Appendix B
TERMINOLOGY

The terminology is included for the purpose of this report and is limited to a few concepts that are important to nuclear criticality safety, have caused discussion and even confusion during the study or are not clearly defined in international glossaries, guides and standards.

Actinides

It is convenient to refer to actinides as a group of elements rather than to list them. The reference systems in this report are limited to uranium and plutonium. The benchmarks include other actinides. The actinide group consists of 14 elements starting with atomic number 90 and finishing with number 103. Actinium (89) is not an actinide. Nuclides like ^{235}U and ^{239}Pu are often referred to as actinides but they are actinide nuclides.

Atomic number density

The density of a nuclide is often specified in number of atoms per barn-cm (10^{-24} cm^3). The determination of such atomic number densities is very important to get good reference values. A computer code system may convert other input specifications into atomic number densities.

Best-estimate value

At a certain time and for a given purpose, this value is the most accurate estimation available to the publisher or to the contributor. By definition this means that there was no bias in the value that was known to or assumed by the publisher or contributor. The uncertainties should be specified separately.

Bias

A bias is the difference between a calculated or measured result and a best-estimate result. It can be a constant or a function of one or more parameters. A bias is an error, also referred to as a systematic error, with an estimated (“known”) sign and magnitude. This error should not be confused with the systematic effect (sometimes, but not in this report, also called systematic error). Biases can be correlated to each other. The determination of a bias usually leads to an uncertainty in the bias. This bias uncertainty often results in a systematic effect.

Bias correction

A bias correction is used in this report to obtain a best-estimate value from a calculation, measurement or other procedure. In this case, it has the same value as the bias but with a reversed sign. In other applications, e.g., criticality safety analysis, the bias correction is more open to judgment and need. The bias is considered a fact while the bias-correction in safety applications can be made more or less conservative.

Critical system

A system of fissionable and other materials that, through fission and other processes caused by free neutrons, produces as many neutrons as are lost (absorption and leakage).

Critical value

A critical value is a parameter value that, under specified material and geometry constraints, determines a critical system. This value is a physical constant, a "reference value".

Cross-sections for neutrons

A neutron cross-section for a nuclide or material gives the probability for a reaction between a free neutron and the nuclide or material. The cross-section is dependent on the energy of the neutron, the properties of the nuclide and the environment of the nuclide (material properties, temperature). The cross-sections are evaluated from measurements and theoretical models.

EALF – Energy corresponding to average lethargy of neutrons causing fission

This parameter is considered more useful than the average energy causing fission since the importance of thermal neutron fissions is clearer. The EALF value is an average and will not always be a clear indicator of the neutron physics of the system. It could be like comparing the average colour of the rainbow with the colour of a mud pool. However, EALF has been found to be useful in many cases. Some computer codes include EALF in the output.

Eta – η

A function defined as the ratio of produced to absorbed neutrons for a certain fissionable nuclide, element, compound, solution or mixture. The function is dependent on neutron energy but integral (total energy range or limited energy ranges) values may be of use as well. The JANIS 2.1 code [71] is useful in generating charts of this parameter.

Fissile

A fissile nuclide is a fissionable nuclide that can be fissioned by slow neutrons. The distinction between fissile and non-fissile (as between many other adjectives such as soft/hard, good/bad, homogeneous/heterogeneous, etc.) depends on the application. In nuclear criticality safety, the fissile property is usually related to the support for criticality when some water is present or added to the system. In some criticality safety applications, special moderators such as graphite, beryllium and deuterium may need to be considered in the definition of fissile. Natural uranium is a fissile material in some applications but can be neglected as a criticality safety hazard in the absence of other fissile materials and large quantities of special moderators.

Fissionable

A fissionable nuclide can be fissioned by a free neutron at some energy. In criticality safety applications, this energy needs to be credible during handling, storage and transport operations. A fissionable element, material, system, etc. contains sufficient quantities and concentrations of fissionable nuclides for the neutron-induced fission process to be considered significant. A fissionable nuclide does not necessarily support criticality on its own. As with the fissile concept, the definition of fissionable is application-dependent.

Handbooks and other reference value compilations

Values given in handbooks and other sources are used for various purposes. Safety handbooks may use different approaches than other handbooks. Different criteria may be used to derive and present the values, even when they have the same “label”. This should be understood when a value from a handbook is used together with methods or values from other sources.

