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Preface

This regulatory document provides requirements for the prevention of criticality accidents in the handling, storage, processing, and transportation of fissionable materials. This regulatory document clarifies the physical constraints and limits on fissionable materials that licensees must implement in order to ensure nuclear criticality safety during the construction, operation, or decommissioning of the licensed facility.

This document presents CNSC's requirements regarding nuclear criticality safety. The associated guidance document, GD-327 *Guidance for Nuclear Criticality Safety*, provides information as to how these requirements may be met. The information in these documents is currently reflected in certain existing licence conditions. In those cases, licensees are required to comply. Where no licence condition exists, this regulatory document and the associated guidance document provide guidance and best practices that licensees should apply.

In this document, the word "shall" denotes physical constraints and limits that must be met. The word "should" denotes strongly-recommended best practices, and the word "may" denotes recommended best practices.

Key principles and elements used in developing this document and the associated guidance document are consistent with national and international standards.

Nothing contained in this document is to be construed as relieving any licensee from pertinent requirements. It is the licensee's responsibility to identify and comply with all applicable regulations and licence conditions.

If any discrepancies exist between this regulatory document and guidance document GD-327 *Guidance for Nuclear Criticality Safety*, then the information in this regulatory document RD-327 *Nuclear Criticality Safety* takes precedence.

Contents

RD-327 *Nuclear Criticality Safety*

1.0 Introduction

1.1 Purpose

This draft regulatory document provides requirements for the prevention of criticality accidents in the handling, storage, processing, and transportation of fissionable materials.

This regulatory document clarifies the physical constraints and limits on fissionable materials that the licensee must implement in order to ensure nuclear criticality safety during the construction, operation, or decommissioning of the licensed facility.

1.2 Scope

This regulatory document presents CNSC's requirements regarding nuclear criticality safety. The associated guidance document, GD-327 *Guidance for Nuclear Criticality Safety* [1], provides information as to how these requirements may be met. The information in these documents is currently reflected in certain existing licence conditions. In those cases, licensees are required to comply. Where no licence condition exists, this regulatory document provides guidance and best practices that licensees should apply.

In this document, the word "shall" denotes physical constraints and limits that must be met. The word "should" denotes strongly-recommended best practices, and the word "may" denotes recommended best practices.

Nothing contained in this document is to be construed as relieving any licensee from pertinent requirements. It is the licensee's responsibility to identify and comply with all applicable regulations and licence conditions.

If any discrepancies exist between this regulatory document and guidance document GD-327 *Guidance for Nuclear Criticality Safety*, then the information in this regulatory document RD-327 *Nuclear Criticality Safety* takes precedence.

1.3 Relevant Regulations

The provisions of the NSCA and the regulations made under the NSCA relevant to this guide are as follows:

1. Subsection 24(4) of the NSCA states that "No licence may be issued, renewed, amended or replaced unless, in the opinion of the Commission, the applicant (*a*) is qualified to carry on the activity that the licence will authorize the licensee to carry on; and (*e*) will, in carrying on that activity, make adequate provision for the protection of the environment, the health and safety of persons and the maintenance of national security and measures required to implement international obligations to which Canada has agreed";
2. Subsection 24(5) of the NSCA states that "A licence may contain any term or condition that the Commission considers necessary for the purposes of this Act";

3. Paragraph 3(1)(*i*)of the *General Nuclear Safety and Control Regulations* states that "An application for a licence shall contain the following information: (*i*) a description and the results of any test, analysis or calculation performed to substantiate the information included in the application;"
4. Paragraph 12(1)(*f*) of the *General Nuclear Safety and Control Regulations* states that "Every licensee shall…(*f*) take all reasonable precautions to control the release of radioactive nuclear substances or hazardous substances within the site of the licensed activity and into the environment as a result of the licensed activity;"
5. Subsection 13(1) of the *Radiation Protection Regulations* states that "Every licensee shall ensure that the effective dose received by and committed to a person described in column 1 of an item of the table to this subsection, during the period set out in column 2 of that item, does not exceed the effective dose set out in column 3 of that item;"
6. Paragraph 5(*i*) of the *Class I Nuclear Facilities Regulations* states that "An application for a licence to construct a Class I nuclear facility shall contain the following information…: (*i*) the effects on the environment and the health and safety of persons that may result from the construction, operation and decommissioning of the nuclear facility…;"
7. Paragraph 6(*h*) of the *Class I Nuclear Facilities Regulations* states that "An application for a licence to operate a Class I nuclear facility shall contain the following information…: (*h*) the effects on the environment and the health and safety of persons that may result from the operation and decommissioning of the nuclear facility…;"
8. Paragraph 7(*f*) of the *Class I Nuclear Facilities Regulations* states that "An application for a licence to decommission a Class I nuclear facility shall contain the following information…: (*f*) the effects on the environment and the health and safety of persons that may result from the decommissioning", and
9. Subsection 2(1) of the *Packaging and Transport of Nuclear Substances Regulations* states that these regulations "apply in respect of the packaging and transport of nuclear substances, including the design, production, use, inspection, maintenance and repair of packaging and packages and the preparation, consigning, handling, loading, carriage, storage during transport, receipt at final destination and unloading of packages."

1.4 National and International Standards

Key principles and elements used in developing this regulatory document are consistent with national and international standards.

In particular, some sections of the associated guidance document, GD-327 *Guidance for Nuclear Criticality Safety* [1], are extracted from the American National Standards (as referenced in that guidance document), with permission of the publisher, the American Nuclear Society.

In addition, this regulatory document is consistent with:

1. IAEA Draft Safety Standard, *Safety of Conversion and Enrichment Facilities*, IAEA DS 344, 2005;
2. IAEA Safety Standards, *Safety of Fuel Cycle Facilities*, IAEA DS 316, 2006 [2];
3. IAEA Safety Standards, *Safety of Uranium Fuel Fabrication Facilities*, IAEA DS 317, 2006 [3];
4. IAEA Safety Standards Series No. GS-R-2, *Preparedness and Response for a Nuclear or Radiological Emergency, Safety Requirements*, 2002 [4];
5. Health Canada, *Canadian Guidelines for Intervention during a Nuclear Emergency*, H46-2/03-326E, 2003 [5];
6. Canadian Standards Association (CSA) Standard N292.2-07, *Interim Dry Storage of Irradiated Fuel* [6];
7. CSA Standard N292.3-2008, *Management of Low- and Intermediate-level Radioactive Waste* [7];
8. ISO Standard 1709, *Nuclear energy—Fissile materials—Principles of criticality safety in storing, handling, and processing*, 1995 [8];
9. ISO Standard 7753, *Nuclear energy—Performance and testing requirements for criticality detection and alarm systems*, 1987 [9];
10. ISO Standard 14943, *Nuclear fuel technology—Administrative criteria related to nuclear criticality safety*, 2004 [10]; and
11. IEC Standard 860, *Warning Equipment for Criticality Accidents*, 1987 [11].

2.0 Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors

2.1 Nuclear Criticality Safety Practices

2.1.1 Operations with Fissionable Materials

Operations with fissionable materials shall follow the requirements and recommendations of this regulatory document.

