6. NUCLEAR CRITICALITY SAFETY

The Nuclear Criticality Safety Program for the Mixed Oxide (MOX) Fuel Fabrication Facility (MFFF) will be in accordance with U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide 3.71, *Nuclear Criticality Safety Standards for Fuels and Material Facilities.* Regulatory Guide 3.71 provides guidance on complying with the applicable portions of NRC regulations, including 10 CFR Part 70, by describing procedures for preventing nuclear criticality accidents in operations involving handling, processing, storing, and transporting special nuclear material (SNM) at fuel and material facilities. The MFFF will follow the guidelines in this regulatory guide for specific criticality safety standards drafted by Subcommittee ANS-8 (Fissionable Materials Outside Reactors) of the American Nuclear Society Standards Committee for these purposes.

6.1 ORGANIZATION AND ADMINISTRATION

Duke Cogema Stone & Webster (DCS) will establish a criticality safety organization and administration prior to operation of the MFFF. The criticality safety organization will be responsible for implementing a Nuclear Criticality Safety Program. The criticality safety function during the design phase and envisioned for operations is described in the following section.

6.1.1 Criticality Safety Function (Design Phase)

The MFFF Engineering Manager (see Section 4.1.9) is responsible for the design of the facility and site-related interfaces for the MFFF, including the nuclear discipline (within the Facility Design function) that encompasses the criticality safety function during the design phase. The criticality safety function is responsible for the following during the design phase:

- Establish the Nuclear Criticality Safety design criteria
- Provide criticality safety support for integrated safety analyses and configuration control
- Assess normal and credible abnormal conditions
- Determine criticality safety limits for controlled parameters
- Develop and validate methods to support nuclear criticality safety evaluations (NCSEs)
- Perform criticality safety calculations and write NCSEs
- Specify criticality safety control requirements and functionality.

The minimum qualifications for a criticality safety function manager are a Bachelor of Science (BS) or Bachelor of Arts (BA) degree in science or engineering with at least three years of nuclear industry experience in criticality safety. A criticality safety function manager must understand and have experience in the application and direction of criticality safety programs. A criticality safety function manager has the authority and responsibility to assign and direct activities for the criticality safety function.

The minimum qualifications for a senior criticality safety engineer are a BS or BA degree in science or engineering with at least three years of experience in nuclear criticality safety work. A senior criticality safety engineer has the authority and responsibility to conduct activities assigned to the criticality safety function.

The minimum qualifications for a criticality safety engineer are a BS or BA degree in science or engineering with at least one year of nuclear industry experience in criticality safety. A criticality safety engineer has the authority and responsibility to conduct activities assigned to the criticality safety function, with the exception of independent verification of NCSEs.

The MFFF implements the administrative practices for criticality safety, as contained in Section 4.1 of American National Standards Institute/American Nuclear Society (ANSI/ANS)-8.1-1983 (R1988), *Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors*. The MFFF also implements the administrative practices for criticality safety, as contained in American National Standards Institute/American Nuclear Society ANSI/ANS-8.19-1996, *Administrative Practices for Nuclear Criticality Safety*. See Section 6.4 for more information.

6.1.2 Criticality Safety Function (Operations Phase)

The criticality safety function is anticipated to report to the Regulatory Manager (see Chapter 4), who in turn has the authority to make commitments to the NRC and is accountable for overall safety of the facility. The criticality safety function is administratively independent of production responsibilities and has the authority to shut down potentially unsafe operations. Designated responsibilities of the criticality safety function include the following:

- Establish the Nuclear Criticality Safety Program, including design criteria, procedures, and training
- Provide criticality safety support for integrated safety analyses and configuration control
- Assess normal and credible abnormal conditions
- Determine criticality safety limits for controlled parameters
- Develop and validate methods to support NCSEs
- Perform criticality safety calculations, write NCSEs, and approve proposed change-in-process conditions on equipment involving fissionable material
- Specify criticality safety control requirements and functionality
- Provide advice and counsel on criticality safety control measures, including review and approval of operating procedures
- Support emergency response planning and events
- Assess the effectiveness of the Nuclear Criticality Safety Program through audit programs
- Provide criticality safety postings that identify administrative controls for operators in applicable work areas.

The minimum qualifications for a criticality safety function manager are a Bachelor of Science (BS) or Bachelor of Arts (BA) degree in science or engineering with at least three years of nuclear industry experience in criticality safety. A criticality safety function manager must understand and have experience in the application and direction of criticality safety programs. A criticality safety function manager has the authority and responsibility to assign and direct activities for the criticality safety function.

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The MFFF has a policy that fosters ownership of criticality safety by organizations at all levels; that requires personnel to report defective criticality safety conditions to the criticality safety function for analysis and corrective action; and that requires that they take no further action not specified by approved written procedures until the criticality safety function has analyzed the situation.

6.2 MANAGEMENT MEASURES

DCS will establish management measures prior to operating the MFFF. Management measures provide reasonable assurance that items relied on for safety (IROFS) will be available and reliable to perform their designated safety functions when needed.

Additionally, a formal configuration management program (Section 15.2) is implemented and will evolve for the MFFF. This program will ensure that the MFFF design will remain consistent with the design analyzed by the NCSEs. The program will also ensure that changes to the MFFF design will have appropriate review and controls in place. The implementation of this formal configuration management program will ensure that (1) facility changes are managed to maintain the integrity of the MFFF safety basis and to ensure the changes receive the appropriate level of criticality safety review, and (2) MFFF changes requiring NRC approval are appropriately identified and treated. The MFFF will implement measures to meet the requirements of 10 CFR §70.64 to ensure that the initial facility design meets the baseline design criteria for criticality safety.

Chapter 15 describes the management measures currently envisioned for general MFFF operation. Management measures will be further described in the MFFF license application for possession and use of SNM and will include training, procedures, and audits and assessments.

Specific criticality-related management measures are discussed in the following sections.

6.2.1 Nuclear Safety Training

Employees must complete formal nuclear safety training prior to being granted unescorted access in the restricted area. Methods for evaluating training effectiveness include an initial examination covering the formal training content and observations of operational activities as appropriate during scheduled audits and inspections.

Trained instructors approved by the manager of the criticality safety function and/or the manager of the radiation safety function, as appropriate, perform the training. The managers of the criticality safety and radiation safety functions ensure that the content of the training program is current and adequate by reviewing the training program content on a regularly scheduled basis.

Records of previously trained employees who are allowed unescorted access to the MFFF are retained in accordance with the records program. Visitors are trained commensurate with the scope of their visit and/or are escorted by trained employees.

Nuclear criticality safety training includes training on the following subjects, as applicable to the functions performed:

- Use of process parameters credited for nuclear criticality safety control
- Nuclear criticality safety postings that identify administrative controls for operators
- Fission chain reactions and accident consequences
- Neutron behavior in a fissioning system
- IROFS for criticality safety
- Selected criticality accident histories
- Response to criticality alarm signals
- Policy and procedures.

6.2.2 Criticality and Radiation Audits

Representatives of the criticality safety and radiation safety functions conduct formal, scheduled safety audits of fuel manufacturing and support areas in accordance with documented, approved procedures. These audits ensure that operations conform to criticality and radiation requirements in accordance with ANSI/ANS-8.19-1996, *Administrative Practices for Nuclear Criticality Safety*.

Criticality and radiological audits are performed under the direction of the manager of the criticality safety function and the manager of the radiation safety function. Personnel performing these audits do not report to the production organization and have no direct responsibility for the function and area being audited.

Audit results are communicated in writing to the cognizant operations manager and to the regulatory manager. Required corrective actions are documented and approved by the operations manager and are reported to the MFFF plant manager.

Operations will be reviewed periodically to ensure that procedures are being followed and that process conditions have not been altered to adversely affect nuclear criticality safety. The frequency of these reviews will be established based on the results of the Integrated Safety Analysis (ISA), and will be reflected in the license application for possession and use of SNM. These reviews will be conducted, in consultation with operating personnel, by MFFF staff who are knowledgeable in nuclear criticality safety and who (to the extent practicable) are not immediately responsible for operations.

Periodic nuclear criticality safety walkthroughs of operating MFFF SNM process areas will be conducted and documented. Identified weaknesses will be incorporated into the facility corrective actions program and will be promptly and effectively resolved. The frequency of nuclear criticality safety walkthroughs will be determined based upon the results of the ISA.

6.2.3 Independent Audits

The MFFF Radiation and Nuclear Criticality Safety Programs are audited on a planned, scheduled basis by appropriately trained and experienced individuals who have a degree of independence from the MFFF organization and who are not involved in the routine performance of the work or program being audited. The scope of independent audits covers the adequacy of the safety program, as well as compliance with requirements. The frequency of nuclear criticality safety audits will be determined based upon the results of the ISA.

Audit results are reported in writing to the MFFF plant manager, the operations manager, and the regulatory manager, as appropriate.

6.2.4 Nuclear Criticality Safety Procedures

Procedures are established and implemented for nuclear criticality safety in accordance with ANSI/ANS-8.19-1996. Nuclear criticality safety postings at the MFFF are established that identify administrative controls applicable and appropriate to the activity or area in question. Nuclear criticality safety procedures and postings are controlled to ensure that they are maintained current.

6.3 TECHNICAL PRACTICES

6.3.1 Commitment to Baseline Design Criteria

The double contingency principle stipulated in 10 CFR §70.64(a) and ANSI/ANS-8.1-1983 (R1988) state that "process designs shall incorporate sufficient factors of safety to require at least two unlikely, independent, and concurrent changes in process conditions before a criticality accident can occur." NCSEs are performed to ensure the adequacy of criticality controls. The NCSEs are used to develop the design basis of the facility and to demonstrate compliance with the double contingency principle. Criticality controls identified as necessary in the NCSEs are flowed into the ISA as principal structures, systems, and components (SSCs), or IROFS. The

ISA also documents a comprehensive systematic review of facility hazards, including criticality, that confirms the acceptability of the selected means of criticality control for process stations and SNM areas within the aqueous polishing (AP) and MOX processing (MP) facility designs.

Compliance with the double contingency principle is demonstrated by identifying two or more process conditions on which reliance is placed to ensure criticality control. Common mode failures and the potential interaction between units containing fissionable material are appropriately taken into account. In addition to providing a basis for identifying IROFS, the hazard identification and review processes documented in Section 6.3.4 are used to promote defense-in-depth practices in facility design and plant layout. Defense-in-depth practices are incorporated, such as the preferential selection of engineered controls over administrative controls.

Acceptance criteria applied in performing double contingency and criticality hazard assessments are summarized as follows:

- When applying a single control to maintain limits on two or more controlled parameters, credit is taken for only a single component for double contingency compliance.
- No single credible event or failure will result in a criticality accident.
- Geometry control constitutes the preferred controlled parameter, with fixed neutron absorbers employed as necessary.
- Where practicable, reliance is placed on equipment design that uses passive engineered controls rather than on administrative controls. Techniques for criticality control, listed in order of hierarchical preference, are as follows (see Section 6.3.3 for a description of each control):
    - Passive Engineered Controls
    - Active Engineered Controls
    - Enhanced Administrative Controls
    - Simple Administrative Controls.
- Controlled parameters for process stations and areas within the AP and MP designs are identified. Controlled parameters (functional) are documented in Section 6.3.4. The IROFS associated with maintaining these controlled parameters are provided with the license application for possession and use of SNM. The criticality safety controlled parameters are transferred into the appropriate operating procedures and maintenance procedures as specified in Section 6.2.
- Evaluations are performed to demonstrate that controlled parameters are maintained during both normal and credible abnormal conditions. Summaries of these evaluations are submitted with the license application for possession and use of SNM.
- In cases where controlled parameters are controlled by measurement, reliable methods that ensure representative sampling and analysis are used. Such sampling and analysis requirements are included in the list of IROFS to be provided with the license application for possession and use of SNM and are flowed into facility management measures.

6.3.2 MFFF Criticality Accident Alarm System

The presence of PuO_2 in the MFFF requires continuous control of subcriticality. Criticality safety is based on a rigorous design associated with controlled management of nuclear materials.

Measures are taken by sufficiently reliable means to ensure that the occurrence of a criticality accident is prevented. Nevertheless, a criticality accident alarm system (CAAS) monitors areas in which SNM is handled, used, or stored. CAAS coverage will be exempted from areas that are (1) limited to less than half of a minimum critical mass with no potential for double batching, and (2) used for storage of closed shipping containers. Specific areas qualifying for exemption from criticality accident monitoring requirements will be identified in the LA and the ISA. The basis for such exemptions shall be provided in the ISA.

The CAAS is intended to do the following:

- Detect an accidental dose rate
- Warn personnel as quickly as possible
- Facilitate evacuation to limit personnel dose in the highly unlikely event of a criticality.

The CAAS is designed in accordance with generally accepted practices and those required by 10 CFR §70.24. ANSI/ANS-8.3-1997, *Criticality Accident Alarm System*, is the main guidance document that defines the features of a criticality alarm system. This standard provides guidance for alerting personnel that an inadvertent criticality has occurred. The main requirement linked to the design of the system is the reliability of actuation of the alarm.

Monitoring is performed by groups of detectors called "monitoring units." The data from the monitoring units are centralized, and audible and visual alarms are provided following detection of a criticality accident. The data concerning the accident are sent in real time to an emergency console.

ANSI/ANS-8.3-1997 provides guidance on the criticality alarm locations, their characteristics, and reliability. Specified design criteria include reliability, system vulnerability, seismic tolerance, failure warning, response time, detection criteria, sensitivity, and spacing. Guidance for alarm testing and employee familiarization is also provided.

The MFFF will render operations safe, by shutdown and quarantine if necessary, in an area where CAAS coverage has been lost and not restored promptly. The allowable number of hours where CAAS coverage has been lost and the MFFF is not shut down will be determined on a process-by-process basis because shutting down certain processes, even to make them safe, may carry a larger risk than being without a CAAS for a short period of time. The MFFF will take compensatory measures (e.g., limit access, halt SNM movement) as necessary when the CAAS system is not functioning due to maintenance.

The CAAS evaluation will take into account the effect of credible shielding in demonstrating the adequacy of the dual alarms to detect a nuclear criticality. The alarm coverage radius will be determined (e.g., through the use of shielding codes). The presence of shielding material will be maintained by controls through good housekeeping practices.

6.3.2.1 Principle of Operation

The MFFF CAAS is composed of the following:

- A detection network
- Data processing and alarm actuation units
- A network of audible and visual alarms
- An off-line processing facility.

6.3.2.2 Detection of Accident Radiation Levels

The CAAS is designed to detect a gamma or neutron dose in the highly unlikely event of a criticality accident.

6.3.2.3 Identification of the Alarm

To reduce the reaction time, and thereby the dose received, of personnel following triggering of the alarm, the alarm is identifiable within one-half second of detector recognition of a criticality accident.

6.3.2.4 Range of the Alarm

The alarm is audible in locations normally occupied by personnel present in the building and in close proximity outside. The alarm is also sent to an emergency console. The alarm takes into account the working environments encountered within the facility.

6.3.2.5 Design Features

The design features regarding operation are as follows:

- **Prevent spurious alarms** – The system is designed to prevent spurious alarms.
- **Allow accident records** – After an accident, records and processing of recorded data are possible.

The design criteria for the MFFF CAAS are as follows:

- **Reliability** – The MFFF CAAS is designed using components that do not require frequent servicing. The system is designed to reduce the effects of non-use, deterioration, power surges, and other adverse conditions. The design of the system is as simple as is consistent with the objectives of ensuring reliable actuation of the alarm signal and avoidance of false alarms.
- **Seismic tolerance** – The MFFF CAAS is designed to remain operational in the event of a seismic shock equivalent to the MFFF site-specific design basis earthquake.
- **System vulnerability** – Components of the CAAS are located or protected to reduce the potential for damage in case of fire, explosion, corrosive atmosphere, or other extreme

conditions. The system is designed to reduce the potential of failure, including false alarms, due to human error.

- **Failure warning** – The system is designed to provide a visual or audible warning signal at some normally occupied location to indicate system malfunction or the loss of primary power.
- **Response time** – The MFFF CAAS is designed to produce a criticality alarm signal within one-half second of detector recognition of a criticality accident.
- **Detection criterion** – The MFFF CAAS is designed to respond to the minimum accident of concern. For this purpose, in areas of the MFFF where fissionable material is handled, used, or stored, the minimum accident is assumed to deliver the equivalent of an absorbed dose in soft tissue of 20 rads of combined neutron and gamma radiation at an unshielded distance of 6.6 ft (2 m) from the reacting material within one minute.
- **Spacing** – The spacing of the detectors for the MFFF CAAS is consistent with the alarm trip point and with the detection criterion. The location and spacing of detectors are chosen to minimize the effect of shielding by massive equipment or materials.
- **Electrical power** – Electrical power for the CAAS is provided by the standby power system and the 120-VAC essential uninterruptible power supply in the event of loss of normal power. If the CAAS coverage for an area has been lost or is out of service, compensatory measures will be implemented.

6.3.3 Criticality Safety Control Design Criteria

A design application (system) for an MFFF unit is considered subcritical when the calculated multiplication factor for the design application (system) is shown to be less than or equal to an established maximum allowed multiplication factor that properly accounts for method bias and uncertainty and administrative margin. An administrative safety margin of 0.05 will be used for MFFF design applications (see Section 6.3.5 for more information).

6.3.3.1 Criticality Control Modes

Criticality controls are identified in Section 6.3.4 on a functional "control mode" basis at the current phase in facility design. Control modes are the methods of criticality safety control selected for various facility process stations and areas.

