DEFENSE NUCLEAR FACILITIES SAFETY BOARD

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March 5, 2001

The Honorable Spencer Abraham
Secretary of Energy
1000 Independence Avenue, SW
Washington, DC 20585-1000

Dear Secretary Abraham:

During the past year, the staff of the Defense Nuclear Facilities Safety Board (Board) performed reviews of criticality safety programs at four Department of Energy (DOE) sites: Savannah River Site, Oak Ridge Y-12 Plant, Rocky Flats Environmental Technology Site, and the Hanford Reservation. The Board's staff reviews followed, and were complementary to a similar series of reviews sponsored by the DOE Deputy Assistant Secretary for Oversight (EH-2). Observations from the Board's staff reviews are documented in the enclosed technical report.

Several good practices were noted throughout the complex, including the unique marking of procedural steps related to criticality. Additionally, initiatives to establish liaison positions between criticality safety and operations were identified. These will serve to improve the development and implementation of criticality controls. The Board acknowledges these efforts and encourages their continuation.

Several areas for improvement were also noted. The most significant of which include: augmenting the rigor and formality of DOE field office criticality oversight, maintaining the integrity and reliability of design features credited for protection against inadvertent criticality, increasing the presence of criticality engineers on the process floor, achieving consistent infraction reporting, addressing the current overreliance on procedural controls, and clarifying the proper relationship between criticality controls and Safety Analysis Report and the Technical Safety Requirements. Many of these improvement areas were similarly identified by the DOE EH-2 review team. Suggested approaches for addressing these areas are provided in the enclosed technical report for your consideration.

The Board believes both sustaining the recent initiatives for improving criticality safety, and addressing the areas for improvement identified in the enclosed technical report are of primary importance to ensuring adequate protection from inadvertent nuclear criticality in the defense nuclear complex. Therefore, pursuant to 42 U.S.C. § 2286b(d), the Board requests DOE to provide a report within 60 days of receipt of this letter detailing the DOE-Headquarters' path forward for addressing the observations outlined in the enclosed technical report.

Sincerely,

John T. Conway
Chairman

Enclosure

c: Mr. Mark B. Whitaker, Jr.

DNFSB/TECH-29

CRITICALITY SAFETY AT DEPARTMENT OF ENERGY DEFENSE NUCLEAR FACILITIES

Defense Nuclear Facilities Safety Board

Technical Report

February 2001

CRITICALITY SAFETY AT DEPARTMENT OF ENERGY DEFENSE NUCLEAR FACILITIES

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EXECUTIVE SUMMARY

The goal of any nuclear criticality safety program is to prevent inadvertent nuclear criticality. To this end, there are several fundamental areas such a program must address: the analysis of criticality hazards and the development of adequate controls for those hazards, implementation of the criticality controls in facility processes, and feedback and improvement including the maintenance of controls to ensure their integrity and reliability over time.

The American National Standards Institute/American Nuclear Society 8.x series of national consensus standards and relevant Department of Energy (DOE) directives outline in detail the expectations and suggested methods for developing and implementing criticality controls. The guidance provided with respect to maintaining the controls, however, is incomplete. This incomplete guidance has resulted in some divergence of opinion within the DOE complex as to what level of approval and stewardship is appropriate for criticality controls and how they should relate to a facility's Safety Analysis Report (SAR) and Technical Safety Requirements (TSRs). This issue is treated at length in this report, and a suggested approach is outlined.

To better understand the processes being used in the field to develop, implement, and maintain criticality controls, the staff of the Defense Nuclear Facilities Safety Board recently conducted a series of reviews throughout the DOE complex. Also in recent months, DOE performed a series of criticality safety reviews under the sponsorship of the Deputy Assistant Secretary for Oversight. The high-level DOE reviews were aimed at identifying potential vulnerabilities within the DOE complex similar to those that led to the criticality in Tokaimura, Japan, in September 1999. Neither of these reviews revealed imminent criticality safety hazards in the complex. Both, however, identified several areas for improvement.

One of the most important areas needing improvement is oversight of contractors' criticality safety programs by DOE field offices. More formalized and robust reviews by DOE are necessary to ensure that the contractor criticality safety programs are meeting the requirements of the national consensus standards and applicable DOE directives. A second important area for improvement is the maintenance of the integrity and reliability of design features credited for protection against inadvertent criticality. A formalized surveillance, maintenance and configuration management process for these design features should be implemented; however, extant guidance in this regard is incomplete. A third area for improvement is the need for greater presence of criticality safety engineers on the process floor. Criticality safety engineers must continue to increase the time they spend on the process floor with operational personnel to gain greater familiarity with the processes, and to obtain operator input that is essential to the development of successful strategies for preventing inadvertent criticality. Fourth, some degree of consistency in the criteria for infraction reporting between sites is warranted. Fifth, the present overreliance on procedural administrative controls should be reevaluated, and opportunities for replacing these controls with design features should be explored. Finally, DOE's expectations with regard to the proper relationship between criticality controls and the SAR and TSR should be clarified.

By addressing these areas for improvement, as well as others discussed further in the body of this report, DOE will strengthen criticality safety programs complex-wide and increase the overall safety of operations with fissile material.