2.1.1.1 Exempted Quantity of Fissionable Materials

An exempted quantity of fissionable materials in the facility is defined as an inventory of fissionable materials, as follows:

1. Less than 100 g of ^{233}U, or ^{235}U, or ^{239}Pu, or of any combination of these three isotopes in fissionable material combined in any proportion; or
2. An unlimited quantity of natural or depleted uranium or natural thorium, if no other fissionable materials or advanced moderators (more effective than water) are allowed in the facility; or

3. Less then 200 kg in total of natural or depleted uranium or natural thorium if some other fissionable materials are present in the facility, but the total amount of fissile nuclides in those fissionable materials is less than 100 g.

Facilities operating with exempted quantities of fissionable materials are exempt from the requirements and recommendations of this regulatory document.

2.1.1.2 Small Quantity of Fissionable Materials

A small quantity of fissionable materials in the facility is defined as an inventory of fissionable materials, which:

1. Exceeds the exempt limits listed in Subsection 2.1.1.1; but
2. Does not exceed the following limits:
    a. For operations involving isotopes of ^{233}U, ^{235}U, ^{239}Pu, the total inventory of fissionable materials (containing these three isotopes) in the facility does not exceed the single-parameter subcritical mass limits for non-uniform mixtures specified in Subsection 2.2, *Single-Parameter Limits for Fissile Nuclides* (that is, inventory does not exceed 500 g of ^{233}U, or 700 g of ^{235}U, or 450 g of ^{239}Pu, or 450 g of any combination of these three isotopes).
    b. For operations involving other fissile isotopes, the inventory of fissionable materials (containing these isotopes) in the facility does not exceed the subcritical mass limits specified in Section 10.
    c. The inventory of fissionable materials in the facility does not exceed 80% of the appropriate smallest critical mass for operations involving fissionable materials,
        i. in which neutron moderators or reflectors more effective than water are present, or unique material configurations exist such that critical mass requirements may be less than the limits noted in a) and b) above, or
        ii. for which a limit is not noted in a) and b) above, or limit is not applicable or not appropriate.

This regulatory document is partially applicable, as further specified in Subsection 2.1.1.4, to facilities operating with small quantities of fissionable materials.

2.1.1.3 Large Quantity of Fissionable Materials

A large quantity of fissionable materials in the facility is defined as an inventory of fissionable materials that exceeds the limits listed in Subsection 2.1.1.2.

This regulatory document is applicable to facilities operating with large quantities of fissionable materials.

Note that a facility containing a large quantity of fissionable materials may be subject to the *Nuclear Liability Act*.

2.1.1.4 Nuclear Criticality Safety Program

A nuclear criticality safety program shall be developed and maintained in the facility to meet its legal requirements, when specified, and to support its safe operation. The extent of the program depends on the scope of operations with fissionable materials:

1. Facilities involved in operations with small quantities of fissionable materials, as defined in Subsection 2.1.1.2, shall develop and maintain a reduced-scope program based on the applicable sections of this regulatory document, taking into account that the requirements of Subsection 2.1.2.2 are not applicable. The program shall ensure that the entire process remains subcritical under normal and all possible abnormal conditions.
2. Facilities involved in activities with large quantities of fissionable materials, as defined in Subsection 2.1.1.3, shall develop and maintain a full-scope program based on the applicable sections of this regulatory document and the CNSC requirements. Characteristics of a full-scope program are described in Section 12 of this regulatory document.

2.1.2 Program Management Practices

2.1.2.1 Responsibilities

Management shall clearly establish responsibility for nuclear criticality safety. Supervisors should be made as responsible for nuclear criticality safety as they are for production, development, research, or other functions. Each individual, regardless of position, shall be made aware that nuclear criticality safety in their work area is ultimately their responsibility. This may be accomplished through training and periodic retraining of all operating and support personnel. Nuclear criticality safety does not differ in any intrinsic way from industrial safety, and good managerial practices apply to both.

Management shall provide personnel skilled in the interpretation of data pertinent to nuclear criticality safety, and familiar with operations, to serve as advisors to supervisors. These specialists should be, to the extent practicable, administratively independent of process supervisors.

Management shall establish the criteria to be satisfied by nuclear criticality safety controls. Distinction may be made between shielded and unshielded facilities, and the criteria may be less stringent when adequate shielding and confinement assure the protection of personnel.

2.1.2.2 Process Analysis

Before a new operation with fissionable material is begun, or before an existing operation is changed, it shall be determined that the entire process will be subcritical under both normal and credible abnormal conditions (events or event sequences) that have frequency of occurrence equal to or greater than 10^{-6} per year [6, 7] (hereinafter “credible abnormal conditions”). Examples of such conditions are given in GD-327 *Guidance for Nuclear Criticality Safety* [1], Appendix A.

1. An adequate margin of subcriticality shall be established such that:
   a. If calculational methods are applied to predict neutron multiplication factors for safety assessment:
      i. The margin of subcriticality is calculated using formulas presented in GD-327 *Guidance for Nuclear Criticality Safety* [1], Appendix B, *Calculation Methods Yielding k_{eff}*; and
      ii. A minimum value for an administrative margin of subcriticality, as presented in the formulas for calculation of subcriticality, is 5% in neutron multiplication factor.
   b. If calculational methods are not applied to predict neutron multiplication factors for safety assessment:
      i. The applicable subcritical limits shall be as specified in Subsection 2.2 *Single-Parameter Limits for Fissile Nuclides*, or in Section 10; or
      ii. Otherwise a minimum value for an administrative margin of subcriticality shall be 20% of the critical mass.
2. The established adequate margin of subcriticality shall be maintained under all normal and credible abnormal conditions, and:
   c. All credible abnormal conditions (events or event sequences) having frequency of occurrence equal to or more than 10^{-6}/year are identified and assessed; and
   d. The frequency of occurrence for the identified credible abnormal conditions is clearly demonstrated using quantitative or semi-quantitative methods.
3. It shall be demonstrated that adequate mitigation measures are in place such that off-site consequences of a criticality accident, as calculated from the start of the accident, do not violate criteria established as a trigger for a temporary public evacuation by the following international standard and national guidance [6, 7]:
   a. IAEA Safety Standards Series No. GS-R-2, *Preparedness and Response for a Nuclear or Radiological Emergency, Safety Requirements*, Annex III, Subsection III-2 [4]; and
   b. Health Canada, *Canadian Guidelines for Intervention during a Nuclear Emergency*, H46-2/03-326E [5].
4. In item 3, above (the list of requirements to demonstrate the mitigation of off-site consequences of a criticality accident), the licensee may exclude any of the following independent sets of abnormal conditions:
   a. An external event that leads to a criticality accident with frequency of occurrence less than 10^{-7}/year; or
   b. Process deviations for which there is a convincing argument, given by physical laws, that they are not possible, or are unquestionably extremely unlikely; the validity of the argument must not depend on any feature of the design or materials controlled by the facility's system of criticality safety controls, or management measures.

   Considering the impact of external events on the facility, the frequency of occurrence of the impact should be calculated by evaluating the vulnerable impact areas; i.e., areas where fissionable materials are processed or stored. To evaluate the consequences of the impact or the adequacy of the design to resist the impact, only realistic impact scenarios should be considered, which might require the knowledge of various factors such as angle of impact for aircraft crash, etc [3]. If there are no historic records or other scientific grounds to estimate impact of a natural phenomena event at the low limit frequency of occurrence (10^{-7}/year), the impact of the event that is the most severe reasonably possible (sometimes referred to as probable maximum natural phenomena event) may be treated as the bounding event.

