EHS&L Document

SNM-1227 - Chapter 5
Nuclear Criticality Safety

Nature of Changes

Item	Paragraph	Description	Justification
1.	5.4.2.1	Changed the maximum evaluated neutron multiplication factor to 0.97 for worst case abnormal conditions.	To support the AFM project.
2.	5.4.2.1	Added two references to reference 21	A new validation document was issued.
3.	References	Added reference 21.	A new validation document was issued.
4.			
5.			
6.			
7.			
8.			
9.			
10.			

List Below any Documents, including Forms & Operator Aids which must be issued concurrently with this document revision:

NRC License Amendment Approval.		

This Document contains a total of 19 pages excluding the signature page.

DOCUMENT REVIEW/APPROVAL/DELETION CHECKLIST

All new and/or revised procedures shall be approved by the change author, cognizant manager(s) of areas affected by the changes, and by applicable manager(s) of any function that approved the previous revision of the document unless responsibility for such approval has been transferred to another organization. Also, the procedure shall be approved by manager(s) of functional organizations that provide technical reviews with the exception of the Training Department. Finally, Document Control shall verify that the required approvals have been properly obtained and that any documents that must be issued concurrently are ready to be issued.

Document Reviews			**Document Approvals**	
Purpose/Function of Review	Specify Reviewer(s) (Optional except for change author)	(Check all that apply)	Title of Approver	(Check all that Apply)
Document Control (Automatic)		☒	Document Control (Automatic)	☒
Change Author	CD Manning	☒	Author	☒
Independent Technical Review		☐		
Operability Review(s)			Mgr, Richland Operations(1)	☐
Conversion		☐	Mgr, Uranium Conversion & Recovery Operations(1)	☐
Recovery		☐		
Ceramics		☐	Mgr, Ceramic Operations(1)	☐
Rods		☐	Mgr, Rods & Bundles(1)	☐
Bundles		☐		
Components		☐	Mgr, Component Fabrication(1)	☐
Maintenance Review		☐	Mgr, Maintenance(1)	☐
Lab Review		☐	Mgr, Production Support(1)	☐
Transportation		☐	Mgr, Ops Strategy & Supply Chain	☐
EHS&L Review(s)			Mgr, EHS&L(2)	☒
Criticality	WL Doane	☒	Mgr, Nuclear Safety(2)	☐
Radiation Protection		☐		
Safety		☐	Mgr, Safety(2)	☐
Security/Emergency Prep.		☐	Mgr, Security & Emergency Preparedness(2)	☐
Fire Safety		☐		
MC&A		☐	Mgr, Licensing & Compliance(2)	☐
Transportation		☐		
Environmental		☐		
Mechanics Richland Review		☐	Mgr, Mechanics Richland	☐
Mechanics Lynchburg Review		☐		
Thermal-Hydraulics Richland Review		☐	Mgr, Thermal-Hydraulics Richland	☐
Thermal-Mechanics Richland Review		☐	Mgr, Materials & Therm-Mechs	☐
Project & Reliability Review		☐	Mgr, Project & Reliability Eng.	☐
Quality Review		☐	Mgr, Richland Site Quality	☐
Purchasing Review		☐	Mgr, PP&CPC	☐
Others:		☐	Mgr, Richland Site/Other	☐
Document Control		☐	Richland Records Management	☐
Training & Employee Dev.: (3)		☐	Training & Employee Dev.	☐

(1)Note: If approvals include 2 or more product center managers, the Operations manager can be substituted for the applicable product center managers.

(2)Note: If approvals include 2 or more EHS&L functional managers, the EHS&L manager can be substituted for the applicable EHS&L functional managers.

(3)Note: Training department review is required for all procedures that require or affect a Learning Plan and if additional training materials or curriculum must be revised before issuing procedure.

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EHS&L CHANGE IMPACT EVALUATION FORM

The scope and content of this document have been determined by EHS&L to not impact the safety disciplines checked below. Future revisions do not require review by those EHS&L component(s) unless the scope changes such that a previously excluded safety discipline may be impacted.

☐ Criticality ☐ Radiation Protection ☐ Safety/Security ☐ Emergency Preparedness ☐ MC&A ☐ Transportation ☐ Environmental

DOCUMENT VERSION:	EHS&L REVIEW COMPONENT:	EVALUATION DATE:	CHANGE EVALUATOR*: 2ND PARTY APPROVAL*:

The scope and content of this document have been determined by EHS&L to not directly impact the safe handling of licensed materials (enriched uranium). Future revisions to this document do not require the **10CFR 70.72** change evaluation unless the scope of the document changes such that it directly impacts the handling of licensed materials.	☐