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1. INTRODUCTION

During the past several years, the Defense Nuclear Facilities Safety Board (Board) and its staff have monitored the Department of Energy's (DOE) criticality safety programs with growing interest and concern. A number of significant events at defense nuclear facilities during this period have prompted actions by the Board. Examples include the following:

- The declining capacity for criticality research, which led the Board to issue its Recommendation 93-2 (Defense Nuclear Facilities Safety Board, 1993).
- Nuclear criticality safety problems at the Oak Ridge Y-12 Plant in September 1994, which led to the Board's Recommendation 94-4 (Defense Nuclear Facilities Safety Board, 1994).
- Safety violations at Hanford's Plutonium Finishing Plant in 1996 involving nuclear criticality and conduct of operations, which resulted in several reviews and letters from the Board and a moratorium on operations at the facility for more than a year.
- The need, again, to strengthen experimental research in criticality safety and to bolster the technical capability of contractor and DOE personnel in the field of criticality safety, which prompted the Board to issue its Recommendation 97-2 (Defense Nuclear Facilities Safety Board, 1997).

DOE has taken action to address many of the Board's concerns in response to Recommendation 97-2 (Defense Nuclear Facilities Safety Board, 1997). However, the Board and its staff believe DOE must strengthen its actions aimed at furthering the technical capability of its line management employees relative to criticality safety, and ensuring that an experimental capability remains viable within the complex.

The recent criticality accident in Tokaimura, Japan, in September 1999, prompted DOE to reassess its own criticality safety programs to confirm that they contained no significant weaknesses that could lead to a similar accident. To this end, a team sponsored by the DOE Deputy Assistant Secretary for Oversight (EH-2) and led by Dr. Jerry McKamy completed reviews at five sites in late 1999 and early 2000. Although the team found no imminent criticality safety hazards in the complex, it did make several recommendations for improvement.

Also in recent months, the Board's staff has conducted a series of reviews, the results of which are documented in this report. These reviews were prompted by several observations made by the staff, including the following:

- A growing rate of criticality safety infractions at several sites throughout the DOE complex;

- Apparent structural differences among the nuclear criticality safety programs at various sites; and

- Divergent positions developing within the complex with regard to the proper relationship between criticality controls and authorization bases.

Having made these observations, the Board's staff sought to understand more completely the detailed structure of criticality safety programs at sites throughout the complex, as well as the genesis of the controversy over the correct relationship between criticality controls and authorization bases. To this end, the staff visited four sites during the period February–July 2000. The staff also conducted "vertical slice" reviews to trace criticality safety requirements from identification and analysis of hazards, through development of controls, through implementation of those controls in criticality postings and operating procedures, and finally to maintenance of the established controls over time.

The Board's staff found, as did the EH-2 review team, that there are no imminent criticality safety hazards at the sites reviewed. However, excessive reliance on administrative controls at some facilities for the handling of large volumes of enriched uranium solutions may, in time, lead to such a situation. Several aspects of the criticality safety programs at DOE sites could be improved, most notably with regard to (1) augmenting oversight by DOE field offices of contractors' criticality safety programs, (2) maintaining criticality controls over time such that they can continue to be relied upon to perform their intended functions, (3) increasing the presence of criticality safety engineers on the process floor, (4) improving consistency between different sites' infraction reporting criteria, (5) reducing the over-reliance on administrative controls versus engineered or design controls, and (6) clarifying DOE's expectations with respect to the relationship between criticality controls and SAR and TSRs.

This report is organized as follows: Section 2 reviews existing requirements and guidance for nuclear criticality safety programs, while Section 3 summarizes recent reviews and pertinent information with regard to criticality safety at defense nuclear sites. Section 4 addresses the issue of the relationship between criticality controls and authorization bases. Section 5 outlines areas for improvement in nuclear criticality safety programs across the DOE complex. Finally, Section 6 presents conclusions. Appendices A, B, and C include citations from DOE Orders and national standards that address development, implementation, and maintenance of controls, respectively.

We have observed that introducing and maintaining an adequate program in criticality safety offers an excellent example of application of Integrated Safety Management (ISM). That process begins with analyzing the hazard and proceeds through the classic ISM steps to a stage of feedback and improvement, thus completing the circle. The Report is therefore organized internally along these lines of ISM.

2. REQUIREMENTS AND GUIDANCE FOR NUCLEAR CRITICALITY SAFETY PROGRAMS

This chapter summarizes the requirements and guidance promulgated by national consensus standards and DOE policies and orders pertaining to nuclear criticality safety. In many cases, “shall” and “must” statements are repeated here to emphasize the required structure of an acceptable nuclear criticality safety program. The requirements discussed in the following are listed with cross references to their sources in the Appendices.

The goal of a nuclear criticality safety program is to prevent inadvertent nuclear criticality during operations with fissile material. To achieve this goal, a nuclear criticality safety program must perform several functions consistent with the framework of Integrated Safety Management (Define the Work, Identify and Analyze the Hazards, Develop and Implement Controls, Perform the Work, Provide Feedback and Improvement). Within this framework, three of the functions are most essential to a successful criticality safety program, but, due to the desired and commonly used format of NCSEs, the functions are grouped in a slightly different manner:

- *Analyze the hazards and develop controls*—Analyze operations with fissile material, and develop an adequate set of controls for preventing inadvertent criticality.