Human error

Human error is used here loosely as a category to cover deviations between the documented information and the real facts and which lie outside the reported accuracy claims. These claims may not always be obvious but should be available in some form. Many of the discrepancies requested in the scope of this work can be referred to this category. Human errors range from editorial errors to fundamental flaws in established theories and methods.

K_∞ and k_{eff}

See neutron multiplication factor.

Maximum critical value

One or more parameters are optimized while other conditions are fixed to give a maximum critical value for a specified parameter. An example is the maximum critical atomic moderation ratio H/X, where X corresponds to a fissionable nuclide or element.

Minimum critical value

One or more parameters are optimized while other conditions are fixed to give a minimum critical value for a specified parameter. Examples are critical mass and dimensions assuming that the water moderation is optimized. The minimum critical mass is normally expected to have the shape of a sphere but the optimum shape needs to be verified.

Neutron multiplication factor, k_{eff} and k_∞

The effective neutron multiplication factor, k_{eff} is a system property determined by a converged self-generating neutron flux distribution. K_{eff} is an eigenvalue needed to make the “amplitude” of the distribution constant. The infinite neutron multiplication factor k_∞ is a fissionable material or unit property determined for an infinite material or array of identical units. K_{eff} is related to the neutron flux through a complex relation, the neutron transport equation, and can’t be generally modelled as a sum or product of independent variables. Each system has a single value of k_{eff}. A single value of k_{eff} corresponds to many systems; the value itself is not necessarily a sufficient indicator of the system properties. The reactivity effect of multiple parameter changes to the system are not determined by individual reactivities but by the combined effect of system parameter and neutron flux changes.

For critical and near-critical systems, k_{eff} may be defined and measured as the ratio between produced (excluding fixed sources) and lost (absorption and leakage) neutrons. For other systems, the evaluator needs to introduce or select neutrons to comply with the converged flux distribution. The criticality safety properties for such systems are not necessarily indicated by the real neutron flux and multiplication. The eigenvalue model gives information about such properties.

Random effect

If a value changes between evaluations, consistently with a certain probability distribution, the variation may be considered to give a truly random effect for each evaluation. If there is a trend that applies to several evaluations, the trend becomes a systematic effect for the evaluations. It is essential for some evaluations to separate random and systematic effects of each component of the combined uncertainty and to combine them separately.

Reactivity

Reactivity is a change in k_{eff}. It is used here as the absolute k_{eff} change, without normalisation. The unit mk the reactivity multiplied by 1 000, is used in many tables. This is the intended accuracy for the requested reference values. One mk is also used to determine the number of significant digits. Reactivities in the same system are correlated through the neutron flux. Reactivities are not equivalent to reaction rates or reaction rate changes. E.g. ratios of the individual nuclide absorptions to the total absorptions are not equivalent to the ratios of the individual nuclide absorption reactivities to the total absorption reactivity.

Reference values

A value that corresponds to clearly defined conditions and is used in criticality safety applications. The exact specifications may not always be given. In this study, the optimization procedure contributes to the total bias and uncertainty. Maximum and minimum critical values, k_{∞}, etc., are examples of reference values.

Safe values

A safe value is associated with a special operation or type of operation involving fissionable materials. The magnitude of the value does not necessarily in itself inform about the safety margin or even if the operation is safe or unsafe.

Sensitivity

The sensitivity is a change of a variable due to a small variation in a parameter. An example is the change in k_{eff} that corresponds to a small change in the material mass. “Small” is not defined but is related to the validity range of the relationship. A linear sensitivity has a smaller range of validity than a more complicated relationship. A combined change based on several sensitivities need to comply with the same principle; the total change should be within the validity range for each sensitivity.

Statistical distributions – Normal, Gaussian

Input parameters are often assumed to be known with some uncertainty based on a normal or Gaussian probability distribution. It is very unlikely that the corresponding k_{eff} uncertainties have the same distribution, unless the uncertainties are very small. An example is the steel thickness of plates between fuel assemblies in water. Assume that the thickness uncertainty complies with a Gaussian distribution. There is often a plate thickness for which k_{eff} increases, whether it is increased or reduced. For other input parameter uncertainties, the k_{eff} relationships are not linear. The EMS contribution from 2001 reports reference value uncertainties based on k_{eff} uncertainties (Gaussian distribution). The positive and negative k_{eff} limits of confidence are not symmetrical.