DOCUMENT / ECN NO**: **E10-08-005**	EVALUATION DATE: **11/23/2021**	CHANGE EVALUATOR: **CD Manning**

Does the change potentially impact Criticality Alarm System (CAS) coverage?	☐ YES ☒ NO
EVALUATION OF NRC PRE-APPROVAL:	
IS NRC PRE-APPROVAL (LICENSE AMENDMENT) NEEDED? ➢ Based on "**YES**" answer to any of five questions below. ➢ Based on "**NO**" answer to all five questions below.	☒ YES ☐ NO
1. Does the change create new types of accident sequences that, unless mitigated or prevented, would exceed the performance requirements of **10 CFR 70.61** (create high or intermediate consequence events) and that have not previously been described in Framatome's ISA Summary?	☐ YES ☒ NO
2. Does the change use new processes, technologies, or control systems for which Framatome has no prior experience?	☐ YES ☒ NO
3. Does the change remove, without at least an equivalent replacement of the safety function an item relied on for safety **(IROFS)** that is listed in the ISA Summary?	☐ YES ☒ NO
4. Does the change alter any item relied on for safety, listed in the ISA Summary, that is the sole item preventing or mitigating an accident sequence of high or intermediate consequences?	☐ YES ☒ NO
5. Does the change qualify as a change specifically prohibited by NRC regulation, order or license condition?	☐ YES ☒ NO
Evaluation of Actions Required PRIOR TO OR CONCURRENT with Change Implementation:	
6. Modification / Addition to CAS system or system coverage documentation	☐ YES ☒ NO
7. Acquire NRC pre-approval (LICENSE AMENDMENT)	☒ YES ☐ NO
8. Conduct/modify ISA	☐ YES ☒ NO

9. Modify / update the following:	☐ None ☐ Other	☐ ISA Database ☐ Red-Line Drawings/P&ID	☐ NCSA ☐ NCSS	☐ NCSP ☐ PHA	☐ RHA ☐ FHA	☐ ChHA ☒ Procedures
Evaluation of Actions Required SUBSEQUENT TO Change Implementation:						
10. Modify / update the following:	☒ None ☐ Other	☐ ISA Database ☐ AS-Built Drawings/P&ID	☐ NCSA ☐ NCSS	☐ NCSP ☐ PHA	☐ RHA ☐ FHA	☐ ChHA ☐ Procedures

Justification Section for "YES" preceding Questions 1 – 8 or other for 9, 10: Being prepared as part of a License Amendment. Pre-approval of the amendment prior to issuing is required because this change can increases the upper subcritical limit for normal conditions.

(*) Only required if one or more of the boxes to exclude a particular safety discipline review is checked.

(**) If this form exists as a part of a document, the document number is not required.

Table of Contents

5.0 **Nuclear Criticality Safety**

5.1 *Program Applicability, Policy and Objectives*

Framatome Inc. (Framatome) maintains a nuclear criticality safety program that applies to special nuclear material (SNM) activities at the Richland Horn Rapids Road site.

It is Framatome's policy that the double contingency principle [(ANSI/ANS-8.1-1998 will be the basis for design and operation of the SNM processes within the Richland fuel fabrication facility. Where practicable, process designs will incorporate sufficient factors of safety to require at least two unlikely, independent, and concurrent changes in process conditions before a criticality accident is possible.

Nuclear criticality safety shall be assured to meet the requirements of 10CFR70 through both administrative and technical practices.

The objective of the NCS program is preventing an inadvertent nuclear criticality by:

- Conducting nuclear criticality safety analyses and implementing required Items Relied On For Safety (IROFS) to protect against accident sequences that could lead to an inadvertent nuclear criticality.
- Ensuring that sufficient IROFS, including limits and controls, are in place to render all credible nuclear criticality accident sequences highly unlikely.
- Establishing and maintaining NCS safety parameters and procedures to ensure approved margins of subcriticality.
- Establishing and maintaining limits and controls on IROFS to ensure that accidental nuclear criticality remains highly unlikely.
- Providing NCS postings in appropriate areas where SNM is processed or stored.
- Ensuring that personnel understand the policy that they are to report all suspect NCS conditions to the NCS function, only perform actions in accordance with approved procedures, and take no other action until the situation has been evaluated by the NCS staff and recovery instructions are provided.

5.2 *Organizational Structure*

Minimum qualifications of the NCS staff and the organizational relationship to other organizations with NCS responsibilities are described in Chapter 2.0.

The Manager of the EHS&L function is responsible for ensuring adequate staff, skilled in the interpretation of data pertinent to NCS and familiar with the operation of the facility.

The Manager of the NCS function is responsible for the implementation of the NCS program.

Qualified NCS personnel who are independent from the operations organization determine the basis for safety of processes involving the handling and storage of SNM. They shall assess both normal and credible abnormal conditions. They shall also specify functional requirements for criticality safety controls commensurate with design criteria and shall assist in assessment of control reliability.

Audits or assessments associated with the criticality safety program are described in Chapter 11.

5.3 ***NCS Program Administration***

5.3.1 Management Measures

The management measures programs are described in Chapter 11. Key programs include training, procedures development and implementation, records management, audits and assessments, configuration management, maintenance, and incident investigation/corrective action. The configuration management program includes a requirement that prior to use in a process, nuclear criticality safety controls selected and installed are verified to fulfill the requirements identified in the criticality safety analyses. Processes are examined in the "as-built" condition by qualified personnel working to approved procedures to validate the safety design and to verify the installation.

The configuration management program also ensures nuclear criticality safety requirements are maintained and that changes that may impact them are evaluated prior to making the change.