2.1.2.3 Written Procedures

Operations to which nuclear criticality safety is pertinent shall be governed by written procedures.

All persons participating in these operations shall understand and be familiar with the procedures.

The procedures shall specify all parameters that they are intended to control. They should be such that no single, inadvertent departure from a procedure can cause a criticality accident.

2.1.2.4 Materials Control

The movement of fissionable material shall be controlled. Appropriate material labelling and area posting shall be maintained specifying material identification and all limits on parameters subject to procedural control.

2.1.2.5 Equipment Control

Prior to starting a new or modified process or processing line, it shall be ascertained that all equipment is consistent in dimension and material with the assumptions made to ensure subcriticality [8].

2.1.2.6 Quality Assurance Program

A quality assurance (QA) program that meets the applicable requirements of ANSI/ASME NQA-1-2000, CSA N286, or equivalent, shall be established to implement the activities specified in this regulatory document.

Records shall be maintained according to the QA program to demonstrate that the facility and its equipment were constructed according the design specifications. The licensee shall define a formal design change procedure as part of their QA program, so that all modifications made to the facility during all stages of the facility lifecycle are accurately recorded and their impact assessed with respect to nuclear criticality safety [2].

2.1.2.7 Operational Control

Deviations from procedures and unforeseen alterations in process conditions that affect nuclear criticality safety shall be reported to management and shall be investigated promptly. When available, the information about incidents and events in other installations of the same type shall also be investigated and lessons learnt shall be considered. Possible improvements in criticality safety practices or equipment shall be considered and action shall be taken to prevent recurrence [2, 8].

2.1.2.8 Operational Reviews

Operations shall be reviewed frequently (at least annually) to verify that procedures are being followed and that process conditions have not been altered in any way that would affect the applicable nuclear criticality safety evaluation. These reviews shall be conducted in consultation with operating personnel, by individuals who are knowledgeable in nuclear criticality safety and who, to the extent practicable, are not immediately responsible for the operation.

2.1.2.9 Emergency Procedures

Emergency procedures shall be prepared and approved by management. On-site and off-site organizations that are expected to respond to emergencies shall be made aware of conditions that might be encountered, and they should be assisted in preparing suitable procedures governing their responses.

2.1.3 Technical Practices

2.1.3.1 Controlled Parameters

All controlled parameters and their limits shall be specified. The influence of variations in these parameters on the k_{eff} of the system shall be understood.

2.1.3.2 Availability and Reliability

The licensee shall ensure that the necessary levels of availability and reliability are maintained for nuclear criticality safety controls, as established by the process analysis for normal and credible abnormal conditions.

The following principles shall be incorporated as appropriate to attain the required availability and reliability of engineered nuclear criticality safety controls [2].

Double Contingency Principle

Process designs should incorporate sufficient factors of safety to require at least two unlikely, independent, and concurrent changes in process conditions before a criticality accident is possible.

Testability

All engineered nuclear criticality safety controls shall be designed and arranged so that:

1. Their safety function can be adequately inspected and tested; and
2. The engineered nuclear criticality safety controls can be maintained, as appropriate before commissioning and at suitable and regular intervals thereafter in accordance with their importance to safety.

If it is not practicable to provide adequate testability of a component, the safety analysis should take into account the possibility of undetected failures of such equipment [2].

2.1.3.3 Geometry Control

Where practicable, reliance should be placed on equipment design in which dimensions are limited rather than on administrative controls. Full advantage may be taken of any nuclear characteristics of the process materials and equipment. All dimensions and nuclear properties on which reliance is placed shall be verified prior to the beginning of operations, and control shall be exercised to maintain them.

2.1.3.4 Subcritical Limit

Where applicable data are available, subcritical limits shall be established on bases derived from experiments, with adequate allowance for uncertainties in the data. In the absence of directly applicable experimental measurements, the limits may be derived from calculations made by a method shown by comparison with experimental data to be valid in accordance with Subsection 2.1.4, *Validation of a Calculational Method*.

2.1.3.5 Neutron Reflection

Neutron reflection should be considered as a parameter for criticality control. The most effective neutron reflector commonly encountered in handling and in processing fissile material is water of thickness sufficient to yield maximum nuclear reactivity. However, careful consideration shall be given to systems where significant thicknesses of other common structural materials (e.g., wood, concrete, steel), which may be more effective neutron reflectors than water, may be present. For some situations, the reflection provided by personnel may be important [8].

2.1.3.6 Neutron Interaction

Consideration shall be given to neutron interaction between units when at least two units containing fissile material are present. It is possible to reduce neutron interaction to acceptable proportions either by spacing units, by insertion of suitable neutron-moderating and absorbing materials between units, or by some combination of these methods [8].

2.1.4 Validation of a Calculational Method

There are many calculational methods suitable for determining the subcritical state of a system. The methods vary widely in basis and form, and each has its place in the broad spectrum of situations encountered in the nuclear criticality safety field. However, the general procedure to be followed in establishing validity is common to all. For an example of validation of a calculational method, refer to GD-327 *Guidance for Nuclear Criticality Safety* [1], Appendix C.

2.1.4.1 Establishment of Bias

Bias shall be established by correlating the results of critical and exponential experiments with results obtained for these same systems by the calculational method being validated.

When no experimental data are available, establishment of the bias for a calculational method is not possible and the requirements of this Subsection cannot be satisfied.

Validation of a calculational method by comparing the results with those of another calculational method, for example, is unacceptable.

2.1.4.2 Bias Uncertainties

The uncertainty in the bias shall contain allowances for uncertainties in the experimental conditions, for lack of accuracy and precision in the calculational method, and for extension of the area (or areas) of applicability. After allowances are made for the accuracy and precision of the method and for the bias and uncertainty, a margin in the k_{eff} or other correlating parameter shall be applied that is sufficiently large to ensure that conditions (calculated by the method to be subcritical by this margin) will actually be subcritical. Like the bias and its uncertainty, this margin may vary with composition and other variables.

2.1.4.3 Computer Dependence

If the calculational method involves a computer program, checks shall be performed to confirm that the mathematical operations are performed as intended. Any changes in the computer program shall be followed by reconfirmation that the mathematical operations are performed as intended.

2.1.4.4 Validation Report

A written report of the validation shall be prepared. This report shall:

1. Describe the method with sufficient detail, clarity, and lack of ambiguity to allow independent duplication of results;
2. Identify the experimental data and list the parameters derived from the data for use in the validation of the method;
3. State the area (or areas) of applicability;
4. State the bias and uncertainties over the area (or areas) of applicability;
5. State the margin of subcriticality over the area (or areas) of applicability, including the justification for the adequacy of the margin of subcriticality; and
6. State the upper subcritical limit (see GD-327 *Guidance for Nuclear Criticality Safety* [1], Appendix B for details).

2.2 Single-Parameter Limits for Fissile Nuclides

Operations with fissile materials can be performed safely by complying with any one of the limits given in GD-327 *Guidance for Nuclear Criticality Safety* [1], Subsections 2.4.1, 2.4.2, 2.4.3, and 2.4.4 for single units of ^{233}U, ^{235}U, and plutonium, provided the conditions under which the limit applies are maintained.

