chosen all high-quality benchmarks from reliable (e.g., peer-reviewed and widely-accepted) sources?
- Are the critical experiments chosen taken from multiple independent sources, to minimize the possibility of systematic errors?
- Have the experimental uncertainties associated with the critical experiments been provided and used in calculating the bias and bias uncertainty?
- Is the number and distribution of critical experiments sufficient to establish trends in the bias across the entire range of parameters?
- Is the number of critical experiments commensurate with the statistical methodology being used?

Validation Methodological Rigor

Having a sufficiently rigorous validation methodology means having a methodology that is appropriate for the number and distribution of critical experiments, that calculates the bias and its uncertainty using an established statistical methodology, that accounts for any trends in the bias, and that accounts for all apparent sources of uncertainty in the bias (e.g., the increase in uncertainty due to extrapolating the bias beyond the range covered by the benchmark data.) Examples of deficiencies in the validation methodology may include: (1) using a statistical methodology relying on the data being normally distributed about the mean k_{eff} to analyze data that are not normally distributed; (2) using a linear regression fit on data that has a non-linear dependence on a trending parameter; (3) use of a single pooled bias when very different types of critical experiments are being evaluated in the same validation. These deficiencies serve to decrease confidence in the validation results and may warrant additional margin (i.e., a larger MMS). Additional guidance on some of the more commonly observed deficiencies is provided below.

The assumption that data is normally distributed is generally valid, unless there is a strong trend in the data or different types of critical experiments with different mean calculated k_{eff} values are being combined. Tests for normality require a minimum number of critical experiments to attain a specified confidence level (generally 95%). If there is insufficient data to verify that the data are normally distributed, or the data are shown to be not normally distributed, a non-parametric technique should be used to analyze the data.

The critical experiments chosen should provide a continuum of data across the entire validated range, so that any variation in the bias as a function of important system parameters may be observed. The presence of discrete clusters of experiments having a lower calculated k_{eff} than the set of critical experiments as a whole should be examined closely, to determine if there is some systematic effect common to a particular type of calculation that makes use of the overall bias non-conservative. Because the bias can vary with system parameters, if the licensee has combined different subsets of data (e.g., solutions and powders, low- and high-enriched, homogeneous and heterogeneous), the bias for the different subsets should be analyzed. In addition, the goodness-of-fit for any function used to trend the bias should be examined to ensure it is appropriate to the data being analyzed.

If critical experiments do not cover the entire range of parameters needed to cover anticipated applications, it may be necessary to extend the AOA by making use of trends in the bias. Any extrapolation (or wide interpolation) of the data should be done by means of an established mathematical methodology that takes into account the functional form of both the bias and its uncertainty. The extrapolation should not be based on judgement alone, such as by observing that the bias is increasing in the extrapolated range, because this may not account for the increase in the bias uncertainty that will occur with increasing extrapolation. The reviewer should independently confirm that the derived bias is still valid in the extrapolated range and should ensure that the extrapolation is not large. NUREG/CR-6698 states that critical experiments should be added if the data must be extrapolated more than 10%. If the extrapolation is too large, new factors that could affect the bias may be introduced as the physical phenomena in the system change. The reviewer should not view validation as a purely mathematical exercise, but should bear in mind the neutron physics and underlying physical phenomena when interpreting the results.

Discarding an unusually large number of critical experiments as outliers (i.e., more than 1-2%) should also be viewed with some concern. Apparent outliers should not be discarded based purely upon judgement or statistical grounds (such as causing the data to fail tests for normality), because they could be providing valuable information on the method's validity for a particular application. The reviewer should verify that there are specific defensible reasons, such as reported inconsistencies in the experimental data, for discarding any outliers. If any of the critical experiments from a particular data set are discarded, the reviewer should examine other experiments included to determine whether they may be subject to the same systematic errors. Outliers should be examined carefully especially when they have a lower calculated k_{eff} than the other experiments included.

NUREG-1520 states that the MoS should be large compared to the uncertainty in the bias. The observed spread of the data about the mean k_{eff} should be examined as an indicator of the overall precision of the calculational method. The reviewer should ascertain whether the statistical method of validation considers both the observed spread in the data and the experimental and calculational uncertainty in determining the USL. The reviewer should also evaluate whether the observed spread in the data is consistent with the reported uncertainty (e.g., whether χ^2/N . 1). If the spread in the data is larger than or comparable to the MMS, then the reviewer should consider whether additional margin (i.e., a larger MMS) is needed.