Where practicable, reliance is placed on equipment design that uses passive engineered controls rather than administrative controls. Techniques for criticality control, listed in order of hierarchical preference, are as follows:

- **Passive Engineered Controls** – Controls that employ permanent and static design features or devices to preclude inadvertent criticality in operations. No human intervention is required except maintenance and inspection.
- **Active Engineered Controls** – Controls that utilize active hardware to sense conditions and automatically place a system in a safe condition. Actuation and operation of these controls do not require human intervention.

- **Enhanced Administrative Controls** – Controls that rely on human judgment, training, and actions for implementation but employ active warning devices (audible and visual) that prompt specific human actions to occur before the process can proceed to augment the implementation of the controls.
- **Simple Administrative Controls** – Controls that rely solely on human judgment, training, and actions for implementation.

In terms of assumed reliability of criticality controls, NCSEs for the MFFF will consider controls of higher hierarchical preference, to the extent practical, to provide correspondingly higher reliability when assessing criticality risks and demonstrating compliance with the double contingency principle.

To ensure criticality control in activities involving significant quantities of fissionable materials, one or several of the following available control modes are used:

- Geometry control
- Mass control
- Density control
- Isotopics control
- Reflection control
- Moderation control
- Concentration control
- Interaction control
- Neutron absorber (e.g., boron) control
- Volume control
- Heterogeneity control
- Process variable control.

Geometry control constitutes the preferred control mode, with fixed neutron absorbers employed as necessary. Although geometry control is preferred, several methods of criticality control are available and employed in the AP and MP facility designs. These modes of control are described in Section 6.3.3.2. Control modes selected for each facility process station or work area are identified in Section 6.3.4.

Controlled parameters and feasible techniques for controlling these modes are established and justified in NCSEs and documented in the ISA Summary in such a manner as to minimize the risks from inadvertent criticality. Tolerances on the controlled parameters are conservatively taken into account in the establishment of operating limits and controls. The potential for neutron interaction between units is fully evaluated to ensure that the process remains subcritical under all normal and credible accident conditions, and additional controls on spacing are identified and incorporated into facility management measures as necessary.

6.3.3.2 Available Methods of Control

6.3.3.2.1 Geometry Control

Geometry control involves the use of passive engineered devices to control worst-case geometry within ensured dimensional tolerances. Geometry parameters are established in a manner that ensures an adequate margin of subcriticality (including margins to protect against uncertainties in process variables and against limits being accidentally exceeded) using documented and approved methods, standards, or handbooks. Geometry control is used in facility design applications wherever possible, including the following design applications:

- For storage systems containing large quantities of fissile materials (for which mass or mass and moderation control would not be applicable)
- For process equipment whenever the imposed geometry is compatible with the applicable process function.

When the possibility of neutron interaction with other fissile units exists, interaction control or neutron absorber control may also be indicated in conjunction with geometry control.

Geometry control parameter limits are established and implemented as follows:

- Dimensions and nuclear properties of facility features relying on geometry control are subject to facility QA measures during design and fabrication and are verified prior to beginning operations. The facility configuration management program (see Section 15.2) is used to maintain these dimensions and nuclear properties.
- Credible means of transferring fissile materials to an unfavorable geometry are identified and evaluated, and controls (i.e., IROFS) are established to ensure that such transfers are precluded. In particular, leaks from favorable-geometry process vessels are collected in favorable-geometry drip trays.
- Tolerances on nominal design dimensions are treated conservatively.
- Possible mechanisms for changes to fixed geometry are evaluated, and controls are established as necessary. Credible mechanisms that could result in component deformation or changes in geometry are identified and evaluated. Where such credible mechanisms exist (e.g., deformation by static loads or pressure, corrosion, or earthquakes), applicable design allowances and/or surveillance programs are described.

6.3.3.2.2 Mass Control

Mass control involves the use of mass-based single-parameter limits established based upon worst-case geometry (i.e., spherical) and SNM form (e.g., metal, oxide, aqueous solution) unless these parameters are controlled by principal SSCs/IROFS (i.e., implementation of another [or other] criticality control mode(s) in addition to mass control). Single-parameter limits are established in a manner that ensures an adequate margin of subcriticality (including margins to protect against uncertainties in process variables and against limits being accidentally exceeded) using documented and approved methods, standards, or handbooks. Mass control is used in facility design applications where the process function is not compatible with geometry control. Mass control is generally used in combination with moderation control (i.e., allowable mass with moderation control is higher than without moderation control). The mass is generally controlled through a process variable control (i.e., required process controls include weighing and material mass balance functions). Thus, mass control is less desirable than simple geometry control in terms of hierarchical preference. Justification for the use of mass control is provided in NCSEs and the ISA Summary. When the possibility of neutron interaction with other fissile units exists, interaction control or neutron absorber control may also be indicated in conjunction with mass control.

Mass control is considered as a possible control mode in the following design applications:

- The limitation of the mass is compatible with the process function.
- Mass can be reliably controlled during process operation (i.e., by direct weighing and/or mass balances).

Mass control parameter limits are established and implemented as follows:

- Mass limits are derived for a material that is assumed to have a given weight percent of SNM. Determinations of mass are based on either (1) weighing the material and assuming the entire mass is SNM, or (2) taking physical measurements to establish the actual weight percent of SNM in the material. When process variables can affect the bounding weight percent of SNM in the mixture, the SSCs or procedures that affect the process variables are identified as IROFS in NCSEs and the ISA Summary.
- Theoretical densities for fissile mixtures are used unless lower densities are ensured.
- Mass is physically measured using instrumentation that is subject to facility QA measures.
- When overbatching of SNM is possible, the mass of SNM in a single batch is limited so that the mass of the largest overbatch resulting from a single failure is safely subcritical, taking system uncertainties into account. Overbatching beyond double batching is considered in establishing the margin of safety.
- When overbatching of SNM is not possible, the mass of SNM in a batch is limited to be safely subcritical, taking system uncertainties into account.
- Mass limits are established taking tolerances into account. The determination of minimum critical mass is based on spherical geometry, unless actual fixed geometry is controlled.
- Whenever mass control is established for individual rooms, groups of rooms, or units, detailed records, either manual or automatic by computer, will be maintained for mass transfers into and out of these rooms or units. Establishment of mass limits will involve consideration of potential moderation, reflection, geometry, spacing, and material concentration. The evaluation will consider normal operations and expected process upsets for determination of the actual mass limit for the system and for the definition of subsequent controls.

6.3.3.2.3 Density Control

Density control involves taking credit for non-optimal SNM density characteristics within process equipment in the performance of criticality safety design calculations. SNM density limits are established in a manner that ensures an adequate margin of subcriticality (including margins to protect against uncertainties in process variables and against limits being accidentally exceeded) using documented and approved methods, standards, or handbooks. Density control is used in facility design applications where the process function is not compatible with a worst-case SNM density assumption (i.e., maximum theoretical density) and is generally used in combination with mass, geometry, and/or moderation control. Justification for the use of density control is provided in NCSEs and the ISA Summary.

Density control parameter limits are established and implemented as follows:

- Conservative assumptions are always made about the density of the fissile material. The NCSEs will fully justify the use of the conservative values of density.

6.3.3.2.4 Isotopics Control

Isotopic abundance (isotopics) control involves taking credit for established worst-case assumptions regarding SNM isotopic abundance in the performance of criticality safety design calculations. Isotopics control includes both the $^{235}U/U$ concentration (enrichment) and the concentration of fissile and nonfissile plutonium isotopes (e.g., ^{239}Pu, ^{240}Pu, ^{241}Pu), as well as the relative abundance of plutonium to uranium. The presence of ^{240}Pu (5% to 9%) and ^{242}Pu (<0.02%) offsets any contribution from ^{241}Pu (<1%) such that it can be neglected for ^{239}Pu ranges from 90% to 95% as is expected to be the case for the MFFF. This will be demonstrated by analysis. SNM fissile and neutron absorption isotope abundance limits are established in a manner that ensures an adequate margin of subcriticality (including margins to protect against uncertainties in process variables and against limits being accidentally exceeded) using documented and approved methods, standards, or handbooks. Isotopics control is indicated at the point of receipt of fissionable material and may be applied at process stations where down-blending of plutonium content is credited.

Isotopics control is used throughout the MFFF and is used in combination with other control modes (e.g., process variable control). Justification for the use of isotopics control is provided in NCSEs and the ISA Summary.

Isotopics control parameter limits are established and implemented as follows:

- When taking credit for isotopic mixtures, where different isotopic mixtures could coexist, controls are established to clearly label and segregate SNM of different isotopic mixtures. In addition, the determination of isotopic content is based on compliance with the double contingency principle. Consideration is given to sample analysis and verification activities associated with MFFF and vendor-supplied measurements. Vendor data are qualified in accordance with an approved QA plan and are audited by the MFFF QA function. The use of qualified nondestructive assay (NDA) measurement systems is also acceptable in establishing compliance with the double contingency principle.

- Instrumentation used to physically measure isotopics is subject to facility QA measures.

6.3.3.2.5 Reflection Control

Reflection control involves the control of fissile unit geometry and the presence of neutron-reflecting materials in process areas in order to increase neutron leakage from a subcritical fissile system and thereby reduce the calculated subcritical multiplication factor for the system. Although reflection control is generally applied as a passive engineered feature (i.e., configuration of concrete walls or the construction of fixed personnel barriers), reflection control generally also requires surveillance procedures to ensure that neutron-reflecting materials are excluded from the process area or possibly to confirm continued efficacy of personnel barriers. Thus, reflection control is generally less desirable than passive controls such as simple geometry control or a worst-case reflector assumption in terms of hierarchical preference. Justification for the use of reflection control is provided in NCSEs and the ISA Summary. When neutron absorbers are used to limit neutron reflection, neutron absorber control is indicated in lieu of interaction control. Adjacent, contiguous units will be demonstrated acceptable.

Reflection control parameter limits are established and implemented as follows:

- When determining subcritical limits for an individual unit, the wall thickness of the unit and reflecting adjacent materials of the unit are conservatively bounded by the assumed reflection conditions, leaving allowances for transient reflectors as discussed below.
- At a minimum, reflection conditions equivalent to 1-in (2.5-cm) tight-fitting water jacket are assumed to account for personnel and other transient incidental reflectors not evaluated in the unreflected models. In any case, the quantity of water reflection will be demonstrated to be conservative in the NCSE.
- In cases where loss of reflection control can lead to criticality, by itself or in conjunction with another single failure, rigid and testable barriers are established and maintained by facility management measures (i.e., configuration management and maintenance programs).
- In cases where reflection control is not indicated, full water reflection of process stations or fissile units is represented by a minimum of 12 in (30 cm) of tight-fitting water jacket, unless consideration of other materials present in the design (e.g., concrete, carbon, or polyethylene) may be more effective than water.
- Conservative reflection conditions are established when evaluating the criticality safety of arrays. For example, conservative minimum distances from the arrays to reflecting materials (e.g., concrete or water) will be used.

6.3.3.2.6 Moderation Control

Moderation control involves taking credit for non-optimal SNM moderator content or presence within process equipment or areas in the performance of criticality safety design calculations. SNM moderator content limits or exclusion controls for areas are established in a manner that ensures an adequate margin of subcriticality (including margins to protect against uncertainties in process variables and against limits being accidentally exceeded) using documented and approved methods, standards, or handbooks. Moderation control is used in facility design applications where the process function is not compatible with a worst-case SNM moderator content (i.e., optimum moderation) or process/storage area flooding assumption. Moderation control is generally used in combination with mass or geometry control. Moderation control also may require process variable control or other surveillance activities. Justification for the use of moderation control, when needed, is provided in NCSEs and the ISA Summary.

Moderation control is particularly useful in situations where process capacity requirements are not satisfied using mass control alone and where the level of moderation is easily bounded or controlled (e.g., equipment in the powder handling stations confined within gloveboxes).

Potential sources of moderation that must be considered include the following:

- Residual humidity present in powders
- Organic additives (e.g., lubricant, poreformer) used as part of a process
- Moderating fluids (e.g., water or certain oils), which could potentially enter process stations or storage areas under abnormal or accident conditions.

The first two types of moderators (humidity and organic additives) exist during normal operations. Criticality safety calculations employ conservative assumptions to account for moderators normally anticipated to be present in processes (see below). Process stations and areas potentially susceptible to abnormal ingress or introduction of moderating fluids or other materials are identified and evaluated in detail as part of the NCSEs and documented in the ISA Summary.

Moderation control parameter limits are established and implemented as follows:

- Moderation control is implemented consistent with guidance provided in ANSI/ANS-8.22-1997, *Nuclear Criticality Safety Based on Limiting and Controlling Moderators.*
- When process variables can affect the moderation, the SSCs or procedures that affect those process variables are defined as IROFS in NCSEs and the ISA Summary.
- Physical structures credited in NCSEs with performing moderator exclusion functions are designed to preclude ingress of moderator.
- When sampling of moderation properties is required, the sampling program is based on compliance with the double contingency principle. Consideration is given to sample analysis and verification activities associated with MFFF and vendor-supplied measurements. Vendor data are qualified in accordance with an approved QA plan and are audited by the MFFF QA function. The use of qualified NDA measurement systems is also acceptable in establishing compliance with the double contingency principle.
- Fire protection system design and fire-fighting procedures and training programs are developed with appropriate restrictions placed on the use of moderating materials. The effects of credible fire events and the consequences associated with the potential use of moderating material in fighting such fires are evaluated as applicable. However, in the

MFFF moderation-controlled areas, hydrogenous fire-fighting materials are not allowed (see Chapter 7).

- Limits on moderators as fire-fighting agents are established in NCSEs and identified in the ISA Summary. The competing risks from criticality accidents and fires are weighed, which could result in allowing the use of water in cases where the overall risk to the worker and public is minimized.
- Credible sources of moderation are identified and evaluated for potential intrusion into moderator-controlled process stations or areas, and the ingress of moderator is precluded or controlled. Design features or processes required to demonstrate ingress of moderator into moderator-controlled process stations or areas are identified as IROFS in NCSEs and the ISA Summary.
- The effects of varying levels of credible interstitial moderation are evaluated when considering neutron interaction between physically separated fissile units.
- Instrumentation used to physically measure moderator is subject to facility QA measures.
- Drains are provided to prevent water accumulation if that accumulation could lead to unfavorable configurations of fissile material.

6.3.3.2.7 Concentration Control

Concentration control (i.e., exclusive reliance on concentration control) involves the use of concentration-based single-parameter limits established based upon worst-case geometry (i.e., spherical) and SNM fissile composition unless these parameters are controlled by IROFS (i.e., implementation of another [or other] criticality control mode(s) in addition to concentration control). Concentration control is generally applied only to process equipment handling solutions with very low fissile material concentration (secondary streams). Single-parameter limits for concentration are established in a manner that ensures an adequate margin of subcriticality (including margins to protect against uncertainties in process variables and against limits being accidentally exceeded) using documented and approved methods, standards, or handbooks. Concentration control almost always will require process variable control to ensure that concentration limits are not exceeded. Justification for the use of concentration control is provided in NCSEs and the ISA Summary. When the possibility of neutron interaction with other fissile units exists, interaction control or neutron absorber control may be indicated in conjunction with concentration control.

Concentration control parameter limits are established and implemented as follows:

- When process variables can affect the concentration, the SSCs or procedures that affect those process variables are defined as IROFS in NCSEs and the ISA Summary, including assumptions relied on to determine solubility limits.
- Concentrations of SNM in excess of controlled parameter limits are precluded.
- When using a tank containing concentration-controlled solution, the tank is normally closed and locked.

- When sampling of the concentration is specified, the sampling program uses dual independent sampling methods. The process is designed such that a single operator acting alone cannot physically circumvent the sampling program.
- Concentration-controlled processes are designed and operated in a manner that ensures that possible precipitating agents are not inadvertently introduced to the process or that the effects of precipitation are shown to be acceptable by the NCSE.
- Concentration-controlled processes are designed and operated in a manner that prevents overconcentration in excess of controlled parameter limits. Surveillance is provided to ensure the effectiveness of these controls.
- Instrumentation used to physically measure concentration is subject to facility QA measures.

6.3.3.2.8 Interaction Control

Interaction control involves the use of spacing to limit neutron interaction between fissile units. When interaction control is employed using passive engineered features (e.g., fuel assembly storage racks), interaction control is considered equivalent to geometry control in terms of hierarchical preference.

Interaction control is specified only when spacing is employed to limit interaction between fissile units. When neutron absorbers are used to limit interaction between fissile units, neutron absorber control is indicated in lieu of interaction control. Adjacent, contiguous units will be demonstrated to be acceptable.

Interaction control parameter limits are established and implemented as follows:

- When maintaining a physical separation between units, passive engineered features (i.e., spacers or other passive geometrical means) are used to the extent practicable. The structural integrity of such engineered features is sufficient for normal and design basis abnormal conditions.
- When unit spacing is controlled by procedures, justification for the method of control is provided in the applicable NCSE and documented in the ISA Summary. In such cases, it is demonstrated that multiple procedural violations will not by themselves lead to criticality.
- When evaluating the criticality safety of units in an array or pairs of arrays, the spacing limits in ANSI/ANS-8.7-1975, *Guide for Nuclear Criticality Safety in the Storage of Fissile Materials*, are used or spacing is based on validated calculational methods.

6.3.3.2.9 Neutron Absorber Control

Neutron absorber control involves the use of supplemental neutron absorber features to limit subcritical multiplication of a single fissile unit (e.g., cadmium coatings and borated concrete) or to limit neutron interaction between multiple (spaced) fissile units. Justification for the use of neutron absorber control is provided in NCSEs and the ISA Summary.