- *Implement controls*—Implement the identified controls in operations.

- *Feedback and improvement including maintaining controls*—Ensure that the adequacy and applicability of identified controls are maintained over time.

As stated in the Introduction to this Report, the following discussion is developed along these lines of ISM. The requirements and recommendations of DOE Order 420.1, *Facility Safety* (U.S. Department of Energy, 1995), its implementation guides, and the American National Standards Institute/American Nuclear Society (ANSI/ANS) 8.x series of national consensus standards provide the foundation for any acceptable nuclear criticality safety program. They support the development and implementation of controls by providing guidance on the structure of such a program, establishing criteria for the adequacy of controls, and outlining requirements for written procedures. However, they contain incomplete guidance on how the integrity and reliability of controls should be maintained over time. The resulting ambiguity has led to some divergence of opinion throughout the complex on how best to maintain criticality controls.

DOE Order 420.1 (U.S. Department of Energy, 1995) requires contractors that store, handle, or process fissile material to establish a nuclear criticality safety program and document all limits and controls relied upon for criticality safety in nuclear criticality safety evaluations (NCSEs). Controls can be either administrative, such as postings and procedures, or design features, such as drains, specially designed containers, raschig rings, interlocks, and alarms. The necessary elements of an acceptable criticality safety program and the associated requirements are specified primarily by reference to the

ANSI/ANS 8.x series, except where DOE Order 420.1 (U.S. Department of Energy, 1995) makes some additional recommendations. An acceptable format for NCSEs is outlined in DOE-STD-3007-93, *Guidelines for Preparing Criticality Safety Evaluations at Department of Energy Non-Reactor Nuclear Facilities* (U.S. Department of Energy, 1993).

DOE Order 420.1 (U.S. Department of Energy, 1995) vests field elements of DOE with responsibility for ensuring that contractors' nuclear criticality safety programs meet the above requirements. The Order and its implementation guides, however, are not particularly clear on what level of involvement by DOE is appropriate to discharge this responsibility—whether high-level reviews of the structure and function of a contractor's program are sufficient, or detailed review and approval of all NCSEs and the controls therein are necessary. To date, most of DOE's field elements in the complex have interpreted their responsibility as being more in line with the former.

Thus the most common paradigm for instituting criticality safety in the DOE complex is to require the contractor to establish and maintain a criticality safety program by specifying such a program in the Administrative Controls section of the Technical Safety Requirements. DOE then provides high-level oversight to ensure that the contractor's criticality safety program meets the requirements of the standards in the ANSI/ANS 8.x series, as invoked and modified by Order 420.1 (U.S. Department of Energy, 1995) and the contract between DOE and the contractor.

More detailed discussion of the requirements and guidance relating to each of the fundamental functions of a nuclear criticality safety program—analyze the hazards and develop controls, implement controls, and feedback and improvement including maintenance of controls—is provided in the following sections.

2.1 ANALYZE THE HAZARDS AND DEVELOP CONTROLS

The national consensus standards in the ANSI/ANS 8.x series support the analysis of hazards and development of controls in detail. They provide an outline for the structure, roles, and responsibilities for an effective nuclear criticality safety program. Additionally, they establish accepted practices for performing analyses and define the criteria for adequacy of controls. As noted, DOE Order 420.1 (U.S. Department of Energy, 1995) invokes the ANSI/ANS 8.x series of standards by reference with a few modifications. To facilitate quality and consistency, DOE-STD-3007-93 (U.S. Department of Energy, 1993) provides guidance on the proper format for documentation of criticality safety analyses. Guidance on training and qualification of contractors' criticality safety engineers is documented in DOE-STD-1135-99, *Guidance for Nuclear Criticality Engineer Training and Qualification* (U.S. Department of Energy, 1999).

In addition, DOE's Office of Environment, Safety and Health Workshop Handbook, *Your Mission... and Nuclear Criticality Safety* (U.S. Department of Energy, 1999), outlines the oversight responsibilities of DOE's line management with respect to criticality safety, as derived from DOE-P-450.5, *Line Environment, Safety and Health Oversight* (U.S. Department of Energy, 1997). The handbook also provides a detailed model for self-assessments by the contractor's management. Robust oversight by the management of both DOE and contractors is imperative for ensuring that criticality safety programs are capable of developing acceptable sets of controls that will preclude inadvertent criticality. Explicit citations from these supporting standards are provided in Appendix A and summarized below.

2.1.1 Program Structure, Roles, and Responsibilities

If a site's nuclear criticality safety program is to be successful, the activities of the various groups involved—the criticality safety group in DOE's field office, the contractor's management, the line operations component of the contractor, and the contractor's nuclear criticality safety group—must be well coordinated.

The criticality safety group in DOE's field office works with the contractor's management to establish expectations and performance measures for the contractor's programs. Additionally, this group is responsible for performing oversight, in the form of periodic reviews, to ensure that the contractor's criticality safety program is meeting the established expectations. The schedule and content of DOE's oversight reviews should be formalized and robust.

The contractor's management is responsible for promulgating nuclear criticality safety policy to all employees involved in operations with fissile material, and establishing the criteria to be satisfied by the nuclear criticality controls. The contractor's management is also responsible for establishing and staffing a nuclear criticality safety group to support operations with fissile material.