5.3.2 Criticality Safety Control Philosophy

The double contingency principle as defined in the American National Standard ANSI/ANS-8.1-1998 shall be followed in establishing nuclear criticality safety for equipment, systems and operations. Where practicable, process designs shall incorporate sufficient factors of safety during normal and credible abnormal conditions to require at least two unlikely, independent, and concurrent changes in process conditions before a criticality accident is possible. Additionally, accidental nuclear criticality will be demonstrated to be at least highly unlikely.

Process deviations for which there is a convincing argument given physical laws or experimental data that they are not possible are considered not credible.

Double contingency may be provided by either: (i) at least two-parameter control (the control of at least two independent process parameters) or (ii) single-parameter control (a system of multiple independent controls on a single process parameter) The first method is the preferred approach.

Where practical, reliance will be placed on equipment design in which dimensions are limited (i.e., favorable geometry) rather than on administrative controls. Where structural integrity is necessary to provide assurance for safety, the design and construction of the equipment will be made with due regard to abnormal loads, accidents and deterioration.

5.3.3 Preferences of NCS Controls

The relative effectiveness and reliability of controls are considered during the criticality safety analysis process. Passive engineered controls are preferred over other system controls and are utilized when practical and appropriate. Active engineered controls are the next preferred method of control followed by administrative controls.

To be considered a viable defense against accidental criticality, a criticality safety control or set of controls must be capable of preventing a criticality accident independent of the operation or failure of any other defense for a given credible initiating event.

Passive Engineered Controls are physical restraints or features that maintain criticality safety in a static manner (e.g., fixed geometry, fixed spacing, fixed size, fixed nuclear poisons, etc.). Beyond appropriate initial installation, passive engineered controls require no action or other response to be effective when called upon to ensure nuclear criticality safety. In addition to configuration management, assurance is maintained through specific periodic inspections or verification measurement(s) as appropriate.

Active Engineered Controls are a means of criticality control involving active hardware (e.g., electrical, mechanical, hydraulic) that protect against criticality. These devices act by sensing a process variable important to criticality safety and providing automatic action (i.e. no human intervention required) to secure the system to a safe condition. In addition to configuration management, assurance is maintained through specific periodic functional testing as appropriate. Active engineered controls that are provided with fail-safe conditions (i.e. the failure of the control results in a safe condition) are the preferred type of active engineered control.

Enhanced Administrative Controls involve human intervention augmented by warning devices or other automated prompts and are preferred over simple procedural requirements for a specific action.

Administrative Controls are controls that rely on actions, judgment, and responsible actions of people for their implementation. Their use is limited to situations where passive and active engineered controls are not practical. Assurance is maintained through selected management measures.

5.3.4 Nuclear Criticality Safety Analyses (NCSAs)

Operations or processes where the NCS program applies shall be determined by a documented peer reviewed and approved NCSA to be adequately subcritical prior to the start of activities with SNM. Both normal and credible abnormal conditions shall be evaluated and accidental nuclear criticality shall be demonstrated to be at least highly unlikely.

NCSAs shall identify and document the basis of nuclear criticality safety for a particular system. The NCSA demonstrates that NCS criteria including meeting the double contingency principle are met.

The NCSA includes consideration of the potential accident scenarios or initiating events that the system may be subject to and the potential consequences associated with such conditions, and establishes the needed limits, controls, and management measures to ensure that an accidental nuclear criticality is highly unlikely. With the addition of the other safety discipline information, the NCSA is a major portion of the Integrated Safety Analysis (ISA) documentation required to demonstrate compliance with 10 CFR 70.62.

- NCSAs shall be performed and independently reviewed by personnel who meet the requirements specified in Section 2.2.5.1. Such personnel may either be Framatome or contractor employees.
- Records of NCSAs and reviews shall be documented and retained in accordance with Chapter 11, Section 11.7.

5.3.5 Nuclear Criticality Safety Specifications (NCSSs)

NCSSs describe NCS requirements implemented by user organizations.

NCSSs established to document controls for SNM processing systems and storage areas shall be prepared based on limits established in approved and applicable nuclear criticality safety analyses. The NCSSs may be a section of the NCSA or a separate document. NCSSs shall contain, as appropriate, the following information: work location(s), equipment covered, SNM type allowed in the process or storage area, and the associated NCS limits and controls.

5.3.6 NCS Postings

Nuclear criticality safety postings (NCSPs) approved by the NCS function shall be posted at locations where SNM is handled, processed, transported, or stored as determined by the NCS function.

NCSPs contain selected criticality safety limits and controls controllable or observable by the user. The NCSPs normally include the type and form of material permitted, allowable quantity, restrictions on moderators, and required spacing from other special nuclear material. NCSPs are used in conjunction with operating procedures.

5.3.7 Operating Procedures

Operations in which nuclear criticality safety is pertinent shall be governed by written procedures. Personnel working with SNM shall follow these procedures. Persons supervising these operations shall be required to be familiar with such procedures.

The NCS function shall approve operating procedures and procedure changes involving fissile material processing and storage.