Neutron absorber control parameter limits are established and implemented as follows:

- When using fixed neutron absorbers, the facility design and procedural controls are implemented consistent with guidance provided in ANSI/ANS-8.21-1995, *Use of Fixed Neutron Absorbers in Nuclear Facilities Outside Reactors.*

6.3.3.2.10 Volume Control

Volume control involves the use of volume-based single-parameter limits established based upon worst-case geometry (i.e., spherical) and SNM form (e.g., metal, oxide, aqueous solution) unless these parameters are controlled by IROFS (i.e., implementation of another [or other] criticality control mode(s) in addition to volume control). Single-parameter limits are established in a manner that ensures an adequate margin of subcriticality (including margins to protect against uncertainties in process variables and against limits being accidentally exceeded) using documented and approved methods, standards, or handbooks. When volume control is employed using passive engineered features (e.g., use of approved fixed-geometry containers), volume control is considered equivalent to geometry control in terms of hierarchical preference. When the possibility of neutron interaction with other fissile units exists, interaction control or neutron absorber control may be indicated in conjunction with volume control.

Volume control parameter limits are established and implemented as follows:

- When using volume control, geometrical devices are used to restrict the volume of SNM, which limits the accumulation of SNM.
- Instrumentation used to physically measure volume is subject to facility QA measures.
- Volume is limited to a percentage of the minimum critical volume, assuming spherical geometry, optimal concentration, and full water reflection.

6.3.3.2.11 Heterogeneity Control

Heterogeneity control involves taking credit for the distribution of fissile material. Additionally, it may be important to control the lattice pitch (i.e., spacing) in a heterogeneous configuration such as a fuel rod or for pellet fabrication. Heterogeneity control is always applied in conjunction with another control mode (e.g., mass control, geometry control). Heterogeneity control is almost always implemented through process variable control as well. Thus, heterogeneity control is less desirable than passive controls (e.g., geometry control) or worst-case heterogeneity assumptions in terms of hierarchical preference. Justification for the use of heterogeneity control is provided in NCSEs and the ISA Summary.

Heterogeneity control parameter limits are established and implemented as follows:

- When process variables can affect heterogeneity, the SSCs or procedures that affect those process variables are identified as IROFS in NCSEs and the ISA Summary. Potential mechanisms causing material to become inhomogeneous are identified and evaluated.
- Computer calculations that take heterogeneity into account are appropriately validated.

6.3.3.2.12 Process Variable Control

Process variable control involves taking credit for process conditions maintained within fissile systems, including bounding normal operational tolerances on process parameters and abnormal accident conditions. Process variables can involve any of the other 11 control modes, as well as the physical and chemical forms of the fissile material. Process variable control inherently requires some reliance on active engineered features and is thus less desirable than passive controls (e.g., geometry control) or worst-case process variable assumptions in terms of hierarchical preference. Justification for the use of process variable control is provided in NCSEs and the ISA Summary.

Process variable control parameter limits are established and implemented as follows:

- SSCs or procedures that control the parameters necessary to ensure that the process variables relied on for criticality safety are identified as IROFS in NCSEs and the ISA Summary and are subject to facility QA measures sufficient to ensure that the associated controlled parameter safety limit is not exceeded.

6.3.4 Criticality Safety Process Description

6.3.4.1 Overview

Criticality hazards arise from the handling and processing of fissionable materials in the MFFF. Such hazards could result in a criticality event leading to dispersal of radioactive material and/or direct exposure of nearby personnel.

In the AP process, fissile material is present in both solid form (plutonium oxide powder, plutonium oxalate precipitate) and liquid form (plutonium nitrate). In the MP process, fissile material is present as plutonium oxide powder, uranium oxide powder, MOX powders with different plutonium contents (master blend, final blend), pellets, rods, and assemblies.

The criticality risk is due primarily to the fissile isotope ^{239}Pu, although the presence of other fissile isotopes (present in small quantities) is also considered.

6.3.4.2 Applicable Safety Principles

The MFFF is designed such that the risk of nuclear criticality accidents is limited by assuring that under normal and credible abnormal conditions, all nuclear processes are subcritical, including use of an approved margin of subcriticality for safety. This goal is primarily achieved through adherence to the double contingency principle as stated in ANSI/ANS-8.1-1983 (R1988).

The objective of criticality safety analysis is to demonstrate that the risk of a criticality event is acceptably low based on consideration of the following:

- Highly reliable facility design features capable of withstanding applicable internal and external hazard events

- Management measures implemented during normal operating conditions
- Implementation of corrective action to avoid exceeding design limits in the event of a malfunction.

Specific safety principles incorporated during the development of the MFFF design in order to enhance the inherent reliability of criticality controls are summarized as follows: (a) the preferred use of passive engineered features over active engineered features, (b) the preferred use of engineered features over administrative controls, (c) the preferred use of enhanced administrative controls over simple administrative controls, and (d) the preferred use of two-parameter control over single parameter control.

6.3.4.3 General Design Approach

The design approach with respect to criticality is as follows:

- Separate the facility into criticality control units (usually based on process units or areas)
- For each criticality control unit:
  - Identify the physical and chemical (i.e., physicochemical) forms of the fissile medium in the unit
  - Define the criticality control method(s) and applicable controlled parameter(s)
  - For each controlled parameter:
    - Assume the credible optimal condition (i.e., most reactive condition physically possible) for the parameter, or
    - Calculate the allowed range for the parameter.
  - Specify controls to be implemented to limit controlled parameter(s) to the specified allowable range of values
  - Demonstrate compliance with the double contingency principle.

Controls implemented to limit controlled parameters within an allowable range of values can involve engineered design features and/or management measures. Compliance with the double contingency principle will be demonstrated for normal and credible abnormal conditions.

6.3.4.3.1 Physical and Chemical Forms

Control of physicochemical characteristics is applied to several AP process units where non-optimal solution chemistry or specific values for some parameters (e.g., pellet diameter) are used in the definition of the fissile media and are assumed in criticality design calculations.

The physicochemical form of the fissile material is defined by the following:

- Its chemical composition
- The pellet diameter (if applicable)
- The rod characteristics (if applicable)

- The assembly characteristics (if applicable).

Note: Other characteristics (e.g., density) could be considered as being part of the physicochemical characteristics, but they are listed as control modes (in Section 6.3.4.3.2). The various physicochemical forms for the MFFF processes are described in the following sections. The isotopic composition of the fissile material, including impurities, is discussed in Section 6.3.4.3.2.4.

6.3.4.3.1.1 Chemical Form

In the MP process, no chemical transformations take place. As a consequence, the oxide form of the fissile medium (PuO_2 or UO_2, as applicable) is always assumed.

For the AP process, a conservative assumption concerning the chemical form of the fissile matter is made for each step of the process, taking into account not only the nominal conditions but also the possible process upsets (e.g., failure of a PuO_2 filter or unwanted soda introduction that may cause precipitates) defined based on the double contingency principle. The different chemical forms used in the criticality analyses are as follows:

- PuO_2
- $Pu(NO_3)_4$
- $Pu(NO_3)_3$
- Plutonium oxalate.

6.3.4.3.1.2 Pellet Diameter (MP Process)

In some cases, the reference fissile medium is an array of pellets. In such cases, the pellet diameter is part of the definition of the reference fissile medium (as well as the pellet density and the plutonium content).

Note: For broken pellets, fragments, and grinding dust, the diameter of the original pellet is not controlled. Instead, bounding assumptions are used to evaluate the material.

The process values for pellets are as follows:

• Green standard pellets:	9.5 mm to 11.5 mm	(estimated value)
• Sintered standard pellets:	7.9 mm to 9.6 mm	(estimated value)
• Ground standard pellets:	7.84 mm to 9.49 mm	(nominal value)
• Green recycled-scrap pellets:	12.6 mm	(estimated value)
• Sintered recycled-scrap pellets:	10.49 mm	(nominal value).

Depending on the type of products that are likely to be contained or handled by each unit (i.e., green or sintered pellets, standard pellets, or recycled-scrap pellets), including those in an off-normal situation as defined by the safety analysis, the appropriate range of diameters is studied in the criticality calculations.

6.3.4.3.1.3 Rod Characteristics (MP Process)

In some cases, the reference fissile medium is an array of rods. In such a case, the rod geometry and material are part of the definition of the reference fissile medium (as well as the pellet density and the plutonium content).

The nominal values are as follows:

• Pellet diameter:	7.84 mm to 9.49 mm (standard ground pellet)
• Clad material:	M5 zircalloy or zircalloy-4
• Clad thickness:	0.571 mm to 0.635 mm
• Clad outer diameter:	9.14 mm to 10.9 mm
• Active fuel stack height:	3,614 mm to 3,658 mm.

These parameters are important to the final product. The impact of a variation of these parameters on the calculated effective neutron multiplication factor (k_{eff}) will be justified based upon the criticality calculations and evaluated by the NCSEs.

6.3.4.3.1.4 Assembly Characteristics (MP Process)

In some cases, the assembly geometry is part of the definition of the reference fissile medium (as well as the rod characteristics and the plutonium content).

The process values are as follows:

• Number of rods:	204 to 264
• Rod lattice arrangement:	15×15 or 17×17
• Rod pitch:	12.60 mm to 14.43 mm.

These parameters are important to the final product. The nominal values are used in the criticality calculations since the impacts are small.

6.3.4.3.2 Choice of the Criticality Control Mode

Criticality safety in the MFFF is ensured by application of one or more of the following control modes, as well as by the control of the physicochemical forms of the fissile material (see Section 6.3.4.3.1):

- Geometry control
- Mass control
- Density control
- Isotopics control
- Reflection control
- Moderation control
- Concentration control
- Interaction control
- Neutron absorber (e.g., boron) control

- Volume control
- Heterogeneity control
- Process variable control.

Each of the available methods of control listed above is described in detail in Section 6.3.3. The criticality control methods to be implemented for each of the major AP and MP process units and areas are summarized in Tables 6-1 and 6-2, respectively. Detailed descriptions of the AP and MP processes are provided in Sections 11.3 and 11.2, respectively. The rationale for choosing the criticality control method for the different types of MFFF process units and areas is provided in the following sections.

6.3.4.3.2.1 Geometry Control

Geometry is the preferred control mode and is used for the following:

- Storage areas containing large quantities of fissile materials
- Process equipment whenever this imposed geometry is compatible with its process function, which is the case for most equipment of the AP process and for some pellet or rod handling equipment of the MP process.

The choice of geometry control implies the following:

- A thorough control of the equipment dimensions during design and fabrication.
- The nominal dimensions of the different pieces of equipment are defined taking into account possible deformations or changes in geometry due, for example, to corrosion, bulging, or the design basis earthquake, as applicable. The following accidental situations are among those considered:
  - Design basis earthquake – Seismic design of the structures guaranteeing the geometry as applicable
  - Leaks of chemical process vessels – Design of favorable-geometry drip trays.

Note: In the case of storage areas, geometry control involves not only the specification of the dimensions of the storage containers but also, for example, the specification of the pitch between the containers and sometimes of distances to concrete walls. In that case, neither reflection control nor interaction control as such is indicated (see Sections 6.3.4.3.2.5 and 6.3.4.3.2.8, respectively). However, neutron absorber control is sometimes used in combination with geometry control (see Section 6.3.4.3.2.9).

In the MFFF, all identified instances of geometry control are passive, controlled by design, and not the result of process control. As a consequence, geometry control is not listed as a process variable in Table 6-1 or 6-2.

6.3.4.3.2.2 Mass Control

Mass control is applied to several MP process units where the process function is not compatible with geometry control alone. Mass control can be used in combination with moderation control so that the mass limit is compatible with the quantity used in the process equipment.

Mass control can be implemented to eliminate unfavorable geometry concerns such as when the shape and size of the equipment is not compatible with the limits that would be imposed if geometry control alone were used. Typically, design calculations are performed assuming that the limiting mass of material is introduced to the unit or component of interest, and that favorable spherical geometry conditions are achieved (i.e., all the mass contained in a component or several components is assumed concentrated in a single sphere). In such cases, process variable control may be required to ensure that mass limits are maintained within the values assumed in the design calculation.

Mass control can be applied in conjunction with geometry control to MP processes involving the storage and handling of fissionable material in fixed-geometry components, or in fixed-geometry containers where interaction between multiple units is of concern. Significant benefits, compared to the implementation of geometry control alone, are achieved by taking advantage of limits imposed by the process function. For example, mass limits are imposed on J60 and J80 jars for the criticality control of the units where process operations take place (e.g., dosing, mixing, ball milling). In cases like the Jar Storage and Handling Unit, mass values corresponding to containers with less than full volume capacity at theoretical densities may be assumed when demonstrating that an interacting array geometry design is acceptable. In such cases, process variable control is required to ensure that mass limits are maintained within the values assumed in the design calculation, in addition to restrictions on geometry or other applicable neutron interaction control features accounted for in the design analysis.

Where mass control is identified in Table 6-1 or 6-2, it is also listed in the process variable column since it is controlled in that case as a result of the process.

6.3.4.3.2.3 Density Control

Density control is used in the cases of PuO_2 and MOX powders. However, in the case of sintered pellets (and most of the time also for green pellets), the maximum theoretical density of the sintered medium is used as a conservative assumption.

In the case of powders, conservative assumptions are made, based on process experience feedback, for the different types of products depending on the step in the process.

For example:

- PuO_2 that is incoming to the dissolution unit: $d \leq 7$ gm/cm^3
- Polished PuO_2, final blend, grinding dust, fresh UO_2: $d \leq 3.5$ gm/cm^3

Note: The assumed density of PuO_2 powder being dissolved (of ≤ 7 gm/cm^3) is quite high and, based upon experience, would not actually be expected. Values have been used in criticality analyses for dissolved materials for conservatism. (Note: the storage of material initially received will be shown to be sub-critical for maximum theoretical density material – 11.46 g/cm^3.)

Since density control in the MFFF is always passive, a result of a bounding assumption controlled by design, and not the result of process control, density control is not listed as a process variable in Table 6-1 or 6-2.

6.3.4.3.2.4 Isotopics Control

Isotopics control includes the following:

- The control of $^{235}U/U$ concentration (enrichment) in the uranium and the concentration of fissile and non-fissile plutonium isotopes (e.g., ^{239}Pu, ^{240}Pu, ^{241}Pu) in the plutonium
- The relative abundance of plutonium to uranium in MOX mixtures.

Concerning plutonium and uranium isotopics, a conservative assumption is made based on the range of isotopics for the incoming products, and this control is not listed as a process variable in Table 6-1 or 6-2. On the other hand, the plutonium content in MOX mixtures is obtained by the MP process. In that case, wherever isotopic control is indicated in Table 6-1 or 6-2, it is also shown as a process variable.

Incoming Plutonium for the AP Process

Incoming plutonium will respect the following conditions (for the main plutonium isotopes):

$$90\% \le \frac{^{239}Pu}{Pu_{total}} \le 95\% \ , \ 5\% \le \frac{^{240}Pu}{Pu_{total}} \le 9\% \qquad (6\text{-}1)$$

Among the impurities, some uranium may be contained in this plutonium:

$$\frac{U}{Pu_{total}} \le 2\% \qquad (6\text{-}2)$$

The isotopics of this uranium verify: $\frac{^{235}U}{U_{total}} \le 93.2\%$

The assumptions used in the criticality calculations are, typically, as follows:

$$\frac{^{239}\mathrm{Pu}}{\mathrm{Pu}_{total}} = 96\% \ , \ \frac{^{240}\mathrm{Pu}}{\mathrm{Pu}_{total}} = 4\% \ \text{and} \ \frac{^{235}\mathrm{U}}{\mathrm{Pu}_{total}} = 0\% \qquad (6\text{-}3)$$

Note: ^{239}Pu is assumed to be 96%, which is larger than the specification value of 95%. As such, the calculations bound the actual fissile isotopic content, which actually includes trace amounts of all other plutonium isotopes. Besides ^{239}Pu, the main other isotope is ^{241}Pu, which is specified to be less than 1%. Preliminary calculations have shown that these values are bounding. For example, calculations have demonstrated that increasing the ^{239}Pu content by 1.0 wt % while decreasing the ^{240}Pu content by a corresponding amount is sufficient to offset any reactivity effect from ^{241}Pu and ^{235}U, such that these isotopes can be omitted when performing application calculations.

It is assumed that the possible uncertainties in the characterization of the plutonium isotopics, including all other impurities, are within the margin between the criticality calculation hypotheses of Equation 6-3 and the nominal values of Equations 6-1 and 6-2.

Extracted Uranium for the AP Process

The uranium contained as an impurity in the incoming plutonium is extracted by the AP process. For the corresponding extracted stream, the following bounding assumption is made:

$$\frac{^{235}U}{U_{total}} = 1\% \qquad (6\text{-}4)$$

Polished PuO_2 Entering the MP Process

This plutonium will respect the following conditions:

$$90\% \leq \frac{^{239}Pu}{Pu_{total}} \leq 95\% \;,\; 5\% \leq \frac{^{240}Pu}{Pu_{total}} \leq 9\% \text{ and } \frac{U}{Pu_{total}} \leq 0.01\% \qquad (6\text{-}5)$$

The assumptions used in the criticality calculations are as follows:

$$\frac{^{239}Pu}{Pu_{total}} = 96\% \;,\; \frac{^{240}Pu}{Pu_{total}} = 4\% \text{ and } \frac{^{235}U}{Pu_{total}} = 0\% \qquad (6\text{-}6)$$

These values are bounding, including all other impurities, as noted with respect to equation 6-3 above.