The contractor's line operations component is responsible for performing work in accordance with applicable criticality limits and controls provided by the contractor's nuclear criticality safety group, and for developing written procedures and postings that implement process criticality controls. This component also assists the contractor's nuclear criticality safety group in the development of controls by providing operational information on manufacturing processes.

The contractor's nuclear criticality safety group is responsible for providing technical support to operations personnel on criticality matters related to the design and operation of equipment and processes, and for developing criticality controls. This group should be staffed with nuclear criticality safety engineers familiar with the physics of nuclear criticality and associated safety practices. Further, the contractor's nuclear criticality safety group should be familiar with operations and should, to the extent practicable, be administratively independent of the line operations organization. It is the responsibility of the nuclear criticality safety engineers who form this group to maintain familiarity with all operations that require nuclear criticality safety controls and to ensure that written procedures and postings properly implement the applicable controls. They must also maintain familiarity with current developments in standards, guides, and codes for nuclear criticality, and are encouraged to solicit the assistance of knowledgeable outside experts when necessary.

2.1.2 Process Analyses

Before any new operation with fissile materials is initiated, the determination should be made that the process will remain subcritical under both normal and credible abnormal conditions. Credible abnormal conditions that could result in the maximum multiplication factor should be determined.

The analyses performed to establish the subcriticality of operations with fissile material are to be documented in an NCSE. The NCSE should follow the format outlined in DOE-STD-3007-93 (U.S. Department of Energy, 1993), explicitly identifying all controlled parameters and associated limits that serve as the basis for the conclusion that operations will remain subcritical. The NCSE should be documented clearly and with appropriate detail to allow independent review and evaluation of the results.

Where applicable data are available, subcritical limits should be established on bases derived from experiments, with adequate allowance for uncertainties in the data. In the absence of directly applicable experimental measurements, the limits may be derived from validated calculations. The validity of any calculational method employed in the analyses should have been established by comparison with experimental data, and the range of its applicability shown to be appropriate for the process being analyzed. A bound on the bias of a method used should be determined and accounted for through an adequate margin of subcriticality. If the calculational method involves a computer program, a written validation report should be prepared.

The NCSE analysis for an operation must be independently assessed for adequacy before the operation commences.

The ANSI/ANS 8.x series standards and the DOE Orders are not clear about the relationship between the NCSE and the facility SAR and TSRs. This issue is discussed further in Chapter 4 of this report.

2.1.3 Adequacy Criteria for Controls

A criterion for the adequacy of a safety margin is established by answering, either directly or indirectly, the question, "How good is good enough?" The national consensus standards in the ANSI/ANS 8.x series set forth two requirements that must be met to consider controls adequate:

- The process must remain subcritical for all normal and credible abnormal conditions.

- Process designs should exhibit defense in depth by meeting the double contingency principle, which requires that sufficient factors of safety be incorporated such that at least two independent, unlikely, and concurrent events are necessary before a criticality is possible:

- Independent—The two events must be independent and not subject to common mode failure; that is, the occurrence of one should not result in the occurrence of the other. This objective is best achieved by controlling two different parameters. Reading of the results of an assay of a solution by two operators would not be considered independent because the common mode of failure would be an error in the results of the assay.

– Unlikely—The two events should be unlikely to occur during the life of the operation. Errors by operators are expected to happen. Too much reliance on administrative controls leaves the operations vulnerable to incidents.

– Concurrent—The two events must occur simultaneously before a criticality accident is possible.

The importance of ensuring appropriate defense in depth for criticality safety controls cannot be overstated. It is therefore imperative that the additional step be taken, once the controls have been identified, of assessing their independence and their likelihood of failure. This does not need to be a detailed common-mode failure or probabilistic analysis, but a qualitative analysis performed to identify the two controls that satisfy the double contingency principle.

Additionally, the national consensus standards encourage the use of design features over administrative controls wherever practical. This preference is echoed in the guidance of DOE Order 420.1 (U.S. Department of Energy, 1995).

Order 420.1 (U.S. Department of Energy, 1995) is more prescriptive than the national standards in its treatment of the double contingency principle by specifying what shall constitute "sufficient factors of safety." The Order states that double contingency protection shall be provided by either control of two independent process parameters or multiple controls on a single process parameter. A preference for multiparameter controls is made clear. However, with single-parameter controls being deemed acceptable, it has become commonplace for control sets to meet only these minimum expectations. Further, the final report of the recently completed DOE EH-2 complex-wide review of criticality safety recommends that DOE Orders and guidance be brought into closer alignment with the national consensus standards to rectify the situation.

2.2 IMPLEMENTATION OF CONTROLS

The national consensus standards in the ANSI/ANS 8.x series also support the implementation of controls. The responsibilities for implementing nuclear criticality safety controls are outlined, expectations of operating procedures are presented, and operator training and emergency preparedness are discussed. DOE Order 420.1 (U.S. Department of Energy, 1995) invokes these standards by reference, with no significant modifications pertaining to implementation of controls. Explicit citations from the supporting standards are provided in Appendix B and summarized below.