3.0 Criticality Accident Alarm System

3.1 General Principles

3.1.1 General

The purpose of an alarm system is to reduce risk to personnel. Evaluation of the overall risk should recognize that hazards may result from false alarms and subsequent sudden interruption of operations and relocation of personnel.

Subject to the evaluation of the overall risk described above, a criticality alarm system meeting the requirements of this regulatory document shall be installed unless:

1. A convincing argument exists, given by physical laws, that inadvertent criticality cannot occur; the validity of the argument must not depend on any feature of the design or materials controlled by the facility's system of criticality safety controls; or
2. No excessive radiation dose to personnel is credible should the inadvertent criticality occur.

Where alarm systems are installed, emergency procedures shall be maintained. Information on the preparation of emergency plans is provided in Section 16.

3.1.2 Coverage

3.1.2.1 Evaluation of Criticality Alarm Systems

In view of the requirement of item 1 in Subsection 3.1.1, the need for criticality alarm systems shall be evaluated:

1. For all activities involving ^{233}U, ^{235}U, and ^{239}Pu, in which the inventory of fissionable materials (containing these three nuclear substances) exceeds single parameter subcritical mass limits for non-uniform mixtures specified in Section 2; namely, if inventory exceeds:
   a. 500 g of ^{233}U;
   b. 700 g of ^{235}U;
   c. 450 g of ^{239}Pu; or
   d. 450 g of any combination of these three nuclear substances.
2. For all activities involving other fissile nuclear substances, in which inventory of fissionable materials (containing these nuclear substances) exceeds the subcritical mass limits specified in Section 10 of GD-327 *Guidance for Nuclear Criticality Safety* [1];
3. For all activities involving fissionable materials in which neutron moderators or reflectors more effective than water are present, or unique material configurations exist such that critical mass requirements may be less than the subcritical mass limits listed above; or
4. For all activities in which inventory of fissionable materials exceeds 80% of the appropriate critical mass if subcritical mass limits listed above are not applicable, or not appropriate.

This evaluation shall be performed for all activities in which the inventory of fissionable materials in individual unrelated areas exceeds the subcritical mass limits noted above.

For this evaluation, individual areas may be considered unrelated when the boundaries between the areas are such that there can be no transfer of materials between areas [9], the minimum separation between material in adjacent areas is 10 cm, and the areal density of fissile material averaged over each individual area is less than 50 g/m^2. This stipulation applies only to ^{233}U, ^{235}U, and ^{239}Pu.

3.1.2.2 Installation of Criticality Alarm Systems

A criticality alarm system meeting the requirements of Section 3 of this regulatory document shall be installed in areas where personnel would be subject to an excessive radiation dose. For this purpose, the maximum fission yield integrated over the duration of the accident may be assumed not to exceed 2.0 x 10^{19} fissions. The basis for a different maximum fission yield shall be documented.

If criticality accidents of lesser magnitude than the minimum accident of concern given in Subsection 3.2.3, *Detection Criterion*, are of concern, then other detection methods (e.g., audible personnel dosimetry) should be considered. These other detection methods are not considered to be criticality alarm systems and are not covered by Section 3 of this regulatory document.

3.1.2.3 Detection of Criticality Accidents

In areas in which criticality alarm coverage is required, a means shall be provided to detect a criticality accident and to signal that prompt protective action is required.

3.1.3 Criticality Alarm

Criticality alarm signals shall be for prompt evacuation or other protective actions. The criticality alarm signals should be uniform throughout the system. The signals shall be distinctive from other signals or alarms that require a response different from the response necessary in the event of a criticality accident.

The signal generators shall be automatically and promptly actuated upon detection of a criticality accident.

After actuation, the signal generators shall continue to function as required by emergency procedures, even if the radiation falls below the alarm point, and at least long enough to allow people to reach their evacuation assembly points and perform the procedures to account for all personnel. Manual resets, with limited access, should be provided outside areas that require evacuation [9].

A means for manual actuation of the criticality alarm signal may be provided.

For all occupied areas where personnel protective action is required in the event of criticality accident detection, the number and placement of criticality alarm signal generators shall be such that the signals are adequate to notify personnel promptly throughout those areas.

3.1.4 Dependability

Consideration shall be given to the avoidance of false alarms. This may be accomplished by providing reliable single detector channels or by requiring concurrent response of two or more detectors to initiate the alarm.

In redundant systems, failure of any single channel shall not prevent compliance with the detection criterion specified in Subsection 3.2.3.

Where portable instruments are used to meet the intent of Section 3 of this regulatory document, the usage shall be evaluated to determine appropriate criteria are met. Criteria for such use of portable instruments shall be specified in procedures.

Process areas in which activities will continue during power outages shall have emergency power supplies for alarm systems, or such activities shall be monitored continuously with portable instruments.

Adequate sensitivity of the alarm system to respond to the minimum accident of concern is addressed in Subsections 3.2.3 and 3.2.4.

Detectors shall not fail to trigger an alarm when subjected to intense radiation exceeding 1000 Gy/h. Compliance with this provision may be demonstrated by a test of sample detectors or by a manufacturer's test of production samples [9].

3.2 Criteria for System Design

3.2.1 Reliability

The system shall be designed for high reliability and should use components that do not require frequent servicing (such as lubrication or cleaning).

3.2.2 Response Time

The system shall be designed to produce the criticality alarm signal within one half-second (0.5 s) of detector recognition of a criticality accident.

3.2.3 Detection Criterion

A basic consideration in the design of a criticality accident alarm system is the definition of the lower magnitude of the event size to be detected, termed the "minimum accident of concern".

Criticality alarm systems shall be designed to respond immediately to the minimum accident of concern.

Document LA-13638 [12] describes nuclear criticality accidents that occurred during processing or handling of fissile material. Consideration of these events resulted in the following definition of the minimum accident of concern:

> *The minimum accident of concern is the accident resulting in a dose to free air of 0.2 Gy (20 rad) in the first minute at a distance of 2 metres from the reacting material.*

In situations where there is only nominal shielding, this definition should be used. The basis for a different minimum accident of concern shall be documented.

3.2.4 Sensitivity

Criticality alarm systems shall be designed so that alarm actuation shall occur as a result of the minimum duration transient. It may be assumed that the minimum duration of the radiation transient is one millisecond (1 ms).

The alarm trip point shall be set low enough to detect the minimum accident of concern. The alarm trip point should be set high enough to minimize the probability of an alarm from sources other than criticality.

3.2.5 Placement of Detectors

The spacing of detectors shall be consistent with the selected alarm trip point and with the detection criterion.

3.3 Testing

3.3.1 Initial Tests

Initial tests, inspections, and checks of the system shall verify that the fabrication and installation were made in accordance with design plans and specifications.

3.3.2 Special Tests

Following modifications or repairs, or events that call the system performance into question, there shall be tests and inspections adequate to demonstrate system operability.

3.3.3 Response to Radiation

System response to radiation shall be measured periodically to confirm continuing instrument performance. The test interval should be determined on the basis of experience. In the absence of experience, tests should be performed at least monthly.

Records of tests shall be maintained. System designs may incorporate self-checking features to automate portions of this testing.