5.3.8 Fissile Content Determination

The fissile isotope content (enrichment) of incoming SNM shall be confirmed to meet NCS limits on enrichment prior to the conduct of any activity other than storage and sampling. Nondestructive analysis or laboratory analysis of material sampled on plant site or provided by the supplier may be used to make this determination.

5.3.9 Reporting Off-Standard NCS Conditions

Off-standard NCS conditions, regardless of how they are discovered, shall be reported to management and the NCS function and shall be resolved in accordance with the problem identification and corrective action follow up program described in Chapter 11 and, when necessary, in accordance with emergency response procedures.

When such conditions are observed, only recovery actions in accordance with approved procedures are allowed and no other action is permitted until the situation has been evaluated by the NCS staff and recovery instructions are provided.

5.3.10 Operational and Incident Reviews

A system of criticality safety audits and assessments shall be established (see Chapter 11, Section 11.5). The purpose of these reviews shall be to confirm that the criticality safety program meets the intended functions.

Criticality safety-related incidents are subject to the corrective action, incident investigation and causal analysis programs described in Chapter 11.

In addition to audits and assessments, the NCS staff conducts walkthroughs of the various process areas. These walkthroughs are conducted per approved procedures and consistent with these procedures, the frequency of the walkthroughs is based on plant activity levels and safety performance.

5.3.11 Emergency Procedures

Guidance on classifying, reporting, and responding to actual or potential criticality accidents shall be provided to personnel responsible for these activities.

Personnel other than escorted visitors shall be trained to the proper response to an activation of the Criticality Accident Alarm System.

5.4 ***Methodologies and Technical Practices***

Framatome uses NCS methodologies for calculating k_{eff} that meet the requirements of ANSI/ANS-8.1-1998 as it relates to methodologies.

The authorized technical practices used to establish controls on controlled parameters that will ensure an adequate margin of subcriticality include the following:

- Using validated computer codes to calculate the effective multiplication factor (k_{eff}) (see section 5.4.1)
- Comparing critical values to peer reviewed handbooks and applying approved safety factors.
- Using single parameter subcritical limits listed in NRC endorsed ANSI/ANS Series 8 standards.
- Using empirical/semi-empirical techniques such as Buckling/Shape Conversion, Surface Density, Limiting Surface Density, Density Analog and Solid Angle Methods as described in Reference 20.

5.4.1 Methodologies for Calculating k_{eff}

If the methodology employs computer programs for calculating the effective multiplication factor (k_{eff}), the software and hardware associated with the program shall be controlled to ensure that changes that could impact results are evaluated prior to using them in criticality safety analysis calculations.

The documentation of the validation of methods used for calculating k_{eff} will include the following elements:

1. Justification for the safety margin applied to the methodology.
2. Justification that the methodology is applicable for the intended use.
3. A description of the theory of the methodology in sufficient detail to allow understanding of the methodology.
4. A description of how the methodology was verified to function correctly.
5. A description of the data used to validate the methodology and an explanation as to why they are applicable to plant conditions.
6. Any assumptions or boundaries that could limit the appropriate use of the methodology.
7. Justification of any extrapolations of its use beyond the area of applicability of the benchmark experiments. These methods will include trending of the bias.
8. A description of any calculation bias, and total methods uncertainty including uncertainty in the bias and benchmark experiments.

9. If the methodology uses computer calculations, a description of the software version and hardware configuration that has been validated.

The use of critical or near critical benchmarks shall be referenceable and peer reviewed.

5.4.2 Technical Practices

The technical criticality safety practices are summarized in this section. Section 5.4.2.1 discusses the limits placed on the maximum effective multiplication factor. Sections 5.4.2.2 through 5.4.2.15 discuss the parameters used to control the effective multiplication factor to acceptable values at normal and credible abnormal conditions and include acceptable alternatives to calculated k_{eff} limits.

5.4.2.1 Limits on Maximum Multiplication Factors

The maximum evaluated neutron multiplication factor ~~at normal and credible abnormal conditions~~ shall not exceed $k_{95/95}$ = ~~0.95 for normal conditions or~~ 0.97 for credible abnormal conditions, if justified by a sensitivity analysis. The documented justification accompanying this sensitivity analysis shall clearly discuss the sufficiency of the margin of subcriticality in terms of the parameters being controlled. The definition of $k_{95/95}$ is as shown below.

$$k_{95/95} = k_{calc} + 2\sigma + \Delta k_b$$

where:

σ = The statistical or convergence uncertainties in the calculation of k_{calc}.

Δk_b = The calculational bias.

Alternatively, $k_{95/95}$ may be calculated from the expression:

$$k_{95/95} = k_{calc} + \Delta k_b + \Delta k_u$$

where:

Δk_b = The mean calculational method bias.

Δk_u = The uncertainty term defined by $M_{95/95}\,(\sigma_m^2 + \sigma_{keno}^2)^{1/2}$ where $M_{95/95}$ is the 95/95 multiplier appropriate to degrees of freedom for the number of validation analyses, σ_m^2 is the mean calculational variance deduced from the validation analyses, and σ_{keno} is the standard deviation appropriate to the KENO multiplication factor of interest.