Uranium as UO_2 Used for the MP Process

Dilution UO_2 used in the MP process is depleted uranium satisfying the following condition:

$$\frac{^{235}U}{U} < 0.25\% \qquad (6\text{-}7)$$

The assumptions used in the criticality calculations are as follows:

$$\frac{^{235}U}{U} = 0.3\% \;,\; \frac{^{238}U}{U} = 99.7\% \qquad (6\text{-}8)$$

These values are bounding.

Plutonium Content (MP Process)

In the MP process, the plutonium content considered for the MOX is a characteristic of the reference fissile medium.

At each step of the process (pure PuO_2, master blend, final blend, and pellets), a conservative assumption is made based on process values. The process values are as follows:

- 20% plutonium for the master blend
- 2% to 6% for the final blend and pellets.

To ensure a necessary margin for operations, the plutonium content used for criticality calculations is as follows (actual design values are less than these):

- 22% for the master blend
- 6.3% for the final blend.

The facility is designed so that the plutonium content is controlled during operations. This goal is achieved through the following:

- The control of the relative quantity of PuO_2 and UO_2 (mass of PuO_2 divided by the total mass of oxide) in the master blend and in the final blend at the corresponding dosing stage
- The control of the homogeneity of the master blend (if required by downstream units) and of the final blend (see Section 6.3.4.3.2.11)
- The use of different types of containers for the master blend (J60 jars) and final blend (J80 jars)
- The tracking of the different types of products throughout the facility.

6.3.4.3.2.5 Reflection Control

Whenever possible, criticality calculations are made assuming bounding reflection conditions (e.g., 12-in [30-cm] tight-fitting water jacket or an appropriate concrete reflector). When such assumptions are not possible, reflection control becomes necessary. However, a 1-in (2.5-cm) water jacket reflector is still assumed to account for personnel and other transient incidental reflectors not evaluated in the unreflected models.

Reflection control is often used in combination with geometry control. Reflection control is used in the following cases:

- When distances between process equipment and concrete reflectors (walls) can be guaranteed
- When the allowable dimensions of the process equipment obtained with full reflection are not compatible with its process function.

The choice of reflection control implies the following:

- If applicable, the layout of equipment with respect to concrete reflectors (walls) should be controlled during design and construction. The need for guaranteeing this layout during the design basis earthquake, among other potential accidents, should be considered.
- If applicable, design and surveillance measures are applied to guarantee that neutron-reflecting materials (e.g., water, personnel) are excluded from the vicinity of the equipment.

Note 1: In the case of several neighboring pieces of process equipment or in the case of storage areas, interactions have to be considered and full reflection around each piece of equipment or each storage container may not constitute the worst case. In that case, the worst-case configuration is searched, either by applying a water jacket of varying thickness around each piece of equipment (or container) or by considering water with a variable density between the pieces of equipment (or containers). If the worst case is not acceptable, the presence of water between the pieces of equipment (or containers) is controlled.

Note 2: When neutron absorbers are used to limit neutron reflection, neutron absorber control is indicated (see Section 6.3.4.3.2.9).

No instances of active reflection control have been identified in the MFFF. Rather, reflection control (e.g., between the fissile medium and a concrete reflector) is addressed by ensuring a minimum spacing between the fissile medium and the reflector, which is not a process variable and thus is not indicated as such in Table 6-1 or 6-2.

6.3.4.3.2.6 Moderation Control

In the MFFF, moderation control is generally used together with another control mode (generally mass and/or geometry control). Moderation control is used for some process equipment when its needed capacity is not compatible with mass control alone, such as equipment in the Powder Area and some units in the Pellet Process Area and Fuel Rod Process Area. Wherever moderation control is indicated as an active control (control of additive introduction), it is shown as a process variable in Tables 6-1 and 6-2.

The moderators that could be in contact with the fissile materials include the following:

- Residual humidity of the powders
- Organic additives (e.g., lubricant, poreformer) used for the process
- Fluids (e.g., oil, water) that could leak to the gloveboxes or process equipment.

The first two types of moderators (humidity and organic additives) exist during normal operation. In the criticality calculations, conservative assumptions are made to account for these moderators. The last type of moderator (leaked oil or water) can exist only in accidental situations.

The assumptions concerning the residual humidity and the organic additives contained in the powder are as follows:

- Residual humidity
  - The nominal humidity of the powders is below 0.3 wt % of water for UO_2 and below 0.5 wt % of water for incoming PuO_2 and for polished PuO_2. Most gloveboxes are ventilated with dry nitrogen or dry air. A bounding value of 1 wt % is considered for normal situations in the criticality analyses.
  - In addition, the experimental values of the maximum humidity uptake of PuO_2 (corresponding to polished PuO_2 in the MFFF) in wet air is 2.5 wt %. A bounding value of 3 wt % is considered for off-normal situations in the criticality analyses.
- Organic additives
  - Lubricant (zinc stearate) can be added in the master blend and in the final blend for pressing.
  - Poreformer $(N\text{-}CO\text{-}NH_2)_2$ can be added in the final blend.
  - The total quantity of organic additives in the final blend is below 1.5 wt %, which is equivalent to 2 wt % of water (in terms of moderation).
  - The organic additives are eliminated by the sintering operation.

Criticality control by moderation implies the following:

- Controlling the organic products added to the powder for the process
- Eliminating fluids in process rooms, unless they are necessary for process reasons (e.g., fire suppression agent should not be water)
- If moderator fluids are necessary for the process (usually as oil for the mechanical process equipment):
  - Minimizing the quantities of these moderator fluids, or
  - Replacing them by non-moderators (e.g., non-hydrogenated oil), or
  - Maintaining a double barrier between the fissile material and the moderator (e.g., a leaktight casing and an earthquake-resistant recovery pan).

6.3.4.3.2.7 Concentration Control

Concentration control is used for equipment of the AP process solutions with a very low fissile material concentration (secondary streams).

The use of concentration control implies the following:

- The limitation of the nominal concentration of the product that can be handled by the corresponding unit
- The design of the facility so that the concentration can be controlled during operation.

Wherever concentration control is indicated as an active control, it is also shown as a process variable in Tables 6-1 and 6-2.

6.3.4.3.2.8 Interaction Control

Interaction control is used when several pieces of process equipment are located in the same area or room and when the distance between the different pieces of equipment needs to be specified in order to guarantee the subcriticality of each piece of equipment. In such a case, the control mode of each piece of equipment can involve mass control or geometry control. In the case of storage areas controlled by geometry, the control of the interaction between the stored containers is included in (passive) "geometry control" (see Section 6.3.2.2). Active interaction control is not indicated.

The choice of interaction control implies the following:

- The distances specified for interaction control should be controlled during design and construction, with appropriate allowance for tolerances.
- The need to guarantee these distances in accidental situations (e.g., design basis earthquake) should be analyzed.

Note 1: Interaction between two fissile units does not depend only on the distance between the two units, but also on the presence of water between the units. In the criticality calculations, the worst-case configuration is searched, either by applying a water jacket of varying thickness around each fissile unit (i.e., piece of equipment or storage container) or by considering water with a variable density between the fissile units. If the worst case is not acceptable, the presence of water between the fissile units is controlled.

Note 2: When neutron absorbers are used to limit interactions between fissile units, neutron absorber control is indicated (see Section 6.3.4.3.2.9).

No instances of active interaction control have been identified in the MFFF. Rather, passive interaction control is addressed by spacing, which is not a process variable and thus is not indicated as such in Table 6-1 or 6-2.

6.3.4.3.2.9 Neutron Absorber Control

In the MFFF, criticality control by neutron absorbers is generally used in conjunction with geometry control. Criticality control is applied to the following:

- AP vessels (as reflection mitigation or neutron isolation shields) in order to increase the allowable dimensions so that the vessels can perform their process functions
- Storages (as neutronic isolation shields) in order to allow for a more compact arrangement.

The use of neutron absorber control implies the following:

- A thorough control of the shields upon fabrication, installation, and surveillance during operation

- To take accidental conditions into account, the following accidental situations are among those considered:
  - Seismic design is considered.
  - If applicable, shields are protected against high temperatures (e.g., loss of hydrogen as water).

Wherever neutron absorber control is used in the MFFF, it is part of the geometry and is fixed by design. Therefore, neutron absorber control is not shown as a process variable in Table 6-1 or 6-2.

6.3.4.3.2.10 Volume Control

Volume control could be used for small process equipment. Volume control is similar to geometry control, except that a single-parameter limit can be used and no specific criticality calculation is necessary. No specific application of this control has been identified in the MFFF. However, volume control can be used in the NCSEs to be performed in the future (e.g., for parts of process equipment globally controlled by geometry in order to simplify the calculation models).

Volume control implies the following:

- The volume of the piece of equipment must be compatible with the corresponding single-parameter limit.
- A thorough control of the equipment volume during design and fabrication is necessary.
- The following accidental situations are among those considered:
  - Design basis earthquake – Seismic design of structures guaranteeing the volume, if necessary
  - Leaks of chemical process vessels – Design of favorable-geometry drip trays.

6.3.4.3.2.11 Heterogeneity Control

In the MFFF, the main instance when homogeneity is taken credit for, and thus needs to be controlled, is in the MP process. Two types of homogeneity can be needed:

- Homogeneity of PuO_2 + UO_2 mixtures (in relation with plutonium content control) (see Section 6.3.4.3.2.4)
- Homogeneity of the moderation normally present in the fissile powder (humidity + organic additives) (see Section 6.3.4.3.2.6).

Both types of homogenization (PuO_2 + UO_2 homogenization, and oxide + additives homogenization) take place at the same process steps: during constitution of the master blend (PuO_2 + UO_2 + additives homogenization) and during constitution of the final blend (master blend + UO_2 + additives homogenization). The process equipment performing this operation will be qualified during testing of the MFFF, as applicable. Tests will be performed to link the operating parameters of the equipment (e.g., the number of revolutions of the mixing arm) to the homogeneity of the product. During operation, the proper operation of this mixing equipment will be controlled as a criticality safety parameter.

Downstream of the mixing equipment, credit is taken for the homogeneity of the PuO_2 + UO_2 + additives mixture since the homogeneity characteristics will not change downstream.

Wherever heterogeneity control is indicated as an active control, it is also shown as a process variable in Tables 6-1 and 6-2.

6.3.4.3.2.12 Process Variable Control

Process variables can involve any of the other 11 control modes, as well as the physicochemical forms (see Section 6.3.1). In Tables 6-1 and 6-2, the process variable column shows which of the other 11 control modes and/or physicochemical forms are controlled in the MFFF. The result is that parameters controlled as process variables are listed both in the "physicochemical characteristics" column or other control method columns and in the "process variable" column.

6.3.4.4 Application of the Double Contingency Principle

This section provides an overview of the main design consequences resulting from the application of the double contingency principle to the MFFF processes.

6.3.4.4.1 AP Process

The main design implications of application of the double contingency principle to the AP process are as follows:

- Transfer from a favorable-geometry vessel to an unfavorable-geometry vessel is controlled by concentration. Such transfers will involve engineered controls to prevent inadvertent or unauthorized transfers exceeding concentration limits.
- Favorable-geometry drip trays are placed below favorable-geometry process vessels to collect potential leaks.
- Controls to guarantee the chemical form of the products are implemented when necessary (i.e., when credit is taken for the fact that the process transforms the product from a more severe chemical form into a less severe chemical form). For example, after the dissolution step, a double control of the absence of PuO_2 in downstream equipment is implemented.

6.3.4.4.2 MP Process

The main design implications of application of the double contingency principle to the MP process are as follows:

- Design controls are used whenever possible.
  - Geometry is the preferred control mode.

- No moderator fluids are allowed in process rooms where moderation control is used; if moderator fluids are necessary for the process, then (1) a double wall is placed between the moderator and the fissile material, (2) a non-hydrogenated fluid is used, or (3) the quantity of moderator fluid is reduced to a value that is acceptable in case of a leak (i.e., the leak situation should be subcritical with an appropriate margin).
- To avoid mix-up between master blend (plutonium content 20%) and final blend (plutonium content below 5%), the mechanical devices are designed so that a J60 jar containing master blend cannot be emptied at a location intended to receive a J80 jar for final blend (foolproofing device).

- Operation controls are used for the following:
  - Relative quantities of plutonium and uranium (plutonium content control)
  - Masses
  - Quantities of organic additives (moderation control).

6.3.4.5 Application to the MFFF

Table 6-3 shows the admissible values for optimum moderated conditions, and Table 6-4 shows the safe masses of oxide for different water-equivalent moderation. The orders of magnitude provided in Tables 6-3 and 6-4 are typical values only. For the MFFF, values actually used to demonstrate criticality safety will be determined using standard criticality safety codes, including an upper safety limit, based on the validation analysis as discussed in Section 6.3.5 (i.e., Tables 6-3 and 6-4 will not be referenced in criticality calculations or NCSEs).

Tables 6-1 and 6-2 provide the criticality control methods implemented in the major AP and MP workstations, respectively, and provide preliminary definitions of the reference fissile medium and control methods for the different units in the process. Some of this information may change in the course of final design. Chapter 11 describes the AP and MP processes.

NCSEs will be performed to demonstrate MFFF compliance with the double contingency principle. A systematic evaluation process is applied consistent with the general design approach outlined in Section 6.3.4.3. Each MFFF process unit or area is evaluated separately. Applicable fissile medium characteristics and criticality control methods for each process unit or area are identified as an initial step in the systematic NCSE process. Preliminary fissile medium and control method identification results are presented in Tables 6-1 and 6-2 for the AP and MP processes, respectively. Listing all twelve potentially applicable control methods plus the fissile medium allows for a complete description of the criticality design approach. Process units and areas where bounding assumptions are planned, or where criticality controls are to be implemented by a connected process unit, are indicated in addition to controls required specifically for each process unit or area. A "Yes" in the tables indicates that the control method is expected to be relied upon in an active sense. A "No" indicates that the method is not expected to be used in an active sense. However, in many cases, bounding assumptions are assumed in some parameters (e.g., density, isotopic composition, an upstream control, or the fact that a control method is included in another control method). In this case, the bounding assumptions are indicated in the table, in the comments or in a note, along with the "No." These control methods constitute best estimates for preliminary design and will be justified in the NCSE.

6.3.5 Nuclear Criticality Analysis and Safety Evaluation Methods

The operations with fissionable materials proposed at the MFFF introduce risks of a criticality accident. Therefore, criticality safety must be ensured through design and administrative practices. Criticality analysis design methods require a high level of validation. In addition to providing single- and multi-parameter limits that may be referenced in criticality safety calculations, ANSI/ANS-8.1-1983 (R1988) provides guidance used in performing criticality analysis method validation. NCSEs are performed to develop and document the safety basis for facility operations. NCSEs are the main source of information demonstrating the adequacy of criticality controls and the effectiveness of administrative practices.

6.3.5.1 Criticality Analysis Methodology

Criticality analysis methods to be used in MFFF design activities and facility safety programs comply with the technical guidance of ANSI/ANS-8.1-1983 (R1988). In some cases, single- and multi-parameter limits provided by ANSI/ANS-8.1-1983 (R1988) may be used. Single- and multi-parameter limits may also be developed specific to MFFF design applications (i.e., limiting fissile material isotopic composition) using validated and approved computational methods. Validated and approved computational methods may also be used directly to demonstrate criticality safety through analysis of specific design applications. Computational methods to be applied in MFFF design analysis include Criticality Safety Analysis Sequence (CSAS) computer code control modules included in the SCALE system of codes, and the Monte Carlo N-Particle (MCNP) computer code package for reactivity determination.

Criticality safety calculations supporting initial MFFF design activities that use SCALE 4.4 code sequences employ the 238 energy group neutron cross-section set (i.e., 238GROUPNDF5).

The cross-sectional data used with MCNP in criticality analyses supporting initial MFFF design activities is the ENDF60 library file.

6.3.5.2 Method Validation and Calculated k_{eff} Design Limits

The validation process establishes method bias by comparing measured results from laboratory critical experiments to method-calculated results for the same systems. The verification and validation processes are controlled and documented as required by program QA procedures. Hardware system access controls are put in place to ensure that the same codes and data used in the validation are used in NCSE applications. Changes or maintenance to approved software is formally controlled and documented to the same level of control as the original verification and validation procedure.

The verification process ensures proper functioning of the mathematical operations in the methodology through comparison of sample problem results provided by the software supplier or in published literature with results produced by the access-controlled source code loaded on the production computer environment (i.e., hardware and operating system).

The validation establishes a method bias by correlating the results of critical experiments with results calculated for the same systems by the method being validated. Critical experiments are selected to be representative of the systems to be evaluated in specific design applications. The range of experimental conditions (e.g., material compositions and geometric arrangements) encompassed by a selected set of benchmark experiments establishes the "area(s) of applicability" over which the calculated method bias is applicable. Technical justifications are provided when extending the area(s) of applicability of a calculational method beyond the range of experimental conditions used in establishing the method bias discussed in ANSI/ANS-8.1-1983 (R1988).

The MFFF handles fissile materials in a variety of forms and compositions. MFFF processes include over 40 stages of process operations, ranging from receipt of PuO_2 and UO_2 powders through fabricated MOX fuel assembly storage and shipment. Criticality safety calculations are performed for each stage of processing, and the calculational methods are validated for each application. Separate validations may be required for the same criticality analysis method used in analyzing the various process stages. Separate validations are necessary to account for significant differences in the configurations analyzed. (For example, the method validation performed to justify dry PuO_2 powder mass limits in the Receiving Area will likely be different from that required to support the design of MOX fuel assembly storage racks.). The relationship between the validation process and the criticality design analyses is illustrated in the verification and validation process flow diagram presented in Figure 6-1.