Systematic effects (but not systematic errors or uncertainties)

An uncertainty that represents a potential error that is common to more than one value or common to more than one evaluation of the same value has sometimes in the past been called a systematic error or systematic uncertainty. To be consistent with [94], it is now called just "an uncertainty". This uncertainty shall be included in the combined uncertainty for the calculation or measurement. However, the systematic effects of different components of each combined uncertainty need to be understood and combined properly when this is motivated.

Examples of systematic effects are calibration errors that remain unchanged between measurements and are not corrected for, a single calculation value that is applied to several operations or designs, validation uncertainties (not biases) determined from statistical evaluations, etc. The systematic effect can be dependent on time and other variables. It is important in assessing the safety of a facility with many operations or designs or of a particular design that is used in many operations. It is also important in assessing the cost of large uncertainties for such facilities or multiple uses of a design.

Theoretical density

The theoretical density is a maximum density based on pure material properties under conditions that are likely to be maintained in all credible environments. It is used to estimate densities in mixtures of materials. The sum of volume fractions of each material is normally assumed to be one. Void may then be considered as a material with a volume fraction. The nuclide densities in solutions are important in this study. They are often empirical.

Uncertainty, single

An uncertainty may be either a statistical result of calibration or validation, an allowance for unknown errors or a combination of both. It is separated from the bias, which has a known sign and a probable magnitude. There are many sources for uncertainties. The uncertainty is usually specified by a statistical measure, such as a confidence level or a standard deviation, often assuming a normal distribution of the probabilities. The uncertainty can lead to both random and systematic effects.

A large uncertainty can be converted to a bias and a smaller uncertainty using more resources (including more experiments or better evaluations of experiments). An uncertainty is thus a subjective view as seen by one evaluator. To another evaluator the uncertainty may be partially known (a bias), leaving only a smaller remaining uncertainty. A numerical rounding effect is a bias to the person who knows a higher precision and an uncertainty to the one who does not know. The effect can be systematic (multiple use) or random (single use).

Uncertainty, combined

The combined uncertainty may be derived from individual uncertainties in a procedure that needs to be validated in each case. The combination of uncertainties into a single combined uncertainty does not mean that each uncertainty can be forgotten. Evaluation of systematic effects requires consideration of each uncertainty. Independent uncertainties are described separately. The reason for this emphasis on uncertainties is that they are very important in the evaluation of critical experiments, of reference values and of safety of real systems.

Uncertainties, independence

For any system evaluated in this report (critical experiment benchmarks and reference value applications), there are no independent uncertainties in k_{eff} or in the associated reference value, see Appendix M, Appendix S and [92]. All k_{eff} uncertainties are correlated. The uncertainties of the input parameters may be independent but the uncertainties in k_{eff} (and in the associated reference value) are not. An example based on a system with a metal plate in a fissile material shows this clearly. The input parameters are plate thickness and plate absorption cross-sections. The input parameter uncertainties are independent. If the plate thickness is smaller, the uncertainty in the absorption cross-sections will have a reduced effect on k_{eff} (extreme: if the plate is not there at all, the cross-section uncertainty has no influence at all on k_{eff}). Similarly, if the absorption cross-section is much smaller than expected, due to less boron in the aluminium, the reactivity influence of the plate thickness is reduced (no boron at all may actually increase reactivity of the plate compared with water).

Validation

Validation of a value or a method involves evaluation of the total bias and uncertainties for a defined range of applications. The difference between validation and verification is dependent on the application of the method or the value. If the evaluation of the method or value is the overall purpose of a study, validation is correct. However, if the method or value is a part of a wider study, verification may be a more appropriate term for testing the accuracy and uncertainty in the method or value. It is thus not contradictory when a code developer refers to a validation report while the safety evaluator refers to the same document as a verification report. Sometimes the distinction is important and this report should be clear in such cases.

Validation for safety purposes should reflect the user influence on typical results. In this study of reference values, calculation method user influence on the results should be minimized.

Verification

Verification of a value or a method is more limited than validation. It relates to components of the method or a sub-range of the application range of the value. In some contexts, the distinction is not important and either term can be used. This report uses verification when it is clear that further verification of other overall method components is required to validate the requested reference values. The verification of the calculation method to obtain the best-estimate reference value can take advantage of non-standard and more resourceful options than what are normally applied by a user of the method.