The bias and its standard deviation are calculated using the methods described in References 17 and 21. These methods use standard analysis of variance principles.

Δk_b is calculated as $1-k_c$. The value for k_c is the weighted average (grand average) of the average k_{eff} values for a series of benchmark cases that are applicable to the system being modeled. Each individual benchmark case is weighted by the inverse of the k_{eff} variance (square of standard deviation). A negative bias indicates conservative calculational results. A conservative bias will not be used unless the reason for the bias is well understood and justified.

The value for Δk_u is a statistical combination of several uncertainties. These uncertainties include σ_m^2 (the mean calculational method variance deduced by the validation analysis) and σ^2_{keno} (the square of the standard deviation appropriate to the KENO multiplication factor of interest). The

9. If the methodology uses computer calculations, a description of the software version and hardware configuration that has been validated.

The use of critical or near critical benchmarks shall be referenceable and peer reviewed.

5.4.2 Technical Practices

The technical criticality safety practices are summarized in this section. Section 5.4.2.1 discusses the limits placed on the maximum effective multiplication factor. Sections 5.4.2.2 through 5.4.2.15 discuss the parameters used to control the effective multiplication factor to acceptable values at normal and credible abnormal conditions and include acceptable alternatives to calculated k_{eff} limits.

5.4.2.1 Limits on Maximum Multiplication Factors

The maximum evaluated neutron multiplication factor shall not exceed $k_{95/95} = 0.97$ for credible abnormal conditions, if justified by a sensitivity analysis. The documented justification accompanying this sensitivity analysis shall clearly discuss the sufficiency of the margin of subcriticality in terms of the parameters being controlled. The definition of $k_{95/95}$ is as shown below.

$k_{95/95} = k_{calc} + 2\sigma + \Delta k_b$

where:

σ	=	The statistical or convergence uncertainties in the calculation of k_{calc}.
Δk_b	=	The calculational bias.

Alternatively, $k_{95/95}$ may be calculated from the expression:

$k_{95/95} = k_{calc} + \Delta k_b + \Delta k_u$

where:

Δk_b	=	The mean calculational method bias.
Δk_u	=	The uncertainty term defined by $M_{95/95}\ (\sigma_m^2 + \sigma_{keno}^2)^{1/2}$ where $M_{95/95}$ is the 95/95 multiplier appropriate to degrees of freedom for the number of validation analyses, σ_m^2 is the mean calculational variance deduced from the validation analyses, and σ_{keno} is the standard deviation appropriate to the KENO multiplication factor of interest.

The bias and its standard deviation are calculated using the methods described in References 17 and 21. These methods use standard analysis of variance principles.

Δk_b is calculated as $1-k_c$. The value for k_c is the weighted average (grand average) of the average k_{eff} values for a series of benchmark cases that are applicable to the system being modeled. Each individual benchmark case is weighted by the inverse of the k_{eff} variance (square of standard deviation). A negative bias indicates conservative calculational results. A conservative bias will not be used unless the reason for the bias is well understood and justified.

The value for Δk_u is a statistical combination of several uncertainties. These uncertainties include σ_m^2 (the mean calculational method variance deduced by the validation analysis) and σ^2_{keno} (the square of the standard deviation appropriate to the KENO multiplication factor of interest). The term σ_m^2 is the sum of the variance about the mean and the average total uncertainty which includes consideration of the uncertainty of the benchmark experiments. The pooled uncertainty [$(\sigma_m^2 + \sigma_{keno}^2)^{1/2}$] is multiplied by the 95/95 multiplier appropriate for the degrees of freedom for a one-sided 95% confidence limit. The 95% upper limit for k_{eff} of a process system is the sum of the calculated k_{eff} for the most reactive credible condition for the system, plus the bias, plus the pooled uncertainty that has been multiplied by the appropriate k factor.

The specific validation method used will be described in the appropriate validation documents, and may alternatively include nationally-recognized methods such as those documented in NUREG/CR-4604, "Statistical Methods for Nuclear Material Management"; NUREG/CR-6361, "Criticality Benchmark Guide for Light Water Reactor Fuel in Transportation and Storage Packages"; and NUREG/CR-6698 "Guide for Validation of Nuclear Criticality Safety Calculational Methodology".

The current validation documents are listed in References 17, and 21. Whenever Framatome makes significant changes to these documents , Framatome will notify the NRC by letter and will include in that letter a description of the changes made.

5.4.2.2 Limits on Controlled Parameters

When establishing limits on controlled parameters for credible abnormal conditions, conditions that are not controlled or limited shall be considered to be in the optimum credible condition for causing criticality. These parameters include heterogeneity. Less than optimum conditions may be used when historical data and/or sound engineering determinations can be applied to justify a lesser reactive condition. Data may be obtained by controlled experimentation.

When less than the optimum credible conditions for causing criticality are used, the justification for such use shall be documented in a peer reviewed and approved safety analysis.

5.4.2.3 Mass Limits

Mass Limits on Uranium

Mass limits on fissile material may be used for criticality control on their own or in combination with other controlled parameters. Mass may be controlled such that the k_{eff} of the unit / process meet the guidelines given in Section 5.4.2.1.