As a final test of the code's accuracy, the bias should be relatively small (i.e., bias . 2 percent), or else the reason for the bias should be determined. No credit should be taken for positive bias, because this would result in making changes in a non-conservative direction without having a clear understanding of those changes. If the absolute value of the bias is very large–and especially if the reason for the large bias cannot be determined–this may indicate that the calculational method is not very accurate, and a larger MMS may be appropriate.

Some questions that the reviewer may ask in evaluating the rigor of the validation methodology as justification for the MMS include:

- Are the results from use of the methodology consistent with the data (e.g., normally distributed)?

- Is the normality of the data confirmed prior to performing statistical calculations? If the data does not pass the tests for normality, is a non-parametric method used?

- Does the assumed functional form of the bias represent a good fit to the critical experiments? Is a goodness-of-fit test performed?

- Does the method determine a pooled bias across disparate types of critical experiments, or does it consider variations in the bias for different types of experiments? Are there discrete clusters of experiments for which the bias appears to be non-conservative?

- Has additional margin been applied to account for extrapolation or wide interpolation? Is this done based on an established mathematical methodology?

- Have critical experiments been discarded as apparent outliers? Is there a valid reason for doing so?

Performing an adequate code validation is not by itself sufficient justification for any specific MMS. The reason for this is that the validation analysis determines the bias and its uncertainty, but not the MMS. The MMS is added after the validation has been performed to provide added assurance of subcriticality. However, having a validation methodology that either exceeds or falls short of accepted standards for validation may be a basis for either reducing or increasing the MMS.

Statistical Conservatism

In addition to having conservatism in k_{eff} due to modeling practices, licensees may also provide conservatism in the statistical methods used to calculate the USL. For example, NUREG/CR-6698 states that an acceptable method for calculating the bias is to use the single-sided tolerance limit approach with a 95/95 confidence (i.e., 95% confidence that 95% of all future critical calculations will lie above the USL). If the licensee decides to use the single-sided tolerance limit approach with a 95/99.9 confidence, this would result in a more conservative USL than with a 95/95 confidence. This would be true of other methods for which the licensee's confidence criteria exceeds the minimum accepted criteria. Generally, the NRC has accepted 95% confidence levels for validation results, so using more stringent confidence levels may provide conservatism. In addition, there may be other reasons a larger bias and/or bias uncertainty than necessary has been used (e.g., because of the inclusion of inapplicable benchmark experiments that have a lower calculated k_{eff}).

The reviewer may credit this conservatism towards having an adequate MoS if: (1) the licensee demonstrates that this translates into a specific Δk_{eff}; and (2) the licensee demonstrates that the margin will be dependably present, based on license or other commitments.

(3) Additional Risk-Informed Considerations

Besides modeling conservatism and the validation results, other factors may provide added assurance of subcriticality. These factors should be considered in evaluating whether there is adequate MoS and are discussed below.

System Sensitivity and Uncertainty

The sensitivity of k_{eff} to changes in system parameters can be used to assess the potential effect of errors on the calculation of k_{eff}. If the calculated k_{eff} is especially sensitive to a given

parameter, an error in that parameter could have a correspondingly large contribution to the bias. Conversely, if k_{eff} is very insensitive to a given parameter, then an error may have a negligible effect on the bias. This is of particular importance when assessing whether the chosen critical experiments are sufficiently similar to applications to justify a small MMS.

The reviewer should not consider the sensitivity in isolation, but should also consider the magnitude of uncertainties in the parameters. If k_{eff} is very sensitive to a given parameter, but the value of that parameter is known with very high accuracy (and its variations are well-controlled), the potential contribution to the bias may still be very small. Thus, the contribution to the bias is a function of the product of the the k_{eff} sensitivity with the uncertainty. To illustrate this, suppose that k_{eff} is a function of a large number of variables, x_1, x_2,..., x_N. Then the uncertainty in k_{eff} may be expressed as follows, if all the individual terms are independent:

$$\delta k^2 = \sum_{i=1}^{N} \left(\frac{\partial k}{\partial x_i} \right)^2 \delta x_i^2$$

where the partial derivatives $\partial k/\partial x_i$ are proportional to the sensitivity and the terms δx_i represent the uncertainties, or likely variations, in the parameters. Each term in this equation then represents the contribution to the overall uncertainty in k_{eff}.