Benchmark experiments are selected that resemble as closely as practical the systems being evaluated in a design application in all characteristics, such as system configuration (i.e., rod lattice versus homogeneous solution), moderator characteristics, fuel material composition (e.g., ^{239}Pu content) and density, moderator-to-fuel ratio, multiple fuel unit interaction, presence and form of strong neutron-absorbing materials, and reflector characteristics. The validation process includes statistical analysis of validation results to ensure compliance with ANSI/ANS-8.1-1983 (R1988) guidance to consider any extensions in area(s) of applicability necessary to demonstrate the adequacy of the criticality safety margin in design applications.

The validation process is comprised of the following basic steps:

1. Selection of suitable experiments to encompass the appropriate composition and configuration conditions that may exist in a specific design application
2. Statistical analysis to correlate k_{eff} results against significant experiment attributes, such as plutonium content, or absorbed neutron energy spectrum
3. Confirmation that specific design applications fall within the areas of applicability encompassed by the experiments for the key system attributes evaluated or additional margin added as applicable.
4. Establishment of criticality analysis method bias and subcritical limits.

Separate detailed validation calculations are performed for each specific MFFF process operation as necessary to account for the range of varying conditions that exist throughout the MFFF processes. Experiments are selected for each validation case consistent with guidance provided in NUREG/CR-6361, *Criticality Benchmark Guide for Light-Water-Reactor Fuel in*

Transportation and Storage Packages. Each design application is evaluated, and experiments are selected based on fundamental criticality parameters, such as type, mass, and form of fissile material, degree of moderation, amount and distribution of absorber materials, internal and external system characteristics (i.e., fuel unit interaction), reflector effectiveness, and neutron energy spectrum. Experiments are also identified on the basis of the ranges of characteristics that facilitate method bias to be correlated as a function of these fundamental parameters.

Calculated benchmark experiment k_{eff} results are analyzed statistically to establish method bias and to justify subcritical limits for specific applications in accordance with ANSI/ANS-8.1-1983 (R1988) guidance. Statistical techniques have previously been developed specifically for such method validation purposes. Statistical techniques similar to those described and demonstrated for light-water-reactor fuel transportation and storage packages in NUREG/CR-6361 are applied in MFFF criticality design applications to establish method bias and to justify subcritical limits. The statistical analysis methods for determining method bias and subcritical limits presented in NUREG/CR-6361 or NUREG/CR-6655, *Sensitivity and Uncertainty Analyses Applied to Criticality Safety Validation*, provide criticality methodology validation tools that are especially useful in situations where large numbers of experiments are not available that closely match the combinations of conditions of concern.

6.3.5.3 Criticality Benchmark Experiments

In accordance with guidance provided in ANSI/ANS-8.1-1983 (R1988), calculation techniques used in criticality safety design applications are validated and a bias is established by correlating the measured results of criticality benchmark experiments with calculated results obtained for these same systems by the method being evaluated. Diverse sets of criticality experiment information are used to validate criticality analysis methods and nuclear data for the design configurations encountered in the MFFF. Experiments, or other sophisticated methods of justification, involving a variety of moderating conditions to encompass normal and credible abnormal conditions involving PuO_2 and MOX configurations. Critical experiments conducted with aqueous solutions address AP processes. MOX powder blending and pellet production are best suited to single-unit MOX critical configurations as benchmarks, while other operations require interacting multi-unit array data. In addition to "physical form" issues, the composition of the fissionable materials is evaluated in the validation analysis. For example, validation analysis of PuO_2 processes consider the relative amounts of plutonium isotopes present in the mixtures being handled.

The anticipated MFFF uranium, plutonium, and MOX fissile material design configurations to be evaluated are represented by a relatively large number of well-documented experiment descriptions provided in technical reports and literature. A large compilation of benchmark quality criticality experiment descriptions is provided in the *International Handbook of Evaluated Criticality Safety Benchmark Experiments.* Of particular note is the similarity in plutonium isotopic composition characteristic (i.e., <10 wt % ^{240}Pu) that many of the plutonium and MOX system experiments share with the PuO_2 powder to be received at the MFFF. A wide range of experimental benchmark data is also available to help validate neutron cross-sections over thermal, intermediate, and fast neutron energy ranges. Additionally, recent investigations (*Investigations and Recommendations on the Use of Existing Experiments in Criticality Safety Analysis of Nuclear Fuel Cycle Facilities for Weapons-Grade Plutonium*, ORNL/TM-2001/262, Oak Ridge National Laboratory, June 2002,) have shown that additional, already published experiments also can be used for criticality benchmark validation purposes since they exhibit similar characteristics to MOX powder to be utilized at the MFFF.

6.3.5.4 Nuclear Criticality Safety Evaluations

As part of the initial design process, before starting a new operation with fissionable materials, or before an existing fissionable material operation is modified, NCSEs are performed to ensure that the entire process will be subcritical under both normal and credible abnormal conditions. NCSEs are documented with sufficient detail, clarity, and lack of ambiguity to allow independent evaluation and judgment of results. NCSEs identify the controlled nuclear and process parameters and their associated limits upon which criticality safety depends.

Thus, NCSEs form the basis for criticality safety for operations in which fissionable material is handled. That is, each NCSE evaluates a respective operation to determine credible accident sequences and identifies sufficient controls such that double contingency protection is provided in those cases in which a criticality is credible. Utilizing the results of validated calculational methodologies, the NCSEs demonstrate that both normal and accident conditions meet the required minimum margin of subcriticality. Finally, the IROFS to provide double contingency protection, along with criticality accident sequences, are identified in NCSEs. Features that are required to ensure that the criticality controls identified in the NCSE are sufficiently available and reliable are provided through the implementation of management measures such as procedures, training, maintenance procedures, and surveillance.

An approved design configuration requires criticality safety design input. Figure 6-2 presents an overview of the steps involved in developing an MFFF NCSE. During preliminary design, criticality safety calculations are performed to justify a preliminary design concept. These calculations assess both the normal operating and assumed accident conditions. Where practical, criticality is precluded by demonstrating that the design is subcritical without the need to implement controls, or by making appropriate design changes to render criticality non-credible. In those cases in which it is not practical to make criticality non-credible, criticality control parameters are selected and limits on these parameters are established.

6.3.5.5 Design Control

Criticality safety during design and operation is ensured for the MFFF through design and administrative practices. MFFF design and safety features are documented and controlled through the implementation of a rigorous configuration management program (see Section 15.2). Criticality safety calculations and NCSEs are maintained up to date and consistent with existing facility process and design features and administrative practices. The configuration management program ensures the following:

- Reports validating the method for analyzing criticality are maintained consistent with criticality safety documentation provided in criticality safety calculations and NCSEs.
- NCSEs are maintained consistent with existing facility process and design features and administrative practices and rely only on validated calculational methods.

- Credible optimum conditions (i.e., most reactive conditions physically possible) for each controlled parameter are assumed in criticality safety calculations and NCSEs unless specified controls are implemented to limit the controlled parameter to a specified value or range.
- Variability and uncertainty in a process condition and the subcritical limit are established and considered when applying computational methods to specific design applications.
- Surveillance programs are established and implemented to ensure the continued efficacy of supplemental neutron-absorber materials (e.g., borated concrete or cadmium) during the operational life of the MFFF.
- During license operation, the configuration management program meets the requirements of 10 CFR §70.72, including review of changes for potential criticality concerns.

6.3.6 ISA Commitments

During development of the ISA, criticality controls credited in the NCSEs will be identified and evaluated, and a more detailed description of the CAAS will be provided. This information will be reflected in the license application for possession and use of SNM and/or its accompanying ISA Summary, as appropriate. Section 6.4 provides additional details.

6.4 DESIGN BASES

This section discusses the design bases requirements applicable to the design and operation of criticality safety SSCs. These requirements may be modified during the final design phase in accordance with the configuration management system, described in Section 15.2.

Principal SSCs are described in Chapter 5 of this document. Specific IROFS associated with criticality safety will be identified in the ISA.

Criticality in the MFFF will be prevented. The design features, administrative controls, and management measures to ensure that criticality is prevented will be described in the ISA Summary submitted with the license application for possession and use of SNM. Under normal and credible abnormal conditions, nuclear processes will be designed to be subcritical, including the use of a safety margin, which will account for computational bias, uncertainties, and an appropriate administrative safety margin. The design will provide for criticality control including adherence to the double-contingency principle.

A CAAS will be included in the MFFF design in accordance with the design criteria described earlier in this chapter. (Note that a CAAS does not prevent or mitigate design basis events, and is therefore not considered a principal SSC.)

The Nuclear Criticality Safety Program for the MFFF will be in accordance with Regulatory Guide 3.71. Regulatory Guide 3.71 has been developed to provide guidance on complying with the applicable portions of NRC regulations, including 10 CFR Part 70, by describing procedures for preventing nuclear criticality accidents in operations involving handling, processing, storing, and transporting SNM at fuels and material facilities. This regulatory guide endorses specific nuclear criticality safety standards drafted by Subcommittee ANS-8 (Fissionable Materials

Outside Reactors) of the American Nuclear Society Standards Committee for these purposes. The MFFF criticality design basis includes use of ANSI/ANS standards endorsed by Regulatory Guide 3.71 as follows:

ANSI/ANS-8.1-1983 (R1988), Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors

This standard is part of the design basis of MFFF processes and fissile material handling and storage areas. The standard provides general guidance addressing administrative and technical practices, as well as single-parameter and multi-parameter control limits for systems containing ^{233}U, ^{235}U, and ^{239}Pu. Of particular significance to the MFFF design, ANSI/ANS-8.1-1983(R1988) provides guidance for performing NCS analysis methodology validation. ANSI/ANS-8.1 NCS practices will be referenced in NCSEs to support MFFF design and operational approach. MFFF processes and storage areas that contain plutonium, uranium, or plutonium-uranium fuel mixtures will typically be explicitly evaluated using validated NCS analysis methodology in accordance with ANSI/ANS-8.1 technical practice guidance. However, criticality safety may be demonstrated by reference to ANSI/ANS-8.1 single-parameter and multi-parameter control limits in lieu of analysis.

MFFF operations will comply with the guidance and implement the recommendations of ANSI/ANS-8.1-1983 (R1988). Clarifications are noted as follows:

- Section 4.2.2: MFFF process, material handling, or storage area 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. For the purposes of demonstrating compliance with this requirement, "unlikely" is defined as events or event sequences that are not expected to occur during the facility lifetime, but are considered credible. This commitment is considered applicable to process, material handling, or storage area designs where a criticality accident has been determined to be credible.
- Section 4.2.3: MFFF process design will rely on engineered features where practicable rather than administrative controls. Justifications for use of administrative controls will be provided.
- Section 4.3.2: In cases where an extension in the area(s) of applicability of a NCS analysis methodology is required, the method will be supplemented by other methods to provide a better estimate of bias in the extended area(s). As an alternative, the extension in the area(s) of applicability may be addressed through an increased margin of subcriticality.

Note that Regulatory Guide 3.71 endorses the 1983 version of this standard. The MFFF will reference guidance provided in the most recent Subcommittee ANS-8 working group approved version ANSI/ANS-8.1-1983 (R1988).

ANSI/ANS-8.3-1997, Criticality Accident Alarm System

This standard is part of the design basis of MFFF process and fissile material handling and storage areas. The standard provides general guidance for the design, testing, and maintenance of criticality accident alarm systems at facilities where a criticality accident may lead to excessive exposure to radiation. The scope of guidance provided in ANSI/ANS-8.3-1997 is applicable to both MFFF design and operations.

MFFF operations will comply with the guidance and implement the recommendations of ANSI/ANS-8.3-1997 (and the corresponding guidance in Reg. Guide 3.71). Clarifications are noted as follows:

- Section 4.1.3: Overall risk to personnel resulting from hazards that may result from false alarms and subsequent sudden interruption of operations, and relocation of personnel will be evaluated.

ANSI/ANS-8.7-1975, Guide for Nuclear Criticality Safety in the Storage of Fissile Materials

This standard may be part of the design basis of MFFF fissile material storage areas. Although MFFF storage areas that contain plutonium, uranium, or plutonium-uranium fuel mixtures will typically be explicitly evaluated using validated NCS analysis methodology in accordance with ANSI/ANS-8.1-1983 (R1988), criticality safety may be demonstrated by reference to ANSI/ANS-8.7-1975 in lieu of analysis.

If used as part of the design basis, MFFF operations will comply with the guidance and implement the recommendations of ANSI/ANS-8.7-1975. Clarifications are noted as follows:

- Section 4.2.4: The design of storage structures will preclude unacceptable arrangements or configurations without reliance on administrative controls to extent practicable. Any reliance on administrative controls will be justified.
- Section 4.2.6: The design of MFFF fissile material storage areas will be reviewed and administrative controls limiting the introduction of combustible materials during operation applied to ensure an acceptable combustible loading is maintained. Fire protection provisions (i.e., whether or not fire suppression provided and type) in areas where fissile material is processed, handled or stored will be justified.

Note that Regulatory Guide 3.71 endorses the 1975 version of this standard. The MFFF may also reference guidance provided in the most recent Subcommittee ANS-8 working group approved version (i.e., ANSI/ANS-8.7-1998). However, if this is done, a demonstration will be provided that this more recent standard constitutes an acceptable methodology.

ANSI/ANS-8.9-1987, Nuclear Criticality Safety Criteria for Steel-Pipe Intersections Containing Aqueous Solutions of Fissile Materials

This standard has been officially withdrawn by the ANS-8 working group, but continues to be available for reference. This standard will not be referenced as a basis for design for the MFFF. Intersections of process components and piping containing aqueous solutions of fissile materials will be explicitly evaluated using validated NCS analysis methodology in accordance with ANSI/ANS-8.1-1983 (R1988).

ANSI/ANS-8.10-1983, Criteria for Nuclear Criticality Safety Controls in Operations with Shielding and Confinement

MFFF NCSEs performed for each process unit or area will demonstrate compliance with the double contingency principle consistent with guidance provided in Section 4.2.2 of ANSI/ANS-8.1-1983 (R1988). Therefore, the guidance and recommendations provided in ANSI/ANS-8.10-1983 are not generally applicable to the MFFF. However, guidance provided for crediting shielding and confinement may be used when demonstrating compliance with worker safety performance criteria specified in 10 CFR §70.61(b). Therefore, this standard may be referenced as a basis for design for the MFFF.

ANSI/ANS-8.12-1987, Nuclear Criticality Control and Safety of Plutonium-Uranium Fuel Mixtures Outside Reactors

This standard may be reaffirmed or withdrawn in future action by the ANS-8 working group (reference ANS-8 meeting minutes, Albuquerque, New Mexico, March 30, 2000). This standard may be part of the design basis of MFFF process design. Although MFFF processes that contain plutonium-uranium fuel mixtures will typically be explicitly evaluated using validated NCS analysis methodology in accordance with ANSI/ANS-8.1-1983 (R1988), criticality safety may be demonstrated by reference to ANSI/ANS-8.12-1987 in lieu of analysis.

ANSI/ANS-8.15-1981, Nuclear Criticality Control of Special Actinide Elements

This standard is not part of the MFFF criticality design basis, as it is applicable to operations with isolated units containing special actinide nuclides other than ^{233}U, ^{235}U, and ^{239}Pu. Nuclear criticality control of special actinide nuclides will be explicitly evaluated using validated NCS analysis methodology in accordance with ANSI/ANS-8.1-1983 (R1988).

ANSI/ANS-8.17-1984, Criticality Safety Criteria for the Handling, Storage, and Transportation of Light Water Reactor (LWR) Fuel Outside Reactors

This standard is part of the design basis of MFFF fissile material handling and storage areas. The standard provides guidance addressing general safety criteria and criteria for establishing subcriticality for handling, storage, and transportation of LWR fuel rods outside reactor cores. Of particular significance to the MFFF design, ANSI/ANS-8.17-1984 provides general guidance for combining the various bias, uncertainty, and administrative safety margin terms that must be considered when performing criticality calculations in order to establish a final k_{eff} acceptance criteria. Examples of normal and credible abnormal conditions that must be considered when performing NCSEs are also provided in an appendix to the standard.

MFFF operations will comply with the guidance and implement the recommendations of ANSI/ANS-8.17-1984. Clarifications are noted as follows:

- Section 4.11: Fuel units and rods will be handled, stored, and transported in a manner that provides a sufficient factor of safety to require at least two unlikely, independent, and concurrent changes in conditions before a criticality accident is possible. This commitment is considered applicable to process, material handling, or storage area designs where a criticality accident has been determined to be credible.

- Section 5.1: The criticality experiments used as benchmarks in computing k_c will have physical compositions, configurations, and nuclear characteristics (including reflectors) similar to those of the system being evaluated. In cases where similar experiments are not available or are not similar in criticality safety significant respects to the design application, alternative analyses will be presented. Alternative analyses will further demonstrate similarity or, in cases where an extension in the area(s) of applicability of a NCS analysis methodology is required, the method will be supplemented by other methods to provide a better estimate of bias in the extended area(s). As an alternative, the extension in the area(s) of applicability may be addressed through an increased margin of subcriticality.

ANSI/ANS-8.19-1996, Administrative Practices for Nuclear Criticality Safety

This standard is part of the design basis of MFFF processes and fissile material handling and storage areas. This standard provides criteria for the administration of a nuclear criticality safety program for operations outside reactors in which there exists a potential for criticality accidents.