3.3.4 Periodic Tests

The entire alarm system shall be tested periodically. Each signal generator should be tested at least annually. Field observations shall establish that criticality alarm signals are functional throughout all areas where personnel could be subject to an excessive radiation dose. All personnel in affected areas shall be notified before testing of the criticality alarm signals.

3.3.5 Corrective Action

When tests reveal inadequate performance, corrective action shall be taken without unnecessary delay. If portable instrument use is required, the criteria of Subsection 3.1.4, *Dependability*, shall be met.

3.3.6 Test Procedures

Procedures for system testing shall minimize both false alarms and inadvertent initiation of emergency response. The procedures shall require that the systems be returned to normal operation immediately following tests.

The IEC 860 Standard, *Warning Equipment for Criticality Accidents* [11], holds useful information regarding electrical characteristics and testing procedures for alarm equipment. This document may be used as a guide in these areas.

3.3.7 Records

Records of tests and corrective actions for each system shall be maintained. These records provide information on system operability and help identify sources of failure.

3.3.8 Out of Service

The licensee shall develop and implement out-of-service criteria for the nuclear criticality alarm system.

If the system is removed from service due to an unforeseen problem, the licensee shall immediately inform CNSC as to the cause of the removal and its expected duration.

3.4 Employee Familiarization

3.4.1 Posted Instructions

Instructions regarding response to criticality alarm signals shall be posted at strategic locations within areas requiring alarm coverage.

4.0 Use of Borosilicate-Glass Raschig Rings as a Neutron Absorber in Solutions of Fissile Material

The purpose of Raschig rings in criticality safety applications is to assure subcriticality for normal and credible abnormal conditions over the operating life of a vessel. General requirements for use of Raschig rings for criticality control are:

1. The nuclear criticality safety criteria of Section 2, *Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors*, shall be applied.
2. The physical and chemical properties of Raschig rings specified in this document shall be verified before their initial use as a criticality control.
3. Subsequent to initial use, periodic verification shall assure that the required physical and chemical properties of the Raschig rings are maintained.
4. The extent and frequency of the verification of the physical and chemical properties may be determined from a documented history of trends in these properties of the Raschig rings in the particular environment in which they are used. Otherwise, the frequencies specified in Subsection 4.7.4 of GD-327 *Guidance for Nuclear Criticality Safety* [1] shall apply at all times.

5. Methods for measuring the Raschig ring properties shall be documented and reviewed by qualified personnel for applicability and technical validity.
6. Raschig rings shall be compatible with the chemical environment and physical conditions of the solutions in which they are immersed.
7. Use of Raschig rings in criticality safety applications other than those addressed by this document should be evaluated on a case-by-case basis.

For additional safety information and guidance on the use of borosilicate-glass Raschig rings as a neutron absorber for criticality control in ring-packed vessels containing solutions of ^{235}U, ^{239}Pu, or ^{233}U, refer to Section 4 of GD-327 *Guidance for Nuclear Criticality Safety* [1].

5.0 Safety in Conducting Subcritical Neutron Multiplication Measurements In Situ

Personnel protection during *in situ* experiments depends on the avoidance of a criticality accident. Safety criteria and practices for conducting such experiments shall be followed.

For additional safety information and guidance on conducting subcritical neutron-multiplication measurements where physical protection of personnel against the consequences of a criticality accident is not provided, refer to Section 5 of GD-327 *Guidance for Nuclear Criticality Safety* [1].

6.0 Nuclear Criticality Safety in the Storage of Fissile Materials

All operations with fissile material, including storage, shall be conducted in accordance with Section 2, *Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors*.

For additional safety information and guidance on general storage criteria based on validated calculations, refer to Section 6 of GD-327 *Guidance for Nuclear Criticality Safety* [1]. GD-327 includes additional engineering and administrative practices appropriate to the storage of fissile material.

7.0 Criteria for Nuclear Criticality Safety Controls in Operations with Shielding and Confinement

If adequate shielding against radiation and confinement of radioactive materials are provided, the hazards normally attendant with criticality in a facility lacking shielding and confinement are minimized.

This section applies to operations, with ^{235}U, ^{233}U, ^{239}Pu and other fissile and fissionable materials outside of nuclear reactors, in which shielding and confinement are provided for protection of personnel and the public, except the assembly of these materials under controlled conditions, such as in critical experiments.

Criteria for criticality control under these conditions shall be provided for:

1. The prevention of nuclear accidents in facilities with shielding and confinement; and
2. The adequacy of the required shielding and confinement.

This section does not apply to those operations requiring entry of personnel inside the shielded process areas wherein fissile and fissionable materials are contained. This section does not include engineering specifications for shield design nor for establishing its adequacy. Nothing in this section shall be interpreted as discouraging additional safety features that can be conveniently incorporated.

This section does not include the details of administrative procedures for control (which are considered to be management prerogatives) or details regarding the design of processes and equipment or descriptions of instrumentation for process control.

For additional safety information and guidance, refer to Section 7 of GD-327 *Guidance for Nuclear Criticality Safety* [1].

8.0 Nuclear Criticality Control and Safety of Plutonium-Uranium Fuel Mixtures Outside Reactors

This section applies to operations with plutonium-uranium oxide fuel mixtures outside nuclear reactors, except the assembly of these materials under controlled conditions, such as in critical experiments.

Operations within the scope of this section shall be conducted in accordance with Section 2 except that the limits for plutonium-uranium mixtures given in Section 8 of GD-327 *Guidance for Nuclear Criticality Safety* [1] may be used. Attention shall be given to credible abnormal conditions such as those listed in GD-327 [1], Appendix A.

The administrative and technical practices for criticality safety and control as described in Section 12, *Administrative Practices for Nuclear Criticality Safety*, are applicable herein.

For additional guidance, refer to Section 8 of GD-327 *Guidance for Nuclear Criticality Safety* [1].

9.0 Use of Soluble Neutron Absorbers in Nuclear Facilities Outside Reactors

The use of soluble neutron absorbers for criticality accident prevention shall be conducted in accordance with Section 2.

For guidance on the use of soluble neutron absorbers for criticality control, neutron absorber selection, system design and modifications, safety evaluations, and quality assurance programs, refer to Section 9 of GD-327 *Guidance for Nuclear Criticality Safety* [1].

10.0 Nuclear Criticality Control of Special Actinide Elements

This section applies to operations with the following: $^{237}_{93}Np$, $^{238}_{94}Pu$, $^{240}_{94}Pu$, $^{241}_{94}Pu$, $^{242}_{94}Pu$, $^{241}_{95}Am$, $^{242m}_{95}Am$, $^{243}_{95}Am$, $^{243}_{96}Cm$, $^{244}_{96}Cm$, $^{245}_{96}Cm$, $^{247}_{96}Cm$, $^{249}_{98}Cf$, and $^{251}_{98}Cf$.

Operations within the scope of this section shall be conducted in accordance with Section 2, except that limits given in Section 10 of GD-327 *Guidance for Nuclear Criticality Safety* [1] may be used. Attention shall be given to credible abnormal conditions such as those listed in GD-327 [1], Appendix A.

The administrative and technical practices for criticality safety and control as described in Section 12, *Administrative Practices for Nuclear Criticality Safety*, are applicable herein.

For additional guidance, refer to Section 10 of GD-327 *Guidance for Nuclear Criticality Safety* [1].