Workstations that are controlled only by fissile material mass shall conform to the following requirements:

1. Where engineered controls do not prevent double batching, the work station shall be limited to no more than 0.45 of the minimum critical mass, assuming spherical geometry, of the material in process;
2. A record shall be maintained of the SNM inventory at the mass-limited workstation; and
3. Where engineered controls prevent double batching, and mass is the only controlled parameter, a mass of 75% of a minimum critical mass shall not be exceeded.

Mass Limits on Moderators

Mass limits on moderators may be used in conjunction with fissile material mass limits or concentration limits on moderators.

5.4.2.4 Areal Density Limits

Areal density limits on fissile material may be used for criticality control. Workstations or processes that are controlled by areal density shall conform to the following requirements:

1. The work station or process shall be limited to no more than 0.45 of the minimum critical areal density.
2. The calculation of areal density shall assume the maximum credible mass is present and is distributed over the minimum credible area.
3. SNM shall be assured to not build up over time to the extent that the areal density limit is exceeded.

When areal density control is used and process variables can impact the areal density of the material produced, the process variables that are needed to assure a safe areal density shall be controlled.

5.4.2.5 Limiting Surface Density Limits

Limiting surface density limits on fissile material, as shown in Appendix D of Reference 20, may be used for criticality control.

5.4.2.6 Geometry

Safe dimensions and/or volumes may be established by using any one of the following safety factors:

1. The k_{eff} of the unit may be established by using the guidelines given in Section 5.4.2.1; or
2. Critical dimensions and/or volumes from NRC endorsed ANSI/ANS Series 8 standards or peer reviewed NCS handbooks multiplied by the applicable safety factors given in Tables 5-1 and 5-2. When cylinders and slabs are not infinite in extent, safe dimensions may be increased by means of standard buckling conversion methods or reactivity formula calculations which incorporate validated k-infinities, migration areas (M2), and extrapolation distances.

Where applicable, dimensional limitations shall include an allowance for fabrication tolerance and/or potential dimensional changes from corrosion or mechanical distortion.

When favorable geometry is not designed into equipment, geometry control may be achieved by altering the piece of equipment or by controlling the geometry of the fissile material administratively. An example of such alteration is the installation of drain holes in an otherwise non-safe vessel to control solution slab thickness. Geometry control may also be achieved by administrative action such as limiting the depth of fuel rods on a storage tray or by controlling the volume of a single container or the cumulative volume of multiple containers at a work station.

5.4.2.7 Density

Control of material density may be used to limit the k_{eff} of the unit to meet the guidelines given in Section 5.4.2.1.

When process variables are controlled to limit material density, the process variables will be controlled by IROFS. When density is measured, the measurement shall be made by qualified and controlled methods.

5.4.2.8 Enrichment

Designs shall assume ^{235}U enrichment of 5.0 wt.% unless at least one of the following criticality safety controls on enrichment is established:

- Active engineered controls are established to verify enrichment and to prevent the introduction of uranium at unacceptable enrichment levels within the process system.
- Administrative controls are established to prevent the introduction of unacceptable enrichments within a defined subsystem within the same area. Considerations shall include minimizing human error such as using physical separation of areas of differing enrichment limits when practical.

5.4.2.9 Reflection

Critical parameters for units and arrays of units at abnormal conditions shall be based on full water reflection (30 cm), unless other reflectors in the immediate vicinity could result in higher reactivities, or controls on reflection are established to ensure that the k_{eff} meets the limits in Section 5.4.2.1. In such cases, the limitations on reflectors that are needed to assure criticality safety shall be controlled such that exceeding the amount of reflection assumed in establishing k_{eff} limits for credible abnormal conditions is highly unlikely.

5.4.2.10 Moderation

Critical parameters derived from nuclear criticality safety analyses shall be based on optimum credible moderation, unless controls on the amount of moderator are applied, or other controls on moderators are established to ensure that the k_{eff} meets the limits in Section 5.4.2.1.

The amount of hydrogenous material within the SNM may also be limited to a small percentage by weight of the SNM (moderation control) to prevent criticality, provided that each of the following is met:

1. The permitted concentration of hydrogenous material shall be equal to or less than 50 percent of the critical concentration for the system in question;
2. No credible accident conditions exist where localized concentration of the hydrogenous material could cause the k_{eff} guidelines given in Section; 5.4.2.1 to be exceeded.
3. The material shall be contained within a fire resistant barrier, or in a process area containing limited sources of hydrogenous material. In the absence of a fire resistant or noncombustible barrier, controls shall be used to prevent fires and to control the use of moderators in fire fighting in such process areas.

When moderation control is used and process variables can impact the moderator content of the material produced, the process variables needed to assure a safe amount of moderator shall be controlled.

Other mechanisms of controls on moderators may be used if established consistent with ANSI/ANS-8.22-1997.

5.4.2.11 Uranium Concentration Control

Uranium concentration control may be used for criticality control in areas where geometry control is not practical.