MFFF operations will comply with the guidance and implement the recommendations of ANSI/ANS-8.19-1996. An exception is noted as follows:

- Section 10: Guidance for planned response to nuclear criticality accidents are addressed by ANSI/ANS-8.23-1997. Therefore, no commitments are made to satisfy the guidance or recommendations of this section.

ANSI/ANS-8.20-1991, Nuclear Criticality Safety Training

This standard is part of the design basis for MFFF operational practices. The standard provides detailed guidance for NCS training for personnel associated with operations outside reactors where a potential exists for criticality accidents.

MFFF operations will comply with the guidance and implement the recommendations of ANSI/ANS-8.20-1991. No exceptions or clarifications are noted.

ANSI/ANS-8.21-1995, Use of Fixed Neutron Absorbers in Nuclear Facilities Outside Reactors

This standard is part of the design basis of MFFF processes and fissile material handling and storage areas. The standard provides detailed guidance for use of fixed neutron absorbers used for criticality control.

The MFFF will comply with the guidance of this standard to assure fixed neutron absorber material integrity and reliability to perform NCS functions. The guidance includes no recommendations that require further clarification and no exceptions are taken.

ANSI/ANS-8.22-1997, Nuclear Criticality Safety Based on Limiting and Controlling Moderators

This standard is part of the design basis of MFFF processes and fissile material handling and storage areas. The standard provides detailed guidance for limiting and controlling moderators to achieve criticality control (i.e., process units or areas where "Yes" is indicated in Tables 6.1 or 6.2 under the moderation control column).

MFFF operations will comply with the guidance and implement the recommendations of ANSI/ANS-8.22-1997. Clarifications are noted as follows:

- Section 4.1.7: The design of MFFF fissile material storage areas will be reviewed and administrative controls limiting the introduction of combustible materials during operation applied to ensure an acceptable combustible loading is maintained. Fire protection provisions (i.e., fire suppression type) in areas where fissile material is processed, handled or stored will be justified.

ANSI/ANS-8.23-1997, Nuclear Criticality Accident Emergency Planning and Response.

As discussed in Chapter 14, an NRC-approved Emergency Plan is not required for the MFFF. Nonetheless, MFFF operations will comply with the recommendations of ANSI/ANS-8.23-1997, without exception. While not considered part of the design basis of principal SSCs, this standard provides guidance for minimizing risks to personnel during emergency response to a nuclear criticality accident outside reactors.

Criticality accident emergency planning and response, while an important programmatic element, is not part of the safety basis.

In all cases, no single credible event or failure will result in the potential for a criticality accident. Process designs will incorporate sufficient features such that they can be demonstrated subcritical under both normal and credible accident conditions. For example, in cases where favorable-geometric devices are utilized and no credible means exist by which the device could deform, or by which non-specification fissionable materials can be introduced, the level of safety will be demonstrated to be acceptable.

NCSEs will be performed to ensure the adequacy of criticality controls. The NCSEs will be used to develop the basis of design and facility operations and demonstrate compliance with the double contingency principle. Criticality controls identified as necessary in the NCSEs are flowed into the ISA as IROFS. The ISA also documents a comprehensive systematic review of facility hazards, including criticality, that confirms the acceptability of the selected means of criticality control for process stations and areas within the AP and MP facility designs.

MFFF criticality analyses will follow the guidance provided by ANSI/ANS-8.1-1983 (R1988) in performing criticality analysis method validation.

Critical experiments will be selected to be representative of the systems to be evaluated in specific design applications. The range of experimental conditions, such as material compositions and geometric arrangements, encompassed by a selected set of benchmark experiments establishes the "area(s) of applicability" over which the calculated method bias is applicable. Technical justifications will be provided when extending the area(s) of applicability of a calculational method beyond the range of experimental conditions used in establishing the method bias as required by ANSI/ANS-8.1-1983 (R1988).

Specific guidance regarding the establishment of method bias, the proper accounting for analytical uncertainties, and the determination of subcritical limits in criticality safety analyses provided in ANSI/ANS-8.17-1984 will be followed. A design application (system) is considered subcritical when the calculated multiplication factor for the design application (system) is shown to be less than or equal to an established upper safety limit (USL) that properly accounts for method bias and uncertainty and administrative margin. An appropriate administrative safety margin plus computational bias will be used for MFFF design applications. Justification for use of this value is provided in the Mixed Oxide Fuel Fabrication Facility Criticality Code Validation report submitted separately. Justifications for the remaining design applications will be provided in other reports by the time of the license application.

The design basis for criticality safety can be summarized as follows:

1. Design of facility operations shall comply with the double contingency principle, as stated in ANSI/ANS-8.1-1983 (R1988).

2. Computer calculations shall not exceed a maximum keff, taking all uncertainties and biases into account. Description of calculation methods and their validation, or means of establishing subcritical margins if parameter limits are not based on computer calculations.

3. Facility operations shall be designed to be subcritical under both normal and credible abnormal conditions.

4. Dominant nuclear criticality safety controlled parameters shall be specified for each major process.

5. Design approach shall prefer engineered over administrative controls, and passive over active engineered controls.

6. The facility shall have a criticality accident alarm system that complies with the requirements of 10 CFR 70.24. Description of the detection system and its operating characteristics.

7. The management measures and how they are applied to each controlled parameter shall be described, along with the safety grades for criticality.

8. A description of the organization and administration for NCS, and the key elements of the NCS Program.

9. A description of the technical practices used to determine limits and controls on each controlled parameter, in criticality safety evaluations, including what ANSI/ANS standards are being committed to in whole or in part.

10. Where moderation control is required for subcriticality, a description of the approach to designing the facility to meet both fire safety and criticality safety requirements (including presence and type of fire suppression).

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Tables

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Table 6-1. Preliminary Definition of Reference Fissile Medium and Control Methods for Principal AP Process Units

Criticality Control Unit	Control Method													Comments
	Physicochemical Characteristics (PC)	Mass (M)	Geometry (G)	Density (D)	Isotopics (I)	Reflection (R)	Moderation (MN)	Concentration (C)	Interaction (IN)	Neutron absorber (A)	Volume (V)	Heterogeneity (H)	Process variable	
Decanning Unit														
Unloading workstation	NO $PuO_2 + H_2O$	YES	NO	NO [1] d ≤ 11.46	NO [1] $^{240}Pu \geq 4\%$	NO	YES	NO	NO	NO	NO	NO	NO	
Outer can opening	NO $PuO_2 + H_2O$	YES	NO	NO [1] d ≤ 11.46	NO [1] $^{240}Pu \geq 4\%$	NO	YES	NO	NO	NO	NO	NO	NO	
Inner can opening	NO $PuO_2 + H_2O$	YES	NO	NO [1] d ≤ 11.46	NO [1] $^{240}Pu \geq 4\%$	NO	YES	NO	NO	NO	NO	NO	NO	
Dispatching	NO $PuO_2 + H_2O$	YES	NO	NO [1] d ≤ 11.46	NO [1] $^{240}Pu \geq 4\%$	NO	YES	NO	NO	NO	NO	NO	NO	
Food can opening	NO $PuO_2 + H_2O$	YES	NO	NO [1] d ≤ 11.46	NO [1] $^{240}Pu \geq 4\%$	NO	YES	NO	NO	NO	NO	NO	NO	
Pneumatic transfer departure	NO $PuO_2 + H_2O$	YES	NO	NO [1] d ≤ 11.46	NO [1] $^{240}Pu \geq 4\%$	NO	YES	NO	NO	NO	NO	NO	NO	

Table 6-1. Preliminary Definition of Reference Fissile Medium and Control Methods for Principal AP Process Units (Continued)

Criticality Control Unit	Control Method													Comments
	Physicochemical Characteristics (PC)	Mass (M)	Geometry (G)	Density (D)	Isotopics (I)	Reflection (R)	Moderation (MN)	Concentration (C)	Interaction (IN)	Neutron absorber (A)	Volume (V)	Heterogeneity (H)	Process variable	
Decanning Unit (cont.)														
Pneumatic transfer arrival	NO $PuO_2 + H_2O$	YES	NO	YES [1,9] $d \leq 7$	NO [1] $^{240}Pu \geq 4\%$	NO	YES	NO	NO	NO	NO	NO	NO	
Convenience can opening	NO $PuO_2 + H_2O$	YES	NO	YES [1,9] $d \leq 7$	NO [1] $^{240}Pu \geq 4\%$	NO	YES	NO	NO	NO	NO	NO	NO	
PuO_2 dosing hopper	NO $PuO_2 + H_2O$	NO	YES Slab	YES [1,9] $d \leq 7$	NO [1] $^{240}Pu \geq 4\%$	NO	NO	NO	TBD [2]	YES Cd coating	NO	NO	NO	Plutonium coming from the PuO_2 container storage vault or from repolished buffer storage.
Milling Unit KDM														
Milling pneumatic transfer	NO $PuO_2 + H_2O$	YES	NO	NO [1] $d \leq 11.46$	NO [1] $^{240}Pu \geq 4\%$	NO	YES	NO	NO	NO	NO	NO	NO	
Can transfer	NO $PuO_2 + H_2O$	YES	NO	NO [1] $d \leq 11.46$	NO [1] $^{240}Pu \geq 4\%$	NO	YES	NO	NO	NO	NO	NO	NO	

Table 6-1. Preliminary Definition of Reference Fissile Medium and Control Methods for Principal AP Process Units (Continued)

Criticality Control Unit	Control Method													Comments
	Physicochemical Characteristics (PC)	Mass (M)	Geometry (G)	Density (D)	Isotopics (I)	Reflection (R)	Moderation (MN)	Concentration (C)	Interaction (IN)	Neutron absorber (A)	Volume (V)	Heterogeneity (H)	Process variable	
Milling Unit KDM (cont.)														
Milling	NO $PuO_2 + H_2O$	YES	NO	NO [1] $d \leq 11.46$	NO [1] $^{240}Pu \geq 4\%$	NO	YES	NO	NO	NO	NO	NO	PC	Milling lower density
Sampling	NO $PuO_2 + H_2O$	YES	NO	NO [1] $d \leq 11.46$	NO [1] $^{240}Pu \geq 4\%$	NO	YES	NO	NO	NO	NO	NO	NO	
Sample pneumatic	NO $PuO_2 + H_2O$	YES	NO	NO [1] $d \leq 11.46$	NO [1] $^{240}Pu \geq 4\%$	NO	YES	NO	NO	NO	NO	NO	NO	
Prepolishing buffer storage	NO $PuO_2 + H_2O$	NO	YES Array of cylind ers	NO [1] $d \leq 11.46$	NO [1] $^{240}Pu \geq 4\%$	NO	NO	NO	NO	YES Cole-manite concrete	NO	NO	NO	Colemanite concrete is a type of borated concrete.
Milling pneumatic transfer (arrival)	NO $PuO_2 + H_2O$	YES	NO	YES [1,9] $d \leq 7$	NO [1] $^{240}Pu \geq 4\%$	NO	YES	NO	NO	NO	NO	NO	NO	

Table 6-1. Preliminary Definition of Reference Fissile Medium and Control Methods for Principal AP Process Units (Continued)

Criticality Control Unit	Control Method													Comments
	Physicochemical Characteristics (PC)	Mass (M)	Geometry (G)	Density (D)	Isotopics (I)	Reflection (R)	Moderation (MN)	Concentration (C)	Interaction (IN)	Neutron absorber (A)	Volume (V)	Heterogeneity (H)	Process variable	
Milling Unit KDM (cont.)														
Reusable can emptying	NO $PuO_2 + H_2O$	YES	NO	YES [1,9] d ≤ 7	NO [1] $^{240}Pu \geq 4\%$	NO	YES	NO	NO	NO	NO	NO	NO	
Dosing hopper	NO $PuO_2 + H_2O$	NO	YES Slab	YES [1,9] d ≤ 7	NO [1] $^{240}Pu \geq 4\%$	NO	NO	NO	NO	YES Cd coating	NO	NO	NO	
Recanning Unit KDA														
Convenience can packaging	NO $PuO_2 + H_2O$	YES	NO	NO [1] d ≤ 11.46	NO [1] $^{240}Pu \geq 4\%$	NO	YES	NO	NO	NO	NO	NO	NO	
Inner can packaging	NO $PuO_2 + H_2O$	YES	NO	NO [1] d ≤ 11.46	NO [1] $^{240}Pu \geq 4\%$	NO	YES	NO	NO	NO	NO	NO	NO	
Outer can packaging	NO $PuO_2 + H_2O$	YES	NO	NO [1] d ≤ 11.46	NO [1] $^{240}Pu \geq 4\%$	NO	YES	NO	NO	NO	NO	NO	NO	

Table 6-1. Preliminary Definition of Reference Fissile Medium and Control Methods for Principal AP Process Units (Continued)

Criticality Control Unit	Control Method													Comments
	Physicochemical Characteristics (PC)	Mass (M)	Geometry (G)	Density (D)	Isotopics (I)	Reflection (R)	Moderation (MN)	Concentration (C)	Interaction (IN)	Neutron absorber (A)	Volume (V)	Heterogeneity (H)	Process variable	
KDD Dissolution/Dechlorination														
Electrolyzer	NO PuO_2 + H_2O	YES	YES	YES [1,9] $d \leq 7$	NO [1] $^{240}Pu \geq$ 4%	NO	NO	NO	TBD [2]	YES Cd coating	NO	NO	NO	Mass control credited when cooling coil leaks (IROFS failure)
Dechlorination Columns	NO PuO_2 + H_2O	NO	NO	YES [1,9] $d \leq 7$	NO [1] $^{240}Pu \geq$ 4%	NO	NO	YES	TBD [2]	NO	NO	NO	NO	
Reception tank	NO PuO_2 + H_2O	NO	YES slab	YES [1,9] $d \leq 7$	NO [1] $^{240}Pu \geq$ 4%	NO	NO	NO	TBD [2]	YES Cd coating	NO	NO	NO	
PuO_2 filter	NO PuO_2 + H_2O	NO	YES Cylin -der	YES [1,9] $d \leq 7$	NO [1] $^{240}Pu \geq$ 4%	NO	NO	NO	TBD [2]	NO	NO	NO	NO	Double control to guarantee absence of PuO_2 in downstream equipment.
Dilution and sampling tank	YES $Pu(NO_3)_3$ + H_2O[3,8]	NO	YES Slab	NO	NO [1] $^{240}Pu \geq$ 4%	NO	NO	NO	TBD [2]	YES Cd coating	NO	NO	PC	

Table 6-1. Preliminary Definition of Reference Fissile Medium and Control Methods for Principal AP Process Units (Continued)

Criticality Control Unit	Control Method													Comments
	Physicochemical Characteristics (PC)	Mass (M)	Geometry (G)	Density (D)	Isotopics (I)	Reflection (R)	Moderation (MN)	Concentration (C)	Interaction (IN)	Neutron absorber (A)	Volume (V)	Heterogeneity (H)	Process variable	
UO2 Dissolution														
Buffer Tank	YES $Pu(NO_3)_3 + H_2O$ [3,6]	NO	NO	NO	NO [1] $^{240}Pu \geq 4\%$	NO	NO	YES [7]	TBD [2]	NO	NO	NO	NO	
KDB Dissolution Unit														
Electrolyzer	NO $PuO_2 + H_2O$	NO	YES	NO [1,9] $d \leq 7$	NO [1] $^{240}Pu \geq 4\%$	NO	NO	NO	TBD [2]	YES Cd coating	NO	NO	NO	
Reception tank	NO $PuO_2 + H_2O$	NO	YES slab	NO [1,9] $d \leq 7$	NO [1] $^{240}Pu \geq 4\%$	NO	NO	NO	TBD [2]	YES Cd coating	NO	NO	NO	
PuO_2 filter	NO $PuO_2 + H_2O$	NO	YES Cylin -der	NO [1,9] $d \leq 7$	NO [1] $^{240}Pu \geq 4\%$	NO	NO	NO	TBD [2]	NO	NO	NO	NO	Double control to guarantee absence of PuO_2 in downstream equipment.
Dilution and sampling tank	YES $Pu(NO_3)_3 + H_2O$[3,8]	NO	YES Slab	NO	NO [1] $^{240}Pu \geq 4\%$	NO	NO	NO	TBD [2]	YES Cd coating	NO	NO	PC	
Buffer Tank	YES $Pu(NO_3)_3 + H_2O$ [3,6]	NO	YES Annul -ar	NO	NO [1] $^{240}Pu \geq 4\%$	NO	NO	NO	TBD [2]	YES Cole-manite concrete	NO	NO	NO	Colemanite concrete is a type of borated concrete.