A nuclear criticality safety program is required to implement the limits identified by the NCSEs. To this end, management should assign responsibility for criticality safety and delegate commensurate authority to execute measures necessary for criticality control. Further, it is the responsibility of management to instill in all individuals a realization that nuclear criticality safety in their work areas is ultimately their responsibility by adhering to the appropriate procedures.

Line supervisors must be knowledgeable in those aspects of nuclear criticality safety under their control, and must ensure that the personnel they supervise understand procedures and nuclear criticality safety considerations. To achieve these ends, supervisors should attend, and make available to operators, training related to nuclear criticality safety. Records of training activities should be maintained. The nuclear criticality safety group should support this training. ANSI/ANS-8.20-1991, *Nuclear Criticality Safety Training* (American National Standards Institute/American Nuclear Society, 1991), provides detailed guidance on the proper training of operators.

Operations to which nuclear criticality safety is pertinent must be performed using approved written procedures. Line supervisors should develop or participate in the development of written procedures applicable to operations under their control. The purpose of the written operating procedures is to facilitate the safe and effective conduct of the operations. All persons participating in these operations, including criticality safety engineers, should understand and be familiar with the procedures. The procedures should specify all parameters to be controlled, be organized and presented for convenient use by operators, and be free of extraneous material. Further, no single, inadvertent departure from a procedure should lead to a criticality accident. Procedures should be supplemented by posted nuclear criticality safety limits. Augmentation and revision of procedures, as improvements are identified, should be facilitated, and any new or revised procedures should be reviewed by the nuclear criticality safety group. Before any new or modified equipment is put in use, compliance with nuclear criticality safety specifications should be verified.

Appropriate labeling of materials and posting of areas must be maintained, identifying materials and the limits and parameters subject to procedural control. Controls on the movement of fissile materials and access to areas used for handling, processing, or storage of these materials must also be executed.

Deviations from procedures and unforseen alterations in process conditions that affect nuclear criticality safety must be documented, reported to management, and investigated promptly. Actions must be taken to prevent a recurrence.

Emergency procedures must be prepared and approved by management. Potential conditions with nuclear criticality safety implications should be communicated to appropriate on- and off-site emergency response organizations and assistance provided to these organizations in development of their emergency response plans.

2.3 FEEDBACK AND IMPROVEMENT - MAINTAIN CONTROLS

Ensuring that criticality controls maintain their integrity over time and can be relied on to provide their credited protection is an important matter. For design features, this assurance should be achieved through surveillance and preventive maintenance. For administrative controls, assurance should be achieved through periodic training of operators on the nuclear criticality safety aspects of their jobs and proper conduct of operations. Unfortunately, as noted earlier, the supporting requirements and guidance in the ANSI/ANS 8.x series of standards are incomplete with regard to the maintenance of criticality controls. Operator training is adequately addressed; however, surveillance, maintenance, and configuration management of design features are not. DOE Order 420.1 (U.S. Department of Energy, 1995) and its implementation guides provide little additional support. For all criticality controls, a robust system for reporting infractions also needs to be in place to ensure that the feedback loop is closed. Citations from the supporting standards are provided in Appendix C and summarized below.

The contractor's management personnel are assigned responsibility for the overall safety of operations and are expected to remain vigilant in this regard. Facility line managers are responsible for conducting routine pre-job briefings and job hazards analyses that review the engineered and administrative controls that should be in place to ensure safe work. These reviews are especially important for short-term, non-routine or highly variable activities. In addition, contractor management is charged with initiating periodic reviews (at least annually) of more routine processes to ascertain that procedures are being followed and that processes have not changed to the extent that the existing controls are no longer appropriate. These reviews are to be supported by the nuclear criticality safety group. While these reviews fulfill a useful function, in practice they are often too general in nature to ensure that the integrity of controls is not degraded.

For two specific design features—favorable geometry and neutron absorbers—the national consensus standards do explicitly require that the integrity of these controls be maintained. There is no further discussion on appropriate measures for ensuring geometry control. However, there is explicit guidance for maintaining neutron absorbers in both ANSI/ANS 8.5-1996, *Use of Borosilicate-Glass Raschig Rings as a Neutron Absorber in Solutions of Fissile Material* (American National Standards Institute/American Nuclear Society, 1996), and ANSI/ANS 8.21-1995, *Use of Fixed Neutron Absorbers in Nuclear Facilities Outside Reactors* (American National Standards Institute/American Nuclear Society, 1995). It should be noted that contractors often avoid using neutron absorber controls so as not to be burdened by the need for periodic verification of their integrity. This is unfortunate because neutron absorbers provide a powerful means of protection against criticality incidents.

The lack of clear requirements for maintaining the integrity and reliability of criticality controls has led to a divergence of opinion throughout the DOE complex on how best to perform this important function. Section 5 of this report provides some suggested approaches that may help facilitate resolution of this issue.

3. RECENT REVIEWS AND PERTINENT OBSERVATIONS

In the past year, members of the Board staff and, separately, members of the staff of the EH-2 have conducted independent reviews of the criticality safety programs at several DOE sites (see Table 3-1). As part of DOE's criticality safety initiative in response to the recent Japanese criticality accident, the EH-2 team conducted general reviews aimed at assessing whether the programmatic elements necessary for effective nuclear criticality safety programs were in place across the DOE complex. The reviews by the Board's staff were focused more specifically on the development and implementation of criticality safety controls and how those controls are captured in the facility's safety documentation for subsequent maintenance.