There are several tools available to the reviewer to ascertain the sensitivity of k_{eff} to changes in the underlying parameters. Some of these are listed below:

1. Analytical tools that calculate the sensitivity for each nuclide-reaction pair present in the problem may be used. One example of this is the TSUNAMI code in the SCALE 5 code package. TSUNAMI calculates both an integral sensitivity coefficient (i.e., summed over all energy groups) and a sensitivity profile as a function of energy group. The reviewer should recognize that TSUNAMI only calculates the k_{eff} sensitivity to changes in the underlying nuclear data, and not to other parameters that could affect the bias and should be considered. (See section on Benchmark Similarity for caveats about using TSUNAMI.)

2. Direct sensitivity calculations may be used, in which system parameters are perturbed and the resulting impact on k_{eff} determined. Perturbation of atomic number densities can also be used to confirm the sensitivity calculated by other methods (e.g., TSUNAMI). Such techniques are not limited to considering the effect of the nuclear data.

There are also several sources available to the reviewer to ascertain the uncertainty associated with the underlying parameters. For process parameters, these sources of uncertainty may include manufacturing tolerances, quality assurance records, and experimental and/or measurement results. For nuclear data parameters, these sources of uncertainty may include published data, uncertainty data distributed with the cross section libraries, or the covariance data used in methods such as TSUNAMI.

Some systems are inherently more sensitive to changes in the underlying parameters than others. For example, high-enriched uranium systems typically exhibit a greater sensitivity to changes in system parameters (e.g., mass, moderation) than low-enriched systems. This has

been the reason that HEU (i.e., >20wt% ^{235}U) facilities have been licensed with larger MMS values than LEU (#10wt% ^{235}U) facilities. This greater sensitivity would also be true of weapons-grade Pu compared to low-assay mixed oxides (i.e., with a few percent Pu/U). However, it is also true that the uncertainties associated with measurement of the ^{235}U cross sections are much smaller than those associated with measurement of the ^{238}U cross sections. Both the greater sensitivity and smaller uncertainty would need to be considered in evaluating whether a larger MMS is needed for high-enriched systems.

Frequently, operating limits that are more conservative than safety limits determined using k_{eff} calculations are established to prevent those safety limits from being exceeded. For systems in which k_{eff} is very sensitive to the system parameters, more margin between the operating and safety limits may be needed. Systems in which k_{eff} is very sensitive to the process parameters may need both a larger margin between operating and safety limits and a larger MMS. This is because the system is sensitive to any change, whether it be caused by normal process variations or caused by unknown errors. Because of this, the assumption is often made that the MMS is meant to account for variations in the process or the ability to control the process parameters. However, the MMS is meant only to allow for unknown (or difficult to quantify) uncertainties in the calculation of k_{eff}. The reviewer should recognize that determination of an appropriate MMS is not dependent on the ability to control process parameters within safety limits (although both may depend on the system sensitivity).

Some questions that the reviewer may ask in evaluating the system sensitivity as justification for the MMS include:

- How sensitive is k_{eff} to changes in the underlying nuclear data (e.g., cross sections)?
- How sensitive is k_{eff} to changes in the geometric form and material composition?
- Are the uncertainties associated with these underlying parameters well-known?
- How does the MMS compare to the expected magnitude of changes in k_{eff} resulting from uncertainties in these underlying parameters?

Knowledge of the Neutron Physics

Another important consideration that may affect the appropriate MMS is the extent to which the physical behavior of the system is known. Fissile systems which are known to be subcritical with a high degree of confidence do not require as much MMS as systems where subcriticality is less certain. An example of a system known to be subcritical with high confidence is a light-water reactor fuel assembly. The design of these systems is such that they can only be made critical when highly thermalized. Due to extensive analysis and reactor experience, the flooded isolated assembly is known to be subcritical. In addition, the thermal neutron cross sections for materials in finished reactor fuel have been measured with a very high degree of accuracy (as opposed to cross sections in the resonance region). Other examples of systems in which there is independent corroborating evidence of subcriticality may include systems consisting of very simple geometric shapes, or other idealized situations, in which there is strong evidence that the system is subcritical based on comparison with highly similar systems in published sources (e.g., standards and handbooks). In these cases, the MMS may be significantly reduced due to the fact that the calculation of k_{eff} is not relied on alone to provide assurance of subcriticality.