Table 6-1. Preliminary Definition of Reference Fissile Medium and Control Methods for Principal AP Process Units (Continued)

Criticality Control Unit	Control Method													Comments
	Physicochemical Characteristics (PC)	Mass (M)	Geometry (G)	Density (D)	Isotopics (I)	Reflection (R)	Moderation (MN)	Concentration (C)	Interaction (IN)	Neutron absorber (A)	Volume (V)	Heterogeneity (H)	Process variable	
Purification Unit														
Feeding Tank	YES $Pu(NO_3)_3 + H_2O$ [3,6]	NO	YES Annul-ar	NO	NO [1] $^{240}Pu \geq 4\%$	NO	NO	NO	TBD [2]	YES Cole-manite concrete	NO	NO	NO	Colemanite concrete is a type of borated concrete.
Purification pulsed columns: +Extraction +Scrubbing +Diluent washing column 2100	YES $Pu(NO_3)_3 + H_2O$ [3,6]	NO	YES Cylin-der	NO	NO [1] $^{240}Pu \geq 4\%$	NO	NO	NO	TBD [2]	NO	NO	NO	NO	
Purification pulsed columns: +Pu stripping +U scrubbing +Diluent washing column 3100	YES $Pu(NO_3)_3 + H_2O$ [6]	NO	YES Cylin-der	NO	NO [1] $^{240}Pu \geq 4\%$	NO	NO	NO	TBD [2]	NO	NO	NO	NO	

Table 6-1. Preliminary Definition of Reference Fissile Medium and Control Methods for Principal AP Process Units (Continued)

Criticality Control Unit	Control Method													Comments
	Physicochemical Characteristics (PC))	Mass (M)	Geometry (G)	Density (D)	Isotopics (I)	Reflection (R)	Moderation (MN)	Concentration (C)	Interaction (IN)	Neutron absorber (A)	Volume (V)	Heterogeneity (H)	Process variable	
Purification Unit (Continued)														
Pu barrier mixer settlers	YES $Pu(NO)_3$ + H_2O [3,6]	NO	YES	NO	NO [1] $^{240}Pu \geq 4\%$	NO	NO	NO	TBD [2]	YES Cd coating	NO	NO	NO	
U stripping + diluent washing mixer settlers	YES $UO_2(NO_3)_2$ + H_2O [6]	NO	YES slab	NO	NO $^{235}U \leq 35\%$	NO	NO	NO	TBD [2]	Yes	NO	NO	NO	
Oxidation columns	YES $Pu(NO_3)_3$ + H_2O [3,6]	NO	YES Cylin-der	NO	NO [1] $^{240}Pu \geq 4\%$	NO	NO	NO	TBD [2]	NO	NO	NO	NO	
Pu Rework Tanks	YES $Pu(NO_3)_3$ + H_2O [3,6]	NO	YES Slab	NO	NO [1] $^{240}Pu \geq 4\%$	NO	NO	NO	TBD [2]	YES Cd coating	NO	NO	NO	
Rafinates Reception, and Recycling, Control Tanks	YES $Pu(NO_3)_3$ + H_2O [3,6]	NO	YES Annul-ar	NO	NO [1] $^{240}Pu \geq 4\%$	NO	NO	NO	TBD [2]	YES Cole-manite concrete	NO	NO	NO	Colemanite concrete is a type of borated concrete.
Slab settler	YES $Pu(NO_3)_3$ + H_2O [3,6]	NO	YES Slab	NO	NO [1] $^{240}Pu \geq 4\%$	NO	NO	NO	TBD [2]	YES Cd coating	NO	NO	NO	

Table 6-1. Preliminary Definition of Reference Fissile Medium and Control Methods for Principal AP Process Units (Continued)

Criticality Control Unit	Control Method													Comments
	Physicochemical Characteristics (PC)	Mass (M)	Geometry (G)	Density (D)	Isotopics (I)	Reflection (R)	Moderation (MN)	Concentration (C)	Interaction (IN)	Neutron absorber (A)	Volume (V)	Heterogeneity (H)	Process variable	
Purification Unit (Continued)														
Reception tank	YES $Pu(NO_3)_3 + H_2O$ [3,6]	NO	YES Annul-ar	NO	NO [1] $^{240}Pu \geq 4\%$	NO	NO	NO	TBD [2]	YES Cole-manite concrete	NO	NO	NO	Colemanite concrete is a type of borated concrete.
Oxalic Precipitation and Oxidation Unit														
Preparation tanks	YES $Pu(NO_3)_3 + H_2O$ [3,6]	NO	YES Annul-ar	NO	NO [1] $^{240}Pu \geq 4\%$	NO	NO	NO	TBD [2]	YES Cole-manite concrete	NO	NO	NO	Colemanite concrete is a type of borated concrete.
Precipitators	YES $PuO_2F_2 + H_2O$ [4,6]	NO	YES	NO	NO [1] $^{240}Pu \geq 4\%$	NO	NO	NO	TBD [2]	YES Cd coating	NO	NO	NO	
Rotating flat filter	YES $PuO_2F_2 + H_2O$ [4,6]	NO	YES	NO	NO [1] $^{240}Pu \geq 4\%$	NO	NO	NO	TBD [2]	NO	NO	NO	NO	
Calcination furnace	NO $PuO_2 + H_2O$	NO	YES Cylin-der	YES [1,10] $d \leq 3.5$	NO [1] $^{240}Pu \geq 4\%$	NO	NO	NO	TBD [2]	NO	NO	NO	NO	
Homogenization Unit														
Homogenizing hoppers	NO $PuO_2 + H_2O$	YES	YES Slab	YES [1,10] $d \leq 3.5$	NO [1] $^{240}Pu \geq 4\%$	NO	NO	NO	NO [5]	YES Cd coating	NO	NO	NO	

Table 6-1. Preliminary Definition of Reference Fissile Medium and Control Methods for Principal AP Process Units (Continued)

Criticality Control Unit	Control Method													Comments
	Physicochemical Characteristics (PC)	Mass (M)	Geometry (G)	Density (D)	Isotopics (I)	Reflection (R)	Moderation (MN)	Concentration (C)	Interaction (IN)	Neutron absorber (A)	Volume (V)	Heterogeneity (H)	Process variable	
Canning Unit														
Canning feeding head	NO PuO_2 + H_2O	NO	YES	YES [1,9] $d \leq 3.5$	NO [1] $^{240}Pu \geq$ 4%	NO	NO	NO	TBD [2]	NO	NO	NO	NO	
Oxalic Mother Liquor Recovery Unit														
Oxalic mother liquors recovery main equipment (except for Buffer and Sampling tanks)	YES PuO_2F_2 + H_2O [4,6]	NO	YES	NO	NO [1] $^{240}Pu \geq$ 4%	NO	NO	NO	TBD [2]	YES Cole-manite concrete and Cd coating	NO	NO	NO	Colemanite concrete is a type of borated concrete.
Buffer and Sampling Tanks	YES PuO_2F_2 + H_2O [4,6]	YES	NO	NO	NO [1] $^{240}Pu \geq$ 4%	NO	NO	YES [7]	TBD [2]	NO	NO	NO	NO	
Solvent Recovery Unit														
Solvent recovery mixer settlers	YES $UO_2(NO_3)_2$ + H_2O [6]	NO	NO	NO	NO $^{235}U \leq$ 93.5%	NO	NO	YES [7]	TBD [2]	NO	NO	NO	NO	
Acid Recovery Unit														
Acid recovery	YES $Pu(NO_3)_3$ + H_2O [3,6]	NO	NO	NO	NO [1] $^{240}Pu \geq$ 4%	NO	NO	YES [7]	TBD [2]	NO	NO	NO	NO	

Table 6-1. Preliminary Definition of Reference Fissile Medium and Control Methods for Principal AP Process Units (Continued)

Criticality Control Unit	Control Method													Comments
	Physicochemical Characteristics (PC)	Mass (M)	Geometry (G)	Density (D)	Isotopics (I)	Reflection (R)	Moderation (MN)	Concentration (C)	Interaction (IN)	Neutron absorber (A)	Volume (V)	Heterogeneity (H)	Process variable	
Offgas Treatment Unit														
Offgas Treatment	NO [TBD]	NO	NO	NO	NO	NO	NO	YES [7]	TBD [2]	NO	NO	NO	NO	
Liquid Waste Reception Unit														
Liquid Waste Reception	NO [TBD]	NO	NO	NO	NO	NO	NO	YES [7]	TBD [2]	NO	NO	NO	NO	
Sampling Unit														
Sampling Unit	NO [TBD]	NO	NO	NO	NO	NO	NO	YES [7]	TBD [2]	NO	NO	NO	NO	

NOTES:

[1] Parameter value ranges indicated are selected for use in criticality design calculations to encompass credible optimum conditions without reliance on process variable controls.
[2] To be determined (TBD). Analysis of interaction between components to be evaluated to confirm spacing requirements, or determine if additional criticality control design features or management measures are required to address interaction.
[3] Actual chemical form of Pu Nitrate is $Pu(NO_3)_4$ for most process steps, which is less reactive than $Pu(NO_3)_3$.
[4] Actual chemical form is a mixture of Pu Oxalate and Pu Nitrate. Either chemical form is less reactive than PuO_2F_2.
[5] Interaction limited by geometry (hopper spacing) and cadmium coating of hoppers.
[6] The absence of a more restrictive material is controlled in an upstream unit, which prevents any means of adverse chemical form change.
[7] Concentration controlled by upstream or connected units.
[8] The presence of up to 2% uranium (93.2 w/o ^{235}U) is considered in the evaluation.
[9] Maximum bounding density value is controlled by upstream measurement.
[10] Density value which has been shown to be conservative for identical operations in LaHague. Values will be confirmed during the facility startup test program.

Table 6-2. Preliminary Definition of Reference Fissile Medium and Control Methods for MP Process Units

Criticality Control Unit	Control Method													Comments
	Physicochemical Characteristics (PC)	Mass (M)	Geometry (G)	Density (D)	Isotopics (I)	Reflection (R)	Moderation (MN)	Concentration (C)	Interaction (IN)	Neutron absorber (A)	Volume (V)	Heterogeneity (H)	Process variable	
Receiving Area														
PuO_2 3013 storage pit	NO PuO_2 + H_2O	NO $M \leq 5$ kg per container	YES	NO [1] $d \leq 11.46$	NO [1] $^{240}Pu \geq 4\%$	NO [2]	NO [1] $H_2O \leq 1\%$ inside containers	NO	NO [2]	NO	NO	NO	NO	-Incoming plutonium container I.D. is verified to confirm mass, isotopics, and powder moisture assumptions listed.
PuO_2 Can Opening and Handing Unit	NO PuO_2 + H_2O	YES	NO	YES [1,10] $d \leq 7$	NO [1] $^{240}Pu \geq 4\%$	NO	YES	NO	NO	NO	NO	NO	NO	
PuO_2 buffer storage	NO PuO_2 + H_2O	NO $M \leq 2.5$ kg per container [13]	YES	YES [1,10] $d \leq 3.5$	NO [1] $^{240}Pu \geq 4\%$	NO [2]	NO	NO	NO [2]	YES Borated concrete	NO	NO	NO	
Primary dosing (including master blend homogeniz-ing)	NO PuO_2 $+UO_2$ $+H_2O$,	YES	NO	YES [1,6] PuO_2 and $UO_2 \leq 3.5$; Recy-clable Scrap ≤ 4.6	YES $^{240}Pu \geq 4\%$[1]	NO	YES [4]	NO	NO	NO	NO	YES	M,I, MN [4]	-Mass of PuO_2 per jar is controlled. -The relative quantity of PuO_2 and UO_2 is controlled; used in downstream units. -Homogeneity of master blend is required by downstream units.

Table 6-2. Preliminary Definition of Reference Fissile Medium and Control Methods for MP Process Units (Continued)

Criticality Control Unit	Control Method													Comments
	Physicochemical Characteristics (PC)	Mass (M)	Geometry (G)	Density (D)	Isotopics (I)	Reflection (R)	Moderation (MN)	Concentration (C)	Interaction (IN)	Neutron absorber (A)	Volume (V)	Heterogeneity (H)	Process variable	
Powder Area														
Primary blend ball milling Scrap milling	NO Master blend	YES	NO	YES [1,6] $d \leq 5.5$	YES $^{240}Pu \geq 4\%$[1]; $M_{Pu}/(M_U + M_{Pu}) \leq 22\%$ [5]	NO	YES	NO	NO	NO	NO	NO	M	-U metal balls are present in the ball-mill and are accounted for as reflector in the criticality calculations
	NO Dis-carded Scrap Pow-der	YES	NO	YES [1,6] $d \leq 5.5$	YES $^{240}Pu \geq 4\%$[1]; $M_{Pu}/(M_U + M_{Pu}) \leq 22\%$ [5]	NO	YES	NO	NO	NO	NO	YES	M,H	Homogeneity of discarded scrap powder is required by downstream unit.
Final dosing	NO Master blend	YES	NO	YES [1,6] $d \leq 5.5$	YES $^{240}Pu \geq 4\%$[1]; $M_{Pu}/(M_U + M_{Pu}) \leq 22\%$ [5] $M_{Pu}/(M_U + M_{Pu}) \leq 6.3\%$ in jar	NO	YES	NO	NO	NO	NO	NO	M,I	The relative quantity of master blend and UO_2 is controlled; used in downstream units.

Table 6-2. Preliminary Definition of Reference Fissile Medium and Control Methods for MP Process Units (Continued)

Criticality Control Unit	Control Method													Comments
	Physicochemical Characteristics (PC)	Mass (M)	Geometry (G)	Density (D)	Isotopics (I)	Reflection (R)	Moderation (MN)	Concentration (C)	Interaction (IN)	Neutron absorber (A)	Volume (V)	Heterogeneity (H)	Process variable	
Powder Area (Continued)														
Homogenizing and pelletizing	NO Master blend	YES	NO	YES [1,6] $d \leq 5.5$	YES $^{240}Pu \geq 4\%$[1]; $\%Pu \leq 22\%$ [5,7]	NO	YES	NO	NO	NO	NO	NO	M	-Homogeneity of final blend is required in downstream equipment and to allow introduction of additives in this unit.. -Physicochemical characteristics control applied to control pellet dimensions to extent used in downstream units.
	NO Final blend	YES	NO	NO [1,6] $d \leq 3.5$	YES $^{240}Pu \geq 4\%$[1]; $\%Pu \leq 6.3\%$ [5]	NO	YES [4]	NO	NO	NO	NO	YES	M,MN [4], H	
	NO Pellets	YES	NO	NO [1] $d \leq 11$	YES $^{240}Pu \geq 4\%$[1]; $\%Pu \leq 6.3\%$ [5]	NO	YES	NO	NO	NO	NO	NO [8]	M	

Table 6-2. Preliminary Definition of Reference Fissile Medium and Control Methods for MP Process Units (Continued)

Criticality Control Unit	Control Method													Comments
	Physicochemical Characteristics (PC)	Mass (M)	Geometry (G)	Density (D)	Isotopics (I)	Reflection (R)	Moderation (MN)	Concentration (C)	Interaction (IN)	Neutron absorber (A)	Volume (V)	Heterogeneity (H)	Process variable	
Powder Area (Continued)														
Jar storage and handling unit	NO Arrays of J60 and J80 Jars	YES [13] J60 master blend ≤ 60 kg; J60 PuO_2 ≤ 13.2 kg, J80 total ≤ 80 kg, J80 PuO_2 ≤ 5 kg	YES	YES [1] PuO_2 ≤ 3.5 [6]; UO_2 ≤ 3.5 [6]; Master blend ≤ 5.5 [6]; Scraps ≤ 11;	YES ^{240}Pu ≥ 4%[1]; J60 %Pu ≤ 22% [5]; J80 Master blend %Pu ≤ 22% [5]; J80 Scraps %Pu ≤ 6.3% [5]	NO [2]	YES [14] %H2O <= 5% in the jars	NO	NO [2]	NO	NO	NO	NO	

Table 6-2. Preliminary Definition of Reference Fissile Medium and Control Methods for MP Process Units (Continued)

Criticality Control Unit	Control Method													Comments
	Physicochemical Characteristics (PC)	Mass (M)	Geometry (G)	Density (D)	Isotopics (I)	Reflection (R)	Moderation (MN)	Concentration (C)	Interaction (IN)	Neutron absorber (A)	Volume (V)	Heterogeneity (H)	Process variable	
Powder Area (Continued)														
Scrap Processing Unit	NO Scrap pellets	YES	NO	NO $d \leq 11$	YES $^{240}Pu \geq 4\%$[1]; $\%Pu \leq 6.3\%$ [5]	NO [2]	YES [14]	NO	NO [2]	NO	NO	YES [5,7]	NO	
	NO Scrap powder	YES	NO	YES [6] $d \leq 5.5$	YES $^{240}Pu \geq 4\%$[1]; $\%Pu \leq 22\%$ [5]	NO [2]	YES [14]	NO	NO [2]	NO	NO	YES [5,7]	NO	
Powder Auxiliary Unit	NO MOX Powder	YES	NO	YES [6] $d \leq 5.5$	YES $^{240}Pu \geq 4\%$[1]; $\%Pu \leq 22\%$ [5]	NO [2]	YES [14]	NO	NO [2]	NO	NO	YES [5,7]	NO	
	NO MOX Pellets	YES	NO	NO $d \leq 11$	YES $^{240}Pu \geq 4\%$[1]; $\%Pu \leq 6.3\%$ [5]	NO [2]	YES [14]	NO	NO [2]	NO	NO	YES [5,7]	NO	

Table 6-2. Preliminary Definition of Reference Fissile Medium and Control Methods for MP Process Units (Continued)

Criticality Control Unit	Control Method													Comments
	Physicochemical Characteristics (PC)	Mass (M)	Geometry (G)	Density (D)	Isotopics (I)	Reflection (R)	Moderation (MN)	Concentration (C)	Interaction (IN)	Neutron absorber (A)	Volume (V)	Heterogeneity (H)	Process variable	
Pellet Process Area														
Pellet storage	YES Array of pellets [9]	NO	YES	NO $d \leq 11$	YES $^{240}Pu \geq 4\%$[1]; $\%Pu \leq 6.3\%$ [5]	NO [2]	NO	NO	NO [2]	YES	NO	YES [8]	NO	-Isolation shields provided for interaction control between boats.
Sintering furnace	YES Array of pellets [9]	NO	YES	NO $d \leq 11$	YES $^{240}Pu \geq 4\%$[1]; $\%Pu \leq 6.3\%$ [5]	NO [2]	NO	NO	NO [2]	NO	NO	YES [8]	NO	
Grinding	YES pellets [9]	YES	NO	NO $d \leq 11$	YES $^{240}Pu \geq 4\%$[1]; $\%Pu \leq 6.3\%$ [5]	NO	YES	NO	NO	NO	NO	YES [8]	M	