The concentration of uranium dispersed or dissolved in another medium may be limited to prevent criticality based on either of the following:

1. The concentration limit shall assure that the k_{eff} meets the limit in Section 5.4.2.1 at normal and credible abnormal conditions. The abnormal conditions evaluated shall include:
    a. credible sources of high concentrations of SNM unless analyzed safe at any concentration
    b. precipitation or other credible mechanisms concentrating the SNM to the most reactive credible extent;
    c. increasing the concentration of the SNM to the maximum credible extent due to effects such as evaporation; and
    d. for arrays of units on concentration control, additional abnormal conditions to include (as applicable) array size, unit spacing, and interspersed moderation effects.

or

2. When using handbook values, the concentration limit at worst case credible conditions, including credible precipitation and other mechanisms of concentrating the SNM, shall not exceed 50 percent of the minimum critical concentration in the system being evaluated.

When concentration control is used, the actual concentration shall be measured prior to using concentration control or the process variables that can impact the concentration of the material produced shall be controlled to ensure a safe concentration.

Precautions shall be taken to ensure that precipitating agents will not be inadvertently introduced, e.g. using a normally closed tank. The effect and limitations placed in precipitants may be determined by controlled experimentation.

5.4.2.12 Neutron Interaction

Neutron interaction (exchange between individually subcritical units) shall be considered. Equipment within 365 cm (nominally 12 feet) that contains fissile material shall be considered. Equipment and facilities may be considered to be neutronically isolated if they are separated by any of the following:

- A 30 cm thick slab of water
- A 30 cm thick water equivalent slab of concrete
- 365 cm (nominally twelve feet) of air

The following item may also be excluded from interaction considerations:

- Individual transfer pipes two inches or less in diameter

5.4.2.13 Spacing and Multi-Unit Arrays

The required spacing between moderated units within an array shall be clearly delineated or limited by mechanical means such that at least one of the following requirements is met:

1. The k_{eff} of the array under the maximum credible accident conditions shall be limited by the guidelines given in Section 5.4.2.1;
2. For multi-unit arrays, the number of units in the array does not exceed 50 percent of the calculated critical number.
3. The system may be compared to and shown to meet accepted empirical criteria, (e.g., Solid Angle methods).

The mechanical design of equipment or storage arrays in which deformation or rearrangement could result in the loss of a controlled parameter shall be reviewed for adequacy and verified to be correctly installed.

In instances where physical spacing restrictions from the design of equipment are credited in the supporting analyses, dimensions and, if applicable, nuclear properties will be verified. The facility configuration management program will be used to maintain these parameters.

5.4.2.14 Neutron Absorbers

Fixed Neutron Absorbers

Criticality safety may be assured through the use of fixed neutron absorbers, for example cadmium or boron, provided that:

1. Neutron absorbers are designed and fabricated as an integral part of the equipment;
2. Inspections to verify the continued integrity of the equipment and neutron absorber structure shall be performed on established time frequencies sufficient to ensure their effectiveness.

Borosilicate glass Raschig rings may be used in solutions of fissile material in a manner consistent with ANSI/ANS Standard 8.5-1996.

Neutron Absorber Additives

Credit in the calculation of minimum critical mass or other critical parameters may be taken for the presence of neutron absorbers added to SNM during processing provided that:

1. Its continued presence and uniform distribution in the SNM can be ensured; and
2. The quantity of additive was confirmed to meet the required amount.

Soluble neutron absorbers may be used in a manner consistent with ANSI/ANS-8.14-2004.

5.4.2.15 Process Parameter Controls

The facility may rely on control of process parameters for criticality control, e.g. the control of process temperature and residence time to assure dry powder.

When process variables are used for NCS controls, the process variables that are needed to ensure safe conditions shall be controlled. The bounding conditions and operational limits shall be specifically identified in the criticality safety analysis.

5.5 *Criticality Accident Alarm System (CAAS)*

SNM covered by the NCS program (see section 5.1) shall be located such that at least two detectors in the alarm system are capable of detecting a criticality originating in the material. The system shall be capable of detecting, with at least two detectors, a criticality that provides an absorbed dose in soft tissue of 20 rads of combined neutron and gamma radiation at an unshielded distance of two meters from the reacting material within one minute. This capability meets the requirements of 10CFR70.24(a)(1) and the requirements of ANSI/ANS-8.3-1986. Documentation of this capability shall be maintained by Framatome.

The criticality accident alarm system initiates immediate evacuation of the facility. Employees are trained in recognizing and responding to the evacuation signal.

The alarm shall be clearly audible in areas that must be evacuated or alternate means of notification shall be provided to notify personnel that evacuation is necessary.

The nuclear criticality accident alarm system is maintained through routine calibration and scheduled functional tests conducted in accordance with internal procedures. In the event of loss of normal power, emergency power is supplied to the criticality accident alarm system.

Should the nuclear criticality accident alarm system or a portion of the system be out of service for a period of more than four hours, movement of SNM in the affected area will cease until the alarm service has been restored, or until compensatory monitoring, approved by the nuclear criticality safety component, has been implemented.

The CAAS system shall be uniform throughout the facility for the type of radiation detected, the mode of detection, and the sound generated by the alarm signal.