11.0 Criticality Safety Criteria for the Handling, Storage, and Transportation of Light Water Reactor Fuel Outside Reactors

The handling, storage, and transportation of fuel for nuclear reactors represents a health and safety risk to personnel involved in these activities, as well as to the general public. Appropriate design of equipment and facilities, handling procedures, and personnel training can minimize this risk.

Operations within the scope of this section shall be conducted in accordance with Section 2. A criticality safety evaluation shall be performed for all normal and credible abnormal conditions to determine that the entire operation or system will be subcritical.

For additional information related to the transportation of fissile material, refer to the *Packaging and Transport of Nuclear Substances Regulations*, the IAEA safety guide *Regulations for the Safe Transport of Radioactive Material* (TS-R-1)[13], the associated guidance document *Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material* (TS-G-1.1)[14], and RD-364 *Joint Canada—United States Guide for Approval of Type B(U) and Fissile Material Transportation Packages* [15].

For additional guidance applicable to handling, storage, and transportation of light water reactor nuclear fuel units in any phase of the fuel cycle outside the reactor core, refer to Section 11 of GD-327 *Guidance for Nuclear Criticality Safety* [1].

12.0 Administrative Practices for Nuclear Criticality Safety

12.1 Introduction

An effective nuclear criticality safety program includes cooperation among management, supervision, and the criticality safety staff. For each employee, the program relies upon conformance with operating procedures.

Although the extent and complexity of safety-related activities may vary greatly with the size and type of operation with fissile material, certain safety elements are common. This section represents a codification of such elements related to criticality safety.

12.2 Scope

This section provides criteria for the administration of a nuclear criticality safety program for outside-of-reactor operations in which there exists a potential for criticality accidents.

Responsibilities of management, supervision, and the nuclear criticality safety staff are addressed. Objectives and characteristics of operating and emergency procedures are included.

General guidance for nuclear criticality safety can be found in Section 2, *Nuclear Criticality Safety in Operations with Fissionable Materials outside Reactors*.

12.3 Responsibilities

12.3.1 Management Responsibilities

Management shall accept overall responsibility for safety of operations. Continuing interest in safety should be evident.

Management shall formulate nuclear criticality safety policy and make it known to all employees involved in operations with fissile material. Distinction may be made between shielded and unshielded facilities, with appropriate criticality controls in all cases.

Management shall assign responsibility and delegate commensurate authority to implement established policy. Responsibility for nuclear criticality safety should be assigned in a manner compatible with that for other safety disciplines. Each individual, regardless of position, shall be made aware that nuclear criticality safety in their work area is their responsibility.

Management shall provide personnel familiar with the physics of nuclear criticality and with associated safety practices to furnish technical guidance appropriate to the scope of operations. This function should, to the extent practicable, be administratively independent of operations.

Management shall establish a method of monitoring the nuclear criticality safety program.

Management shall periodically participate in auditing the overall effectiveness of the nuclear criticality safety program.

Management may use consultants and nuclear criticality safety committees to achieve the objectives of the nuclear criticality safety program.

Management shall establish a defined process and procedures for equipment change control [10].

Management shall establish operating procedures and a process for their modification [10].

12.3.2 Supervisory Responsibilities

Each supervisor shall accept responsibility for the safety of operations under their control.

Each supervisor shall be knowledgeable in those aspects of nuclear criticality safety relevant to operations under their control. Training and assistance should be obtained from the nuclear criticality safety staff.

Each supervisor shall provide training and shall require that personnel under their supervision have an understanding of procedures and safety considerations such that they may be expected to perform their functions without undue risk. Criticality safety training programs are addressed in Section 13, *Nuclear Criticality Safety Training*. Records of training activities and verification of personnel understanding shall be maintained.

Supervisors shall develop or participate in the development of written procedures applicable to the operations under their control. Maintenance of these procedures to reflect changes in operations shall be a continuing supervisory responsibility.

Supervisors shall verify compliance with nuclear criticality safety specifications for new or modified equipment before its use. Verification may be based on inspection reports or other features of the quality assurance program.

Each supervisor shall require conformance with good safety practices including unambiguous identification of fissile materials and good housekeeping.

12.3.3 Nuclear Criticality Safety Staff Responsibilities

The nuclear criticality safety staff (NCS Staff) shall provide and accept responsibility for technical guidance in the design of equipment and processes and for the development of operating procedures [10].

The NCS Staff shall maintain familiarity with current developments in nuclear criticality safety standards, guides, and codes. Knowledge of current nuclear criticality information should be maintained. The NCS Staff should consult with knowledgeable individuals to obtain technical assistance as needed.

The NCS Staff shall maintain familiarity with all operations within the organization requiring nuclear criticality safety controls.

The NCS Staff shall assist supervision, on request, in training personnel.

The NCS Staff shall conduct or participate in audits of criticality safety practices and compliance with procedures as directed by management.

The NCS Staff shall examine reports of procedural violations and other deficiencies for possible improvement of safety practices and procedural requirements, and shall report their findings to management.

The NCS Staff shall, upon request, participate in the verification of compliance with nuclear criticality-safety specifications for intended new or modified processes or equipment [10].

12.4 Operating Procedures

The purpose of written operating procedures is to facilitate and document the safe and efficient conduct of the operation. Procedures should be organized for convenient use by operators and be easily available. They should be free of extraneous material. Copies of applicable written procedures should be posted up or available in operating areas [8].

Procedures shall include those controls and limits significant to the nuclear criticality safety of the operation. Procedures should be such that no single inadvertent departure from a procedure can cause a criticality accident.

Supplementing and revising procedures, as improvements become desirable, shall be facilitated.

Operating procedures shall be reviewed periodically by supervisory personnel.

New or revised procedures that affect nuclear criticality safety shall be reviewed by the NCS Staff and by the supervisory personnel, and shall be approved by management [10].

Deviations from operating procedures and unforeseen alterations in process conditions that affect nuclear criticality safety shall be reported to management, investigated promptly, corrected as appropriate, and documented. Action shall be taken to prevent a recurrence.

Operations shall be reviewed frequently (at least annually) to ascertain that procedures are being followed and that process conditions have not been altered so as to affect the nuclear criticality safety evaluation. These reviews shall be conducted, in consultation with operating personnel, by individuals who are knowledgeable in criticality safety and who, to the extent practicable, are not immediately responsible for the operation.

12.5 Process Evaluation for Nuclear Criticality Safety (Nuclear Criticality Safety Evaluation)

Before the start of a new operation with fissile material, or before an existing operation is changed, it shall be determined and documented that the entire process is subcritical under both normal and credible abnormal conditions.

The nuclear criticality safety evaluation shall determine and explicitly identify the controlled parameters and their associated limits upon which nuclear criticality safety depends. The effect of changes in these parameters, or in the conditions to which they apply, shall be understood.

The nuclear criticality safety evaluation shall be documented with sufficient detail, clarity, and lack of ambiguity to allow independent judgment of results.

Before the start of operation, there shall be an independent assessment that confirms the adequacy of the nuclear criticality safety evaluation.

12.6 Materials Control

The movement of fissile materials shall be controlled as specified in documented procedures. The transport of fissile materials within the public domain shall comply with appropriate national and international regulations [10,13,14,15].

Appropriate material labelling and area posting shall be maintained, specifying material identification and all limits on parameters that are subject to procedural criticality control.