Table 3-1. Criticality Safety Program Reviews

Review Team	Dates	Sites Visited
DOE, EH-2	November 1999 – January 2000	• Oak Ridge: Y-12 Plant • Los Alamos National Laboratory: Technical Area-55, Plutonium Facility-4 • Savannah River Site (SRS): FB-Line, H-Area Outside Facilities • Hanford: Plutonium Finishing Plant (PFP) • Rocky Flats Environmental Technology Site (RFETS): Bldg. 371
Board's staff	February 2000 – July 2000	• SRS: F-Canyon, H-Area Outside Facilities • Oak Ridge: Y-12, Bldg. 9215 • RFETS: Bldg. 371, Bldg. 707 • Hanford: PFP, 233-S

Overall, the Board's staff concurs with EH-2's conclusion that ". . . there are no imminent criticality safety hazards at the DOE facilities reviewed."[1] However, as a result of differing interpretations of DOE Orders and national consensus standards, varying approaches to criticality safety have been observed throughout the complex, and several areas for improvement of the criticality safety programs have been identified. Furthermore, it is noted that the continuing existence of large volumes of solutions containing highly enriched uranium at SRS and the excessive reliance on administrative controls for criticality safety may eventually pose a real criticality problem.

[1] U.S. Department of Energy, *Report to the Secretary of Energy on the Review of Nuclear Criticality Safety at Key Department of Energy Facilities*, Office of Oversight Environment, Safety, and Health, Washington, D.C., March 2000.

3.1 ANALYZE THE HAZARDS AND DEVELOP CONTROLS

In general, the Board's staff observed the use of two primary approaches to analyzing criticality safety hazards and developing controls to address those hazards. The first focuses on ensuring that normal and credible abnormal conditions will remain safely subcritical by incorporating sufficient factors of safety such that two independent, unlikely, and concurrent events are required for criticality to be possible. This approach is consistent with the vision of the ANSI/ANS 8.x series of standards (see Section 2.1.3). The second approach focuses on precluding initiating events that could lead to a criticality, and is generally consistent with the more prescriptive modifications of the double contingency principle as presented in DOE Order 420.1 (U.S. Department of Energy, 1995).

Approach 1—Focus on credible abnormal conditions. In this approach, used at Oak Ridge, RFETS, and the Hanford Site, criticality engineers first establish the normal and credible abnormal conditions of the operating process. It should be noted that there may be numerous initiating events that could lead to a given abnormal operating condition. This approach does not attempt to identify and preclude all of the possible initiating events, but rather focuses on ensuring that criticality would not result from the abnormal operating conditions. To this end, a set of controls for the parameters affecting criticality (e.g., mass, moderation, and interaction) is developed. There is no intent to populate the control set with a specified number of controls. Instead, the goal is to ensure that operations under all normal and credible abnormal conditions are subcritical and that two unlikely, independent, and concurrent events (contingencies) must occur before a criticality accident is possible. The controls are viewed as a means of making events unlikely, independent or both. The number of controls necessary is dependent on their quality and on the operational vulnerabilities to criticality.

This approach has the advantage of relieving the criticality engineers of the onerous task of identifying all possible initiating events and accident scenarios that could result in a criticality. There is also less of a burden to develop and implement a large array of criticality safety controls that correspond to all possible accident scenarios. Instead, the criticality safety engineers can focus on a more manageable set of controls that ensure subcriticality of the ultimate upset conditions. However, if specific criticality scenarios have not been identified, it may not be clear to supervisors and operators just what level of safety margin remains when a process error or control failure occurs. Facility operations organizations handle this uncertainty by suspending all operations when one control is lost. With the assistance of the criticality safety engineers, they then assess the situation to determine what controls, if any, remain and how best to recover. This approach tends to lead to underreporting of criticality safety infractions because of the ambiguity of the remaining safety margins.

Approach 2—Focus on initiating events that could lead to a criticality. In this approach, which predominates at SRS, criticality engineers first establish normal operating conditions and then attempt to identify all accident scenarios with probabilities greater than 1×10^{-6}/yr that could lead to a criticality. Accidents that are considered beyond extremely unlikely ($<1 \times 10^{-6}$/yr) may be identified, but not necessarily considered further. The focus in this approach is on precluding these accident scenarios from manifesting by developing two controls for each scenario.

These controls provide protection by either (1) controlling two independent process parameters (preferred) or (2) providing two controls on a single process parameter.

The advantage of this approach is that each criticality scenario is carefully described and documented such that all plant personnel can clearly understand the criticality risk. For each scenario, two controls are explicitly identified. The contingent failure of both of these controls becomes necessary before a criticality is possible. Under this approach, when a process error or control failure occurs, there is little ambiguity with regard to remaining safety margin. The disadvantages are that additional care must be taken to ensure that all credible criticality scenarios have in fact been identified. Further, because there is a large number of criticality scenarios, the identification of at least two controls for every scenario can be difficult. The result is that criticality safety engineers often use nonindependent controls or rely excessively on administrative controls. An additional weakness in this approach stems from the determination of accident frequencies. Analysts must use subjective, engineering judgment about the probabilities of events in an accident sequence, and this introduces a factor of uncertainty into the approach.