Routine testing, calibration and/or maintenance of the system may be performed by trained and authorized personnel in accordance with procedures approved by the Manager of the EHS&L function or his delegate. These procedures shall include the use of continuously attended portable detection instrumentation and the capability to issue area-wide emergency communication when the activity results in the system being out of service.

5.6 *Sources of Criticality Data and Analytical Techniques*

Framatome authorizes the NCS Staff to use the following sources of criticality data and analytical techniques in performing criticality safety analyses:

1. J. H. Chalmers, G. Walker, and J. Pugh, "Handbook of Criticality Data," UKAEA Handbook AHSB (S), 1965.
2. H. C. Paxton, J. T. Thomas, D. Callihan, and E. B. Johnson, "Critical Dimensions of Systems Containing 235U, 239Pu, and 233U," TID-7028, Division of Technical Information Extension, USAEC (1964).
3. Subcommittee 8 of the American Standards Association Sectional Committee N6 and Project 8 of the American Nuclear Society Standards Committee, "Nuclear Safety Guide," TID-7016, Rev. 2, Division of Technical Information Extension, USAEC (1978).
4. H. K. Clark, "Critical and Safe Masses and Dimensions of Lattices of U and UO2 Rods in Water," DP-1014, Savannah River Laboratory (1966).
5. H. K. Clark, "Maximum Safe Limits for Slightly Enriched Uranium and Uranium Oxide," Criticality Control of Fissile Materials, International Atomic Energy Agency, Vienna (1966), pp. 35-49.

6. H. C. Paxton, "Criticality Control in Operations with Fissile Material," LA-3366, Los Alamos Scientific Laboratory (1972).
7. H. F. Henry, C. E. Newlon, and J. R. Knight, "Extensions of Neutron Interaction Criteria," K-1478, Union Carbide Corporation, Nuclear Division (1969).
8. C. E. Newlon, AEC Research and Development Report, "Minimum Critical Cylinder Diameters of Hydrogen Moderated U (4.9) Systems," K-1629, Union Carbide Corporation, ORGDP, (1965).
9. Standards Committee N16 of the American National Standards Institute, "Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors," ANSI N16.1-1969, American National Standards Institute, New York, NY (1969).
10. R. D. Carter, G. R. Kiel, and K. R. Ridgway, "Criticality Handbook," Volumes I, II, and III, ARH-600, Atlantic Richfield Hanford Company, (1968).
11. W. Thomas, W. Weber, and W. Heinicke, "Handbuch zur Kritikalitat," (1970-73).
12. H. F. Henry, "Studies in Nuclear Safety," K-1380, (1957).
13. C. L. Brown, "Nuclear Criticality Safety Analysis, Uranium Fuels Plant," Jersey Nuclear Company, BNW/JN-29, (1971).
14. "Determination of H/U Ratios in UO2 Water and ADU-Water Mixtures," JN-71-2, (1971).
15. C. L. Brown, et. al., "Validation of Boundary Conditions for Assuming Nominal Reflection in Solid Angle Interaction Method (As Applied in Exxon Fuel Fabrication Plants)," BNW/XN-184, (1975).
16. "SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation," NUREG/CR-0200.
17. EMF-2670 PC-SCALE 4.4a Validation Revision 2, dated March 10, 2004.
18. American Nuclear Society, "Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors," ANSI/ANS 8.1-1998.
19. US Nuclear Regulatory Commission Regulatory Guide 3.14, "Validation of Calculational Methods for Nuclear Criticality Safety."
20. Ronald Allen Knief, “Nuclear Criticality Safety Theory and Practice.” American Nuclear Society, 1993.
21. E04-04-0-009, “SCALE 6.2.2 7wt% Enrichment Benchmark Validation Report.”

Table 5-1 Safety Factors for Homogeneous Single Units

Safety Parameter	**Critical Parameter**	**Safety Factor**
Safe Mass SNM, M_s	Critical Mass SNM, M_k	0.45
Safe Mass SNM, M_{sL} (Exceeding of M_{sL} is excluded by engineering controls)	Critical Mass SNM, M_k	0.75
Safe Mass Moderator, M_{smod}	Critical Mass of Moderator, M_{kmod}	0.50
Safe Spherical Volume, V_s	Critical Spherical Volume,	0.80
Safe Infinite Cylinder, D_s	Critical Infinite Cylinder, D_k	0.90
Safe Infinite Slab, S_s	Critical Infinite Slab, S_k	0.85
Safe Concentration, C_s	Critical Concentration, C_k	0.50

Table 5-2 Safety Factors for Heterogeneous Single Units

Safety Parameter	Critical Parameter	Safety Factor
Safe Mass SNM, M_s	Critical Mass SNM, M_k	0.45
Safe Mass SNM, M_{sL} (Exceeding of M_{sL} is excluded by engineered controls)	Critical Mass SNM, M_k	0.75
Safe Mass Moderator, M_{smod}	Critical Mass of Moderator, M_{kmod}	0.50
Safe Spherical Volume, V_s	Critical Spherical Volume, V_k	0.80
Safe Infinite Cylinder, D_s	Critical Infinite Cylinder, D_k	0.90
Safe Infinite Slab, S_s	Critical Infinite Slab, S_k	0.85