If reliance for criticality control is placed on neutron-absorbing materials that are incorporated into process materials or equipment, procedural control shall be exercised to maintain their continued presence with the intended distributions and concentrations.

Access to areas where fissile material is handled, processed, or stored shall be controlled.

Control of spacing, mass, density, and geometry of fissile material shall be maintained to assure subcriticality under all normal and credible abnormal conditions.

12.7 Planned Response to Nuclear Criticality Accidents

Nuclear criticality accident alarm systems are addressed in Section 3, *Criticality Accident Alarm System*. Emergency planning and response are addressed in Section 16, *Nuclear Criticality Accident Emergency Planning and Response*.

Emergency procedures shall be prepared and approved by management. Organizations on- and off-site, that are expected to provide assistance during emergencies, shall be informed of conditions that might be encountered. They should be assisted in the preparation of suitable emergency response procedures.

Emergency procedures shall clearly designate evacuation routes. Evacuation should follow the quickest and most direct routes practicable. These routes shall be clearly identified and should avoid recognized areas of higher risk.

Personnel assembly stations, outside the areas to be evacuated, shall be designated. Means to account for personnel shall be established.

Personnel in the area to be evacuated shall be trained in evacuation methods and informed of evacuation routes and assembly stations. Provision shall be made for the evacuation of transient personnel. Drills shall be performed at least annually to maintain familiarity with the emergency procedures. Drills shall be announced in advance.

Arrangements shall be made in advance for the care and treatment of injured and exposed persons. The possibility of personnel contamination by radioactive materials shall be considered.

Planning shall include a program for the immediate identification of exposed individuals and should include personnel dosimetry. Guidance for dosimetry can be found in the ANSI publication N13.3-1969, *Dosimetry for Criticality Accidents* [16].

Instrumentation and procedures shall be provided for the determination of the radiation intensity at the assembly area and in the evacuated area following a criticality accident. Information should be correlated at a central control point.

Emergency procedures shall address re-entry procedures and the membership of response teams.

Emergency procedures shall provide for shutting off ventilation to prevent release of fission gases outside of affected area. Consideration should be given that shutting off ventilation does not generate other safety hazards.

12.8 Content of a Nuclear Criticality Safety Program

The Nuclear Criticality Safety program:

1. Identifies applicable nuclear criticality safety standards, guidelines, and the CNSC requirements;
2. Lists the requirements that must be met to comply with the applicable standards, guidelines, and the CNSC requirements;
3. Defines a model for the implementation of these requirements;
4. Identifies responsibilities arising from requirements;
5. Describes how the program meets the applicable nuclear criticality safety requirements in every functional category (such as administration, nuclear criticality safety analysis, criticality alarm system, engineering design, procedures, materials control, training, emergency response, ongoing oversight);
6. Identifies the administrative margin of subcriticality (depending on whether it is based on k_{eff} or on mass limits, or both), identifies the method used to determine the margin of subcriticality for safety and the Upper Subcritical Limit (USL); and
7. Identifies the risk assessment methodology to be used to demonstrate that the USL will not be exceeded in all (out-of-reactor) nuclear processes under normal and credible abnormal conditions; that is, accidents or accident sequences that have a frequency of occurrence equal to or more than 10^{-6} per year.

For an example of a nuclear criticality safety program, refer to Appendix G of GD-327 *Guidance for Nuclear Criticality Safety* [1].

13.0 Nuclear Criticality Safety Training

Training of employees associated with fissionable material operations outside reactors where potential exists for criticality accidents shall be performed.

For additional guidance on nuclear criticality safety training, refer to Section 13 of GD-327 *Guidance for Nuclear Criticality Safety* [1].

14.0 Use of Fixed Neutron Absorbers in Nuclear Facilities Outside Reactors

The purpose of fixed neutron absorbers in criticality control applications is to assure sub-criticality for normal and credible abnormal conditions over the operating life of the facility or equipment. For the purposes of this document, fixed neutron absorbers are materials that:

1. Are an integral part of a facility, equipment, or fuel components;
2. Have neutron absorption properties; and
3. Are incorporated into designs to assure margins for subcriticality as needed for normal and abnormal conditions.

The use of fixed neutron absorbers for criticality control application shall be conducted in accordance with Section 2. Verification of the absorbers and their effectiveness to capture neutrons shall be required before the materials are used. After the installation, there shall be verification to ensure that the neutron absorber system is in place as intended.

For additional guidance on the use of fixed neutron absorbers in the design, construction, and operation of non-reactor nuclear facilities, refer to Section 14 of GD-327 *Guidance for Nuclear Criticality Safety* [1].

15.0 Nuclear Criticality Safety Based on Limiting and Controlling Moderators

For many operations, criticality safety is achieved through the limitation of parameters such as geometry, mass, enrichment, and spacing of fissile materials. The amount of fissile material that can be safely handled, stored, or processed at one time can also depend on the credible range of neutron moderation. Optimum moderation, by definition, results in the lowest critical mass of fissile materials, other conditions being unchanged.

Operations within the scope of this section shall be conducted in accordance with Section 2. Safety criteria and practices for achieving criticality safety by the limitation and control of moderators in the range from no moderation to optimum moderation for fissile materials shall be documented and followed.

For additional guidance, refer to Section 15 of GD-327 *Guidance for Nuclear Criticality Safety* [1].

16.0 Nuclear Criticality Accident Emergency Planning and Response

Nuclear criticality safety programs at facilities that use fissionable material are primarily directed at the avoidance of nuclear criticality accidents. However, the possibility of such accidents exists and the consequences can be life-threatening. This possibility mandates advance planning practice in planned emergency responses and verification of readiness.

This section applies to those facilities for which a criticality accident alarm system, as specified in Section 3, *Criticality Accident Alarm System*, is in use. The provisions of this section may be considered in emergency planning for nuclear power plant sites and research reactor facilities. This section does not apply to off-site accidents, or to off-site emergency planning and response.

For additional guidance on minimizing risks to personnel during emergency response to a nuclear criticality accident outside reactors, refer to Section 16 of GD-327 *Guidance for Nuclear Criticality Safety* [1].

Glossary

Accidents or accident sequences
Events or event sequences, including *external events*, that lead to violation of subcriticality margin (i.e., to exceeding the USL). This definition is of a restricted nature for the purposes of this document.

Areal density
The product of the thickness of a uniform slab and the density of fissile material within the slab; hence, it is the mass of fissile material per unit area of slab. For nonuniform slurries, the areal density limits are valid for a horizontal slab subject to gravitational settling, provided the restrictions for uniform slurries are met throughout.

Bias
A measure of the systematic differences between calculational method results and experimental data.

Calculational method
The calculational procedures—mathematical equations, approximations, assumptions, associated numerical parameters (e.g., cross sections)—that yield the calculated results.

CNSC criticality safety requirements
The CNSC criticality safety requirements are regulatory requirements and derived acceptance criteria listed in operating licence conditions or other legally enforceable documents. This definition is of a restricted nature for the purposes of this document.

Controlled parameter
A parameter that is kept within specified limits, and, when varied, influences the margin of subcriticality.

Credible abnormal conditions
Accidents or accident sequences that have frequency of occurrence equal to or more than one in a million years.

Criticality accident
The release of energy as a result of accidental production of a self-sustaining or divergent neutron chain reaction.