Reliance on independent knowledge that a given system is subcritical necessarily requires that the configuration of the system be fixed. If the configuration can change from the reference case, there will be less knowledge about the behavior of the changed system. For example, a finished fuel assembly is subject to strict quality assurance checks and would not reach final processing if it were outside of specifications. In addition, it has a form that has both been extensively studied and is highly stable. For these reasons, there is a great deal of certainty that this system is well-characterized and is not subject to change. A typical solution or powder system (other than one with a simple geometric arrangement) would not have been studied with the same level of rigor as a finished fuel assembly. Even if they were studied with the same level of rigor, these systems have forms that are subject to change into forms whose neutron physics has not been as extensively studied.

Some questions that the reviewer may ask in evaluating the knowledge of the neutron physics as justification for the MMS include:

- Is the geometric form and material composition of the system rigid and unchanging?
- Is the geometric form and material composition of the system subject to strict quality assurance, such that tolerances have been bounded?
- Has the system been extensively studied in the nuclear industry and shown to be subcritical (e.g., in reactor fuel studies)?
- Are there other reasons besides criticality calculations to conclude that the system will be subcritical (e.g., handbooks, standards, published data)?
- How well-known is the nuclear data (e.g., cross sections) in the energy range of interest?

Likelihood of the Abnormal Condition

Some facilities been licensed with different sets of k_{eff} limits for normal and abnormal conditions. Separate k_{eff} limits for normal and abnormal conditions are permissible but are not required. There is some likelihood that processes calculated to be subcritical will in fact be critical, and this likelihood increases as the MMS is reduced (though it cannot in general be quantified). NUREG-1718, “Standard Review Plan for the Review of an Application for a Mixed Oxide (MOX) Fuel Fabrication Facility,” states that abnormal conditions should be at least unlikely from the standpoint of the double contingency principle. Then, a somewhat higher likelihood that a system calculated to be subcritical is in fact critical is more permissible for abnormal conditions than for normal conditions, because of the low likelihood of the abnormal condition being realized. The reviewer should verify that the licensee has defined abnormal conditions such that achieving the abnormal condition requires at least one contingency to have occurred, that the system will be closely monitored so that it is promptly detected, and that it will be promptly corrected upon detection. It is also true that there is generally more conservatism present in the abnormal case, because the parameters that are assumed to have failed are analyzed at their worst-case credible condition.

The increased risk associated with having a smaller MMS for abnormal conditions should be commensurate with and offset by the low likelihood of achieving the abnormal condition. That is, if the normal case k_{eff} limit is judged to be acceptable, then the abnormal case limit will also

be acceptable, provided the increased likelihood (that a system calculated to be subcritical will be critical) is offset by the reduced likelihood of realizing the abnormal condition because of the controls that have been established. Note that if two or more contingencies must occur to reach a given condition, there is no requirement to ensure that the resulting condition is subcritical. If a single k_{eff} limit is used (i.e., no credit for unlikelihood of the abnormal condition), then the limit must be found acceptable to cover both normal and credible abnormal conditions. The reviewer should always make this finding considering specific conditions and controls in the process(es) being evaluated.

(4) Statistical Justification for the MMS

The NRC does not consider statistical justification an appropriate basis for a specific MMS. Previously, some licensees have attempted to justify specific MMS values based on a comparison of two statistical methods. For example, the USLSTATS code issued with the SCALE code package contains two methods for calculating the USL: (1) the Confidence Band with Administrative Margin approach (calculating USL-1), and (2) the Lower Tolerance Band approach (calculating USL-2). The value of the MMS is an input parameter to the Confidence Band approach, but is not included explicitly in the Lower Tolerance Band approach. In this particular justification, adequacy of the MMS is based on a comparison of USL-1 and USL-2 (i.e., the condition that USL-1, including the chosen MMS, is less than USL-2). However, the reviewer should not accept this justification.

The condition that USL-1 (with the chosen MMS) is less than USL-2 is necessary, but is not sufficient, to show that an adequate MMS has been used. These methods are both statistical methods, and a comparison can only demonstrate whether the MMS is sufficient to bound any statistical uncertainties included in the Lower Tolerance Band approach but not included in the Confidence Band approach. There may be other statistical or systematic errors in calculating k_{eff} that are not included in either statistical treatment. Because of this, an MMS value should be specified regardless of the statistical method used. Therefore, the reviewer should not consider such a statistical approach an acceptable justification for any specific value of the MMS.