Many contractor organizations have made or are making improvements in the development of criticality safety controls. Both the EH-2 review team and the Board's staff found an improving level of maturity in the development of NCSEs. In many cases, the NCSEs present a thorough treatment of potential criticality accidents and propose controls that should serve to prevent a criticality. However, there are still too many instances in which the control sets identified do not adequately meet the double contingency principle. Additionally, it was noted in some instances that a clear link does not exist and needs to be established between criticality controls and the abnormal conditions for which they provide protection.

The EH-2 review team also noted a lack of operator involvement in the development of criticality controls. The Board's staff observed efforts at some of the sites to address this issue through more frequent interactions between the criticality safety and line operations organizations.

The Board's staff noted some aspects of the development of criticality controls that need improvement:

- At all of the sites reviewed, there is an overreliance on administrative controls instead of passive design features or engineered controls. However, this overreliance is particularly prominent at SRS. This situation stems, in part, from the age of the facilities and equipment, but also from the process used to develop criticality controls at the site. Since the approach at SRS is to identify all credible criticality accident scenarios and then provide at least two controls for each scenario, a large number of controls must be identified, and many of these turn out to be procedural in nature. The contractor, Westinghouse Savannah River Company (WSRC), is taking some action to address this issue, including modification of the process used to analyze the hazards and develop controls.

- ! The documentation of criticality safety evaluations at the Oak Ridge Y-12 Plant could be improved. The connection between upset conditions and the associated controls is not always clear. This can lead to operator confusion and increased risk. The EH-2 review team made a similar observation.

3.2 IMPLEMENTATION OF CONTROLS

During its reviews, the Board's staff looked at a "vertical slice" of criticality safety controls for specific activities, tracing them down to the facility procedures and observing actual operations using these procedures. In all operations with fissile material reviewed by the staff, work was governed by written operating procedures. A good practice of uniquely marking procedural steps related to criticality safety was in effect at most sites, and operators were aware of the significance of these markings. In some cases, the bases for procedural steps related to criticality were not clear. This could lead to confusion among the operators and increase the likelihood that a procedural control would be breached. This deficiency was also noted by the EH-2 review team.

Similarly, there were instances in which procedural controls were awkward for the operators to perform and postings were overly complex, thus increasing the likelihood of failure. It should be noted that the root cause of the recent criticality accident in Japan was attributed to the complexity of the procedures the operators were required to follow. This situation is symptomatic of a lack of interaction between criticality engineers and operators during the development of controls. As was noted earlier, most sites reviewed have recognized this problem and appear to be making progress on corrective actions.

At SRS, implementation of administrative controls was also observed to be problematic at times. In one case, operators were directed to perform a subjective visual inspection of a liquid sample to determine whether solids were present. This does not appear to be the most effective way of implementing a control for solids in solution.

3.3 FEEDBACK AND IMPROVEMENT - MAINTAIN CONTROLS

As discussed previously, there is incomplete guidance in the ANSI/ANS 8.x series of standards and in DOE Order 420.1 (U.S. Department of Energy, 1995) with regard to feedback and improvement and maintaining the integrity of design features credited for criticality control over time. Since these standards form the foundation for contractors' criticality safety programs, it is not surprising that those contractor programs generally do not provide a complete maintenance function for criticality controls. Though the contractor programs normally include provisions for periodic criticality safety training for operators, which is necessary to maintain confidence in the efficacy of procedural controls, they rarely address periodic surveillance of design features, either engineered or passive, as necessary to ensure their integrity over time.

Unlike controls for other hazards that are treated under the standard safety analysis process, criticality controls are generally not functionally classified and captured in facility authorization bases by explicit identification in the Technical Safety Requirements (TSR). Rather, they are usually blanketed under a programmatic administrative control in the administrative controls section of the facility's TSRs, which requires the contractor to maintain a criticality safety program compliant with national consensus standards in the ANSI/ANS 8.x series, as modified by DOE Order 420.1 (U.S. Department of Energy, 1995). As was stated earlier, the programmatic elements of the ANSI/ANS 8.x series of standards and DOE Order 420.1 (U.S. Department of Energy, 1995) do not adequately address the maintenance of controls. Therefore, most design features for preventing or mitigating criticality are not required to be adequately maintained under the contractor's nuclear criticality safety program, nor are they required to be captured in the Limiting Conditions for Operation (LCO) surveillance requirements or authorization basis configuration management programs.

Most sites have recognized that their nuclear criticality safety programs do not provide adequate maintenance of design features and have captured, to varying degrees, explicit structures, systems, and components (SSCs) credited for criticality control under LCO surveillance requirements or authorization basis configuration management programs. At RFETS, only a few key systems, such as the criticality alarm system, the building structure, and the ventilation system, are classified as safety-significant and captured under authorization basis surveillance and configuration management. At SRS there is variability from facility to facility on site, but most SSCs that are credited in the criticality safety evaluations are classified as safety-significant and captured under authorization basis surveillance and configuration management. For new stabilization processes at the PFP facility, all equipment that affects criticality safety is classified as safety-significant. It should be noted that elevating controls into authorization basis space, though useful from a control maintenance viewpoint, invokes a requirement for DOE review and approval, and should be considered carefully to avoid overly constraining the operation.