Criticality safety control (CSC)
Structures, systems, equipment, components, and activities of personnel that are relied on to prevent potential accidents at a facility or to mitigate their potential consequences. This does not limit the licensee from identifying additional structures, systems, equipment, components, or activities of personnel (i.e., beyond those in the minimum set necessary for compliance with the performance requirements) as items relied on for safety. All safety controls (active engineered control, passive engineered control, simple administrative control, and enhanced administrative control) are CSC. Also called *nuclear criticality safety control (CSC)*.

Criticality safety staff
Specialists skilled in the techniques of nuclear criticality safety assessment and familiar with plant operations while, to the extent practicable, administratively independent of process supervision; also called *nuclear criticality safety staff (NCS Staff)*.

Double contingency protection
A characteristic or attribute of a process that has incorporated sufficient safety factors so that at least two unlikely, independent, and concurrent changes in process conditions are required before a nuclear criticality accident is possible.

Drill
Supervised instruction intended to test, develop, maintain, and practice the skills required in a particular emergency response activity. A drill may be a component of an exercise.

Effective multiplication factor (k_{eff})
Physically, the ratio of the total number of neutrons produced during a time interval (excluding neutrons produced by sources whose strengths are not a function of fission rate) to the total number of neutrons lost by absorption and leakage during the same interval. Mathematically (computationally), the eigenvalue number that, when divided into the actual mean number of neutrons emitted per fission in an assembly of materials, would make the calculated result for the nuclear chain reaction of that assembly critical.

Emergency response
Actions taken from the time of identification of a suspected, imminent, or actual criticality accident to stabilization of the event. These actions include the assumption that an accident has occurred, response to the emergency, and actions to begin subsequent recovery operations.

Excessive radiation dose
Any dose to personnel corresponding to an absorbed dose from neutrons and gamma rays equal to or greater than 0.12 Gy (12 rad) in free air.

External event
An event for which the likelihood cannot be altered by changes to the regulated facility or its operation. This would include all *natural phenomena events*, plus airplane crashes, explosions, toxic releases, fires, etc., occurring near or on the nuclear site.

Fissile material
A material, other than natural uranium, that is capable of sustaining a thermal neutron chain reaction.

Fissile nuclide
A nuclide capable of undergoing fission by interaction with slow neutrons provided the effective thermal neutron production cross section, $\upsilon\sigma_f$, exceeds the effective thermal neutron absorption cross section σ_a. Most actinide nuclides containing an even number of neutrons are non-fissile, but there may be exceptions, such as ^{232}U and ^{236}Pu (which have even numbers of neutrons and approximately equal thermal capture and fission cross sections), which perhaps can be made critical with slow neutrons. Conversely, whereas most nuclides with an odd number of neutrons are fissile, ^{237}U (which is an odd number of neutrons nuclide with a very small thermal fission cross section) cannot be made critical with thermal neutrons.

Fissionable
Capable of undergoing fission.

Fixed neutron absorber
Neutron absorbers in solids with an established geometric relationship to the locations occupied by fissionable material.

Fuel unit
The fundamental item to be handled, stored, or transported. It may be an assembly of fuel rods, canned spent fuel, or consolidated fuel rods.

***in situ* experiment**
Neutron multiplication or other nuclear reactivity-determining measurement on a subcritical fissile assembly where protection of personnel against the consequences of a criticality accident is not provided.

k_{eff}
See *effective multiplication factor (k_{eff})*.

light water reactor
A reactor that uses light water as coolant and/or moderator.

Management measures
Functions performed by the licensee, generally on a continuing basis, which are applied to *criticality safety controls*, to ensure the controls are available and reliable to perform their functions when needed. *Management measures* include configuration management, maintenance, training and qualifications, procedures, audits and assessments, incident investigations, records management, and other quality assurance elements.

Minimum accident of concern
The smallest accident, in terms of fission yield and dose rate, that a criticality alarm system is required to detect.

Moderation
The process of decreasing the energy of neutrons through successive collisions with moderator nuclei without appreciable competing capture.

Moderator
A material that reduces neutron energy by scattering without appreciable capture. Materials of prime concern are those containing light nuclei with large scattering cross sections and relatively low absorption cross sections.

Natural phenomena event
Earthquakes, floods, tornadoes, tsunamis, hurricanes, and other events that occur in the natural environment and could adversely affect safety. *Natural phenomena events* may be credible or incredible, depending on their likelihood of occurrence.

Natural uranium
Reference throughout this document to natural uranium shall be interpreted to mean uranium in which the concentration of the ^{235}U isotope is equal to or less than 0.71 wt%.

Neutron absorber
A neutron-capture material also referred to as a neutron poison.

Neutron absorber system
Any combination of fixed neutron absorbers, fixed moderators, and other materials with an assigned nuclear criticality safety function.

Nuclear criticality
Of or pertaining to a system that supports a sustained fission chain reaction.

Nuclear criticality safety
Protection against the consequences of a criticality accident, preferably by prevention of the accident.

Nuclear criticality safety control (CSC)
See *criticality safety control (CSC).*

Nuclear criticality safety staff (NCS Staff)
See *criticality safety staff.*

Operations with fissionable materials
Any activity involving the handling, use, processing, movement and storage of fissionable materials within nuclear facilities.

Process evaluation
A document that identifies and defines all known criticality safety concerns; documents criticality safety assumptions, requirements, limits, and controls; and demonstrates subcriticality. The process evaluation is often referred to as a Nuclear Criticality Safety Evaluation (NCSE).

Quality assurance (QA)
A planned and systematic pattern of all means and actions designed to provide adequate confidence that items or services meet specified requirements and will perform satisfactorily in service.

Raschig ring
A small, hollow, borosilicate-glass cylinder having approximately equal length and diameter.

Reactivity
A quantity proportional to $(k_{eff}-1) / k_{eff}$, where k_{eff} is the effective neutron multiplication factor. The reactivity of a subcritical fissile assembly is a negative quantity indicating the degree of subcriticality. The reactivity of a critical assembly is zero.

Site
A defined area that contains one or more facilities.

Soluble neutron absorber
Any neutron poison easily dispersed in liquid, solution, or suspension, used specifically to reduce the reactivity of a system and for which reactivity credit is taken in the nuclear criticality safety evaluation of the system.

Solution
Liquid containing dissolved fissile material, or a suspension of that fissile material in the liquid. This includes aqueous (water based) solutions but excludes those where the hydrogen is replaced by either deuterium or tritium.

Subcritical limit
The limiting value assigned to a controlled parameter that results in a subcritical system under specified conditions. The subcritical limit allows for uncertainties in the calculations and experimental data used in its derivation but not for contingencies; e.g., double batching or inaccuracies in analytical determinations.

Training
Instruction that imparts knowledge and skills necessary for safe and efficient on-the-job performance.

Uncertainty in the bias
A measure of both the accuracy and the precision of the calculations and the uncertainty of the experimental data.

Upper Subcritical Limit (USL)
An approved limit that cannot be changed in any specific calculation.

Validated computational technique
A calculational technique that has been validated in conformance with Section 2, *Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors*.

Verification
The establishment of confirmation of the truth or accuracy of a fact by investigation, comparison with a standard, or reference to the facts.

Vessel
A container designed to hold solution. This includes any volume within which criticality control is provided by Raschig rings.

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