(5) Summary

Based on a review of the licensee's justification for its chosen MMS, taking into consideration the aforementioned factors, the staff should make a determination as to whether the chosen MMS provides reasonable assurance of subcriticality under normal and credible abnormal conditions. The staff's review should be risk-informed, in that the review should be commensurate with the MoS and should consider the specific facility and process characteristics, as well as the specific modeling practices used. As an example, approving an MMS value greater than 0.05 for processes typically encountered in enrichment and fuel fabrication facilities should require only a cursory review, provided that an acceptable validation has been performed and modeling practices at least as conservative as those in NUREG-1520 have been utilized. The approval of a smaller MMS will require a somewhat more detailed review, commensurate with the MMS that is requested. However, the MMS should not be reduced below 0.02 due to inherent uncertainties in the cross section data and the magnitude of code errors that have been discovered. Quantitative arguments (such as modeling conservatism) should be used to the extent practical. However, in many instances, the reviewer will need to make a judgement based at least partly on qualitative arguments. The staff should document the basis for finding the chosen MMS value to be acceptable or unacceptable in the

SER, and should ensure that any factors upon which this determination rests are ensured to be present over the facility lifetime (e.g., through license commitment or condition).

Regulatory Basis

In addition to complying with paragraphs (b) and (c) of this section, the risk of nuclear criticality accidents must be limited by assuring that under normal and credible abnormal conditions, all nuclear processes are subcritical, including use of an approved margin of subcriticality for safety. [10 CFR 70.61(d)]

Technical Review Guidance

Determination of an adequate MMS is strongly dependent upon specific processes, conditions, and calculational practices at the facility being licensed. Judgement and experience must be employed in evaluating the adequacy of the proposed MMS. In the past, an MMS of 0.05 has generally been found acceptable for most typical low-enriched fuel cycle facilities without a detailed technical justification. A smaller MMS may be acceptable but will require some level of technical review. However, for reasons stated previously, the MMS should not be reduced below 0.02.

An MMS of 0.05 should be found acceptable for low-enriched fuel cycle processes and facilities if:

1. A validation has been performed that meets accepted industry guidelines (e.g., meets the requirements of ANSI/ANS-8.1-1998, NUREG/CR-6361, and/or NUREG/CR-6698).

2. There is an acceptable number of benchmark experiments with similar geometric forms, material compositions, and neutron energy spectra to applications. These experiments cover the range of parameters of applications, or else margin is provided to account for extensions to the AOA.

3. The processes to be evaluated include materials and process conditions similar to those that occur in low-enriched fuel cycle applications (i.e., no new fissile materials, unusual moderators or absorbers, or technologies new to the industry that can affect the types of systems to be modeled).

The reviewer should consider any factors, including those enumerated in the discussion above, that could result in applying additional margin (i.e., a larger MMS) or may justify reducing the MMS. The reviewer must then exercise judgement in arriving at an MMS that provides for adequate assurance of subcriticality.

Some of the factors that may serve to justify reducing the MMS include:

1. There is a predictable and dependable amount of conservatism in modeling practices, in terms of k_{eff}, that is assured to be maintained (in both normal and abnormal conditions) over the facility lifetime.

2. Benchmark experiments have nearly identical geometric forms, material compositions, and neutron energy spectra to applications, and the validation is specific to this type of application.

3. The validation methodology substantially exceeds accepted industry guidelines (e.g., it uses a very conservative statistical approach, considers an unusually large number of trending parameters, or analyzes the bias for a large number of subgroups of critical experiments).

4. The system k_{eff} is demonstrably much less sensitive to uncertainties in cross sections or variations in other system parameters than typical low-enriched fuel cycle processes.

5. There is reliable information besides results of calculations that provides assurance that the evaluated applications will be subcritical (e.g., experimental data, historical evidence, industry standards or widely-accepted handbooks).

6. The MMS is only applied to abnormal conditions, which are at least unlikely to be achieved, based on credited controls.

Some of the factors that may necessitate increasing (or not approving) the MMS include:

1. The technical practices employed by the licensee are less conservative than standard industry modeling practices (e.g., do not adequately bound reflection or the full range of credible moderation, do not take geometric tolerances into account).