Table 6-2. Preliminary Definition of Reference Fissile Medium and Control Methods for MP Process Units (Continued)

Criticality Control Unit	Control Method													Comments
	Physicochemical Characteristics (PC)	Mass (M)	Geometry (G)	Density (D)	Isotopics (I)	Reflection (R)	Moderation (MN)	Concentration (C)	Interaction (IN)	Neutron absorber (A)	Volume (V)	Heterogeneity (H)	Process variable	
Pellet Process Area (Continued)														
Pellet inspection and sorting, Quality Control and Manual Sorting	YES pellets [9]	YES	NO [15]	NO $d \leq 11$	YES $^{240}Pu \geq 4\%$[1]; $\%Pu \leq 6.3\%$ [5]	NO	YES	NO	NO	NO	NO	YES [8]	NO	-Physicochemical characteristics control applied to verify pellet dimensions.
Pellet tray-baskets storage	YES Array of pellets [9]	NO	YES	NO $d \leq 11$	YES $^{240}Pu \geq 4\%$[1]; $\%Pu \leq 6.3\%$ [5]	NO [2]	NO	NO	NO [2]	YES	NO	YES [8]	NO	-Interaction between storage units controlled by isolation shields.
Scrap pellet storage	YES Final blend pellet scraps [9]	NO	YES	NO $d \leq 11$	YES $^{240}Pu \geq 4\%$[1]; $\%Pu \leq 6.3\%$ [5]	NO [2]	NO	NO	NO [2]	YES	NO	YES [8]	NO	-Interaction between storage units controlled by isolation shields.
Scrap box loading, Pellet Repackaging, Pellet Handling	YES Array of pellets [9]	YES	NO	NO $d \leq 11$	YES $^{240}Pu \geq 4\%$[1]; $\%Pu \leq 6.3\%$ [5]	NO [2]	NO	NO	NO [2]	NO	NO	YES [8]	NO	

Table 6-2. Preliminary Definition of Reference Fissile Medium and Control Methods for MP Process Units (Continued)

Criticality Control Unit	Control Method													Comments
	Physicochemical Characteristics (PC)	Mass (M)	Geometry (G)	Density (D)	Isotopics (I)	Reflection (R)	Moderation (MN)	Concentration (C)	Interaction (IN)	Neutron absorber (A)	Volume (V)	Heterogeneity (H)	Process variable	
Fuel Rod Process Area														
Rod cladding and decontamination	YES pellets/rods [11]	YES	NO [15]	NO $d \leq 11$	YES $^{240}Pu \geq$ 4%[1]; $\%Pu \leq 6.3\%$ [5]	NO [2]	YES	NO	NO	NO	NO	YES [8]	NO	
Rod controls (decontamination, helium leak testing, x-ray inspection, rod scanning, rod inspection, and sorting units, decladding, dry cleaning) Rod Tray Loading	YES rods [11]	YES	NO [15]	NO $d \leq 11$	YES $^{240}Pu \geq$ 4%[1]; $\%Pu \leq 6.3\%$ [5]	NO [2]	YES	NO	NO	NO	NO	YES [8]	NO	
Rod storage	YES Array of rods [11]	NO	YES	NO $d \leq 11$	YES $^{240}Pu \geq$ 4%[1]; $\%Pu \leq 6.3\%$ [5]	NO	NO	NO	NO [2]	YES	NO	YES [8]	NO	-Interaction between storage units controlled by isolation shields.

Table 6-2. Preliminary Definition of Reference Fissile Medium and Control Methods for MP Process Units (Continued)

Criticality Control Unit	Control Method													Comments
	Physicochemical Characteristics (PC)	Mass (M)	Geometry (G)	Density (D)	Isotopics (I)	Reflection (R)	Moderation (MN)	Concentration (C)	Interaction (IN)	Neutron absorber (A)	Volume (V)	Heterogeneity (H)	Process variable	
Assembly Area														
Assembly mock-up loading	YES Array of rods [11]	YES	NO [15]	NO $d \leq 11$	YES $^{240}Pu \geq$ 4%[1]; %Pu $\leq$ 6.3% [5]	NO [2]	YES	NO	NO	NO	NO	YES [8]	NO	
Assembly mounting	YES Array of rods [11]	NO	YES	NO $d \leq 11$	YES $^{240}Pu \geq$ 4%[1]; %Pu $\leq$ 6.3% [5]	NO [2]	YES	NO	NO	NO	NO	YES [8]	PC	-Completeness of assembly controlled for use in downstream process unit

Table 6-2. Preliminary Definition of Reference Fissile Medium and Control Methods for MP Process Units (Continued)

Criticality Control Unit	Control Method													Comments
	Physicochemical Characteristics (PC)	Mass (M)	Geometry (G)	Density (D)	Isotopics (I)	Reflection (R)	Moderation (MN)	Concentration (C)	Interaction (IN)	Neutron absorber (A)	Volume (V)	Heterogeneity (H)	Process variable	
Assembly Area (Continued)														
Assembly handling and inspection Assembly dry cleaning	YES Assembly [12]	NO	YES	NO $d \leq 11$	YES $^{240}Pu \geq 4\%$[1]; $\%Pu \leq 6.3\%$ [5]	NO [2]	YES	NO	YES	NO	NO	YES [8]	NO	-Each inspection station handles only one fuel assembly at a time, and there is no interaction between stations. -All rod positions in an assembly being repaired may not be occupied; requires moderation control.
Assembly storage	YES Array of assemblies [12]	NO	YES	NO $d \leq 11$	YES $^{240}Pu \geq 4\%$[1]; $\%Pu \leq 6.3\%$ [5]	NO [2]	YES	NO	NO [2]	NO	NO	YES [8]	NO	
Assembly packaging	YES Array of assemblies [12]	NO	YES	NO $d \leq 11$	YES $^{240}Pu \geq 4\%$[1]; $\%Pu \leq 6.3\%$ [5]	NO [2]	YES	NO	NO [2]	NO	NO	YES [8]	NO	

Table 6-2. Preliminary Definition of Reference Fissile Medium and Control Methods for MP Process Units (Continued)

NOTES:

[1] Parameter value ranges indicated are selected for use in criticality design calculations to encompass credible optimum conditions without reliance on process variable controls.

[2] Reflection and interaction addressed by geometry control.

[3] {not used}

[4] Moderation control related to introduction of moderator (organic additives) into equipment for process reasons (see Section 6.3.2.6) (process variable control).

[5] Relative quantity of U and Pu ($M_{Pu}/(M_U + M_{Pu})$) process variable control implemented by upstream process units.

[6] Density value which has been shown to be conservative for identical operations in MELOX. Values will be confirmed during the facility startup test program.

[7] Scrap isotopic composition (%Pu) and homogeneity controlled by upstream units (i.e., scraps are recycled MP process product).

[8] Isotopics (including U-Pu homogeneity) and diameter of pellets controlled by Homogenization and Pelletizing Unit.

[9] Diameter of pellets controlled by upstream process units.

[10] Maximum bounding density value is controlled by upstream measurement.

[11] Pellet diameter controlled by upstream process units; clad characteristics guaranteed by supplier.

[12] Assembly characteristics, including dimensions of pellets, controlled by upstream process units or guaranteed by supplier, as applicable.

[13] Mass process variable control implemented by upstream process units.

[14] Moderation (additive addition) process variable control implemented by upstream process units.

[15] In normal conditions, geometry provides additional protection.

Table 6-3. Admissible Values for Optimum Moderated Conditions

These order of magnitudes are typical values and are mainly representative of the AP process.*

	Reflector (water)	Reference Fissile Medium: Most severe PuO_2 ($d \leq 7$)	PuO_2 ($d \leq 3.5$)	PuO_2F_2	Least severe $Pu(NO_3)_3$
Sphere volume	20 cm	1.5 liters	2.9 liters	6.2 liters	7.0 liters
	2.5 cm	2.7 liters	4.7 liters	9.7 liters	10 liters
Cylinder diameter	20 cm	8.5 cm	10 cm	14 cm	15 cm
	2.5 cm	11 cm	14 cm	18 cm	18 cm
Slab thickness	20 cm	2.6 cm	3.2 cm	4.8 cm	5.6 cm
	2.5 cm	5.1 cm	6.7 cm	9.2 cm	9.6 cm
Sphere mass	20 cm	0.39 kg	0.39 kg	0.39 kg	0.40 kg
	2.5 cm	0.53 kg	0.53 kg	0.53 kg	0.54 kg

Values corresponding to $k_{eff} = 0.93$.

* These are typical order-of-magnitude values and are not used in support of criticality calculations or NCSEs; values used to demonstrate criticality safety will be determined based on analyses discussed in 6.3.5

Table 6-4. Permissible Masses of Oxide for Different Homogeneous Moderation Ratios

These order of magnitudes are typical values and are mainly representative of the MP process.*

	Reference Fissile Medium			
	PuO_2 100% Pu d ≤ 3.5	Master Blend 22% Pu d ≤ 5.5	Final Blend 6.3% Pu d ≤ 3.5	Pellets 6.3% Pu d ≤ 11
Dry powder	5.6E+01 kg	5.0E+02 kg	7.6E+04 kg	8.8E+03 kg
3 wt % water equivalent	4.2E+01 kg	2.5E+02 kg	5.6E+03 kg	1.1E+03 kg
5 wt % water equivalent	3.4E+01 kg	1.6E+02 kg	2.1E+03 kg	6.1E+02 kg

Values corresponding to $k_{eff} = 0.93$.

* These are typical order-of-magnitude values and are not used in support of criticality calculations or NCSEs; values used to demonstrate criticality safety will be determined based on analyses discussed in 6.3.5

Figures

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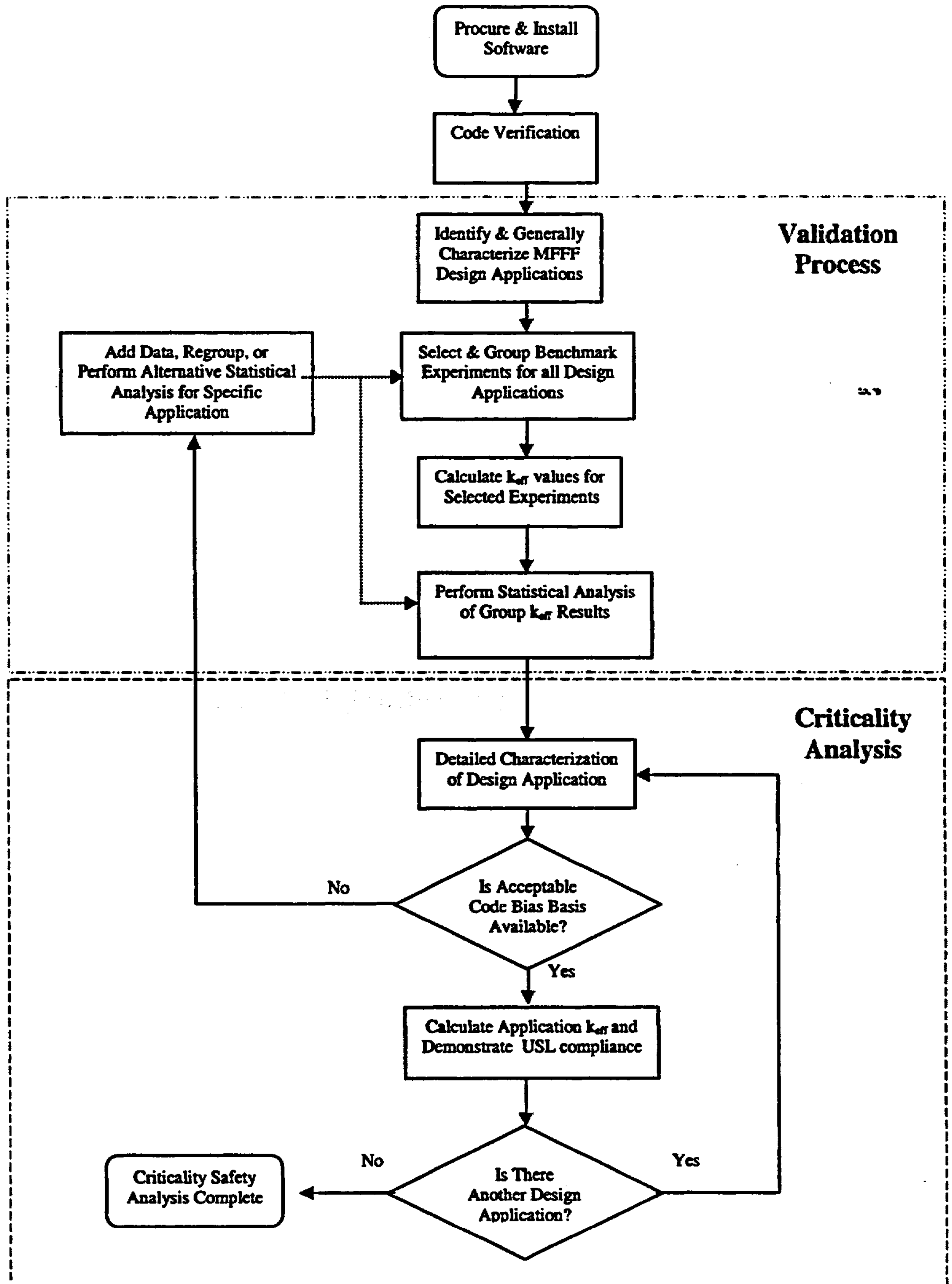

Figure 6-1. Overview of the Method Validation and Criticality Analysis Process

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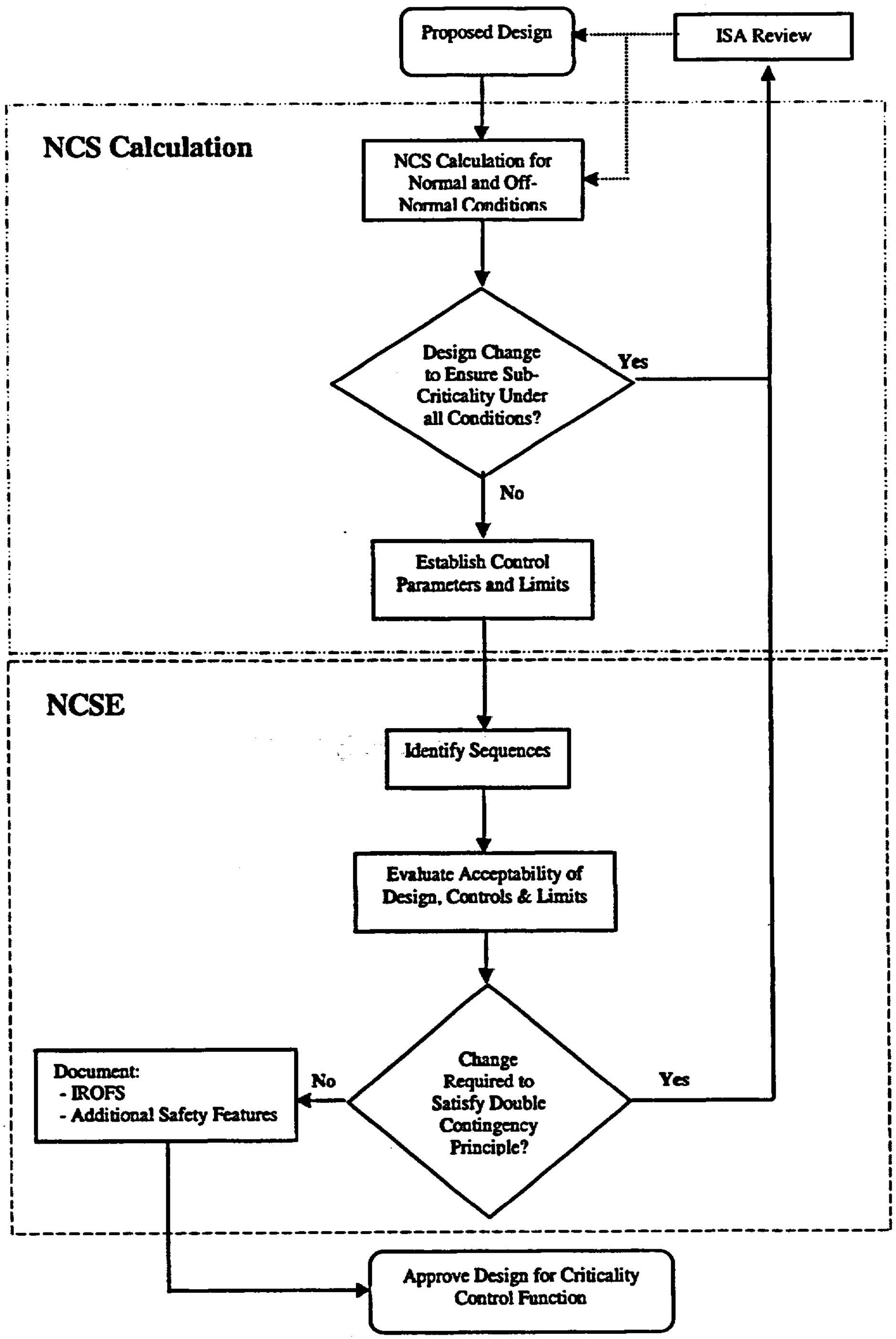

Figure 6-2. Overview of the NCSE Process

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