2. There are few similar critical experiments of benchmark quality that cover the range of parameters of applications.

3. The validation methodology substantially falls below accepted industry guidelines (e.g., it uses less than a 95% confidence in the statistical approach, fails to consider trends in the bias, fails to account for extensions to the AOA).

4. The validation results otherwise tend to cast doubt on the accuracy of the bias and its uncertainty (i.e., the critical experiments are not normally distributed, there is a large number of outliers discarded (/ 2%), there are distinct subgroups of experiments with lower k_{eff} than the experiments as a whole, trending fits do not pass goodness-of-fit tests, etc.).

5. The system k_{eff} is demonstrably much more sensitive to uncertainties in cross sections or other system parameters than typical low-enriched fuel cycle processes.

6. There is reliable information that casts doubt on the results of the calculational method or the subcriticality of evaluated applications (e.g., experimental data, reported concerns with the nuclear data).

The purpose of asking the questions in the individual discussion sections is to ascertain the degree to which these factors either provide justification for reducing the MMS or necessitate increasing the MMS. These lists are not all-inclusive, and any other technical information that demonstrates the degree of confidence in the calculational method should be considered.

Recommendation

The guidance in this ISG should supplement the current guidance in the nuclear criticality safety chapters of the fuel facility SRPs (NUREG-1520 and -1718). However, NUREG-1718, Section

6.4.3.3.4, states that the licensee should submit justification for the MMS, but then states that an MMS of 0.05 is “generally considered to be acceptable without additional justification when both the bias and its uncertainty are determined to be negligible.” These two statements are inconsistent. Therefore, NUREG-1718, Section 6.4.3.3.4, should be revised to remove the following sentence:

> “A minimum subcritical margin of 0.05 is generally considered to be acceptable without additional justification when both the bias and its uncertainty are determined to be negligible.”

References

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

ANSI/ANS-8.17-1984 (R1997), “Criticality Safety Criteria for the Handling, Storage, and Transportation of LWR [Light Water Reactor] Fuel Outside Reactors,” American Nuclear Society.

IN 2005-13, “Potential Non-Conservative Error in Modeling Geometric Regions in the KENO-V.a Criticality Code,” May 17, 2005.

U.S. Nuclear Regulatory Commission (U.S.) (NRC). NUREG-1520, “Standard Review Plan for the Review of a License Application for a Fuel Cycle Facility.” NRC: Washington, D.C. March 2002.

U.S. Nuclear Regulatory Commission (U.S.) (NRC). NUREG-1718, “Standard Review Plan for the Review of an Application for a Mixed Oxide (MOX) Fuel Fabrication Facility.” NRC: Washington, D.C. August 2000.

U.S. Nuclear Regulatory Commission (U.S.) (NRC). NUREG/CR-6698, “Guide for Validation of Nuclear Criticality Safety Calculational Methodology.” NRC: Washington, D.C. January 2001.

U.S. Nuclear Regulatory Commission (U.S.) (NRC). NUREG/CR-6361, “Criticality Benchmark Guide for Light-Water-Reactor Fuel in Transportation and Storage Packages.” NRC: Washington, D.C. March 1997.

Approved: ________________________________ Date: _________

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APPENDIX A

ANSI/ANS-8.17 Calculation of Maximum k_{eff}

ANSI/ANS-8.17-1984 (R1997), "Criticality Safety Criteria for the Handling, Storage, and Transportation of LWR Fuel Outside Reactors," contains a detailed discussion of the various factors that should be considered in setting k_{eff} limits. This is consistent with, but more detailed than, the discussion in ANSI/ANS-8.1-1998.

The subcriticality criterion from Section 5.1 of ANSI/ANS-8.17-1984 (R1997) is:

$$k_s \leq k_c - \Delta k_s - \Delta k_c - \Delta k_m$$

where k_s is the calculated k_{eff} corresponding to the application, Δk_s is its uncertainty, k_c is the mean k_{eff} resulting from the calculation of critical experiments, Δk_c is its uncertainty, and Δk_m is the MMS. The types of uncertainties included in each of these "delta" terms is provided, and includes the following:

Δk_s = (1) statistical uncertainties in computing k_s; (2) convergence uncertainties in computing k_s, (3) material tolerances; (4) fabrication tolerances; (5) uncertainties due to limitations in the geometric representation used in the method; and (6) uncertainties due to limitations in the material representations used in the method.

Δk_c = (7) uncertainties in the critical experiments; (8) statistical uncertainties in computing k_c; (9) convergence uncertainties in computing k_c; (10) uncertainties due to extrapolating k_c outside the range of experimental data; (11) uncertainties due to limitations in the geometric representations used in the method; and (12) uncertainties due to limitations in the material representations used in the method.

Δk_m = an allowance for any additional uncertainties (MMS).

To the extent that not all 12 sources of uncertainty listed above have been explicitly taken into account, they may be allowed for by increasing the value of Δk_m. The more of these sources of uncertainty that have been taken into account, the smaller the necessary additional margin Δk_m. As a general principle, however, the MMS should be large compared to known uncertainties in the nuclear data and limitations of the methodology. However, a value of the MMS below 0.02 should not be used.

Frequently, the terms in the above equation relating to the application are grouped on the left-hand side of the equation, so that the equation is rewritten as follows:

$$k_s + \Delta k_s \leq k_c - \Delta k_c - \Delta k_m$$

where the terms on the right-hand side of the equation are often lumped together and termed the Upper Subcritical Limit (USL), so that the USL = $k_c - \Delta k_c - \Delta k_m$.

Relation to the Minimum Subcritical Margin (MMS)

The MoS has been defined as the difference between the actual value of k_{eff} and the value of k_{eff} at which the system is expected to be critical. The expected (best estimate) critical value of k_{eff} is the mean k_{eff} value of all critical experiments analyzed (bias), including consideration of the uncertainty in the bias (i.e., $k_c - \Delta k_c$). The calculated value of k_{eff} for an application generally exceeds the actual (physical) k_{eff} value due to conservative assumptions in modeling the system. In terms of the above USL equation, the MoS may be expressed mathematically as:

$$MoS = k_c - \Delta k_c - (k_s - \Delta k_{sa}) - \Delta k_s$$

where the term in parentheses is equal to the actual (physical) k_{eff} of the application, k_{sa}. A term, Δk_{sa}, has been added to represent the difference between the actual and calculated value of k_{eff} for the application (i.e., Δk_{sa} = change in k_{eff} resulting from modeling conservatism). In terms of the USL:

$$MoS = USL + \Delta k_m - k_s + \Delta k_{sa} - \Delta k_s$$

The minimum allowed value of the MoS is reached when the calculated k_{eff} for the application, $k_s + \Delta k_s$, is equal to the USL. When this occurs, the minimum value of the MoS is:

$$MoS \geq \Delta k_m + \Delta k_{sa}$$

Thus, adequate margin (MoS) may be assured either by conservatism in modeling practices or in the explicit specification of Δk_m (MMS). This is discussed in the ISG section on modeling conservatism.

Glossary

application: calculation of a fissionable system in the facility performed to demonstrate subcriticality under normal or credible abnormal conditions

area of applicability: the ranges of material compositions and geometric arrangements within which the bias of a calculational method is established

benchmark experiment: a critical experiment that has been peer-reviewed and published and is sufficiently well-defined to be used for validation of calculational methods.

bias: a measure of the systematic differences between calculational method results and experimental data

bias uncertainty: a measure of both the accuracy and precision of the calculations and the uncertainty in the experimental data

calculational method: includes the hardware platform, operating system, computer algorithms and methods, nuclear reaction data, and methods used to construct computer models

critical experiment: a fissionable system that has been experimentally determined to be critical (with k_{eff} . 1).

margin of safety: the difference between the actual value of a parameter and the value of the parameter at which the system is expected to be critical with critical defined as k_{eff} = 1 - bias - bias uncertainty

margin of subcriticality (MoS): the difference between the actual value of k_{eff} and the value of k_{eff} at which the system is expected to be critical with critical defined as k_{eff} = 1 - bias - bias uncertainty

minimum margin of subcriticality (MMS): a minimum allowed margin of subcriticality, which is an allowance for any unknown uncertainties in calculating k_{eff}

subcritical limit: the bounding value of a controlled parameter under normal case conditions

upper subcritical limit (USL): the maximum allowed value of k_{eff} (including uncertainty in k_{eff}), under both normal and credible abnormal conditions, including allowance for the bias, the bias uncertainty, and a minimum margin of subcriticality