A robust system for reporting infractions is another important aspect of feedback and improvement, and needs to be in place to ensure that the feedback loop is closed. Although the reporting requirements for criticality safety infractions are clearly set forth in DOE Order 232.1A, *Occurrence Reporting and Processing of Operations Information* (U.S. Department of Energy, 1997), and its associated manual, the Board's staff observed significant variability in occurrence reporting from site to site:

- At SRS, the process for development of controls leads to a very large set of criticality controls, the majority of which are administrative in nature. Further, process limits are generally imposed on operations to enhance conservatism; these are often more stringent than the actual criticality safety limits. The local procedures established by WSRC at SRS require an off-normal occurrence report when even process limits related to criticality are breached. Given the heavy reliance on administrative controls and the conservatism associated with the process limits, the approach used by WSRC can lead to excessive reporting of infractions, as well as to desensitization of supervisors and operators to serious violations of criticality safety controls.

- At the other extreme, Lockheed Martin Energy Systems (LMES) at the Oak Ridge Y-12 Plant reported no off-normal or unusual criticality occurrences during the period February 1998–January 2000. They did, however, document 287 criticality "deficiencies" during the same period. The Board's staff believes the nature and organization of the criticality safety controls developed by LMES do not support rigorous reporting of violations. At the Y-12 Plant, the violation of one criticality safety control alone would not typically be reported under the occurrence reporting system, while at most other sites this situation would prompt an off-normal occurrence report.

At all sites visited, DOE is not staffed or is significantly understaffed to provide oversight of contractors' criticality safety programs. Since the EH-2 review team noted this problem in its reviews, DOE field offices have taken some corrective action. The Board's staff observed that DOE is taking steps to hire or reassign personnel to assist in the oversight of criticality safety. However, the formality and rigor of most oversight by DOE's field elements are still deficient, and significant improvement remains to be achieved.

4. CRITICALITY SAFETY AND THE AUTHORIZATION BASIS

The nuclear criticality accident was among the first and the most lethal hazard identified by the pioneers in the nuclear industry. Consequently, significant resources and energy were dedicated to this hazard to ensure that its probability of occurrence is reduced to an acceptable level and operations could be conducted safely. This resulted in a comprehensive set of ANSI/ANS standards that have been used for almost half a century, and modified as lessons are learned and technology has developed. A similar effort to identify the safety standards and the necessary controls for most other operational hazards however, was initiated later with the issuance of DOE directives and the Defense Nuclear Facilities Safety Board's Recommendation 95-2 (Defense Nuclear Facilities Safety Board, 1995). Consequently, a nonuniformity may have been created in the way that criticality and other hazards are addressed in the authorization basis documents.

Criticality safety engineers follow the path outlined by the national consensus standards in the ANSI/ANS 8.x series, using the double contingency principle to ensure adequate defense in depth. This approach is generally consistent with the intent of Integrated Safety Management (ISM) as advocated by the Board and implemented at the majority of defense nuclear facilities. However, the approach is lacking with regard to recent expectations concerning the formality of commitments and authorization level for activities performed by DOE's contractors at defense nuclear facilities. This formality, as described in DNFSB/TECH-16, *Integrated Safety Management* (Defense Nuclear Facilities Safety Board, 1997), and the DOE Order 5480 series, is established to clarify the contractors' commitments to perform work safely. Through this formalized process, DOE reserves the right to review and approve certain safety aspects of its facilities and delegates the remainder of that function to the contractor. Delegation however, does not relieve DOE of its own responsibility.

Recently, there has been debate with regard to whether criticality controls should be considered safety aspects that are reviewed and approved by DOE or whether contractor stewardship is appropriate. Some have interpreted the DOE directives as indicating that all criticality controls should be explicitly listed as TSRs and reviewed and approved by DOE. Others believe it is appropriate to delegate stewardship of criticality controls to the contractor by invoking a programmatic TSR requiring the contractor to implement a nuclear criticality safety program that is compliant with DOE Order 420.1 (U.S. Department of Energy, 1995) and the ANSI/ANS 8.x series of national consensus standards.

The Board proposed a graded approach, commensurate with the hazards, for identifying the safety aspects of the activities that should be reviewed and approved by DOE. DOE contractors' analyses of hazards to workers and the protective measures developed to prevent or abate them are conducted at both a macro and micro levels as illustrated in Figures 10 and 11 of DNFSB/TECH-16 (Defense Nuclear Facilities Safety Board, 1997). The macro level is that represented by the Safety Analysis Reports or tailored equivalent processes such as Basis for Interim Operations or Justification for Continued Operations. In particular the Board states that:

These analyses and the control sets derived from them vary in depth and detail, largely as a function of hazard rating. The subset of worker protection controls established by the macro processes are typically a mixture of design features and administrative restrictions. They are directed at protecting workers from fatal or major disabling injuries. Nuclear criticality and chemical explosions are typical of the potential accidental events considered. In the context of these macro processes, workers include not only those doing hazardous work, but also those collocated within the same facility or nearby in the same complex. Both the analysis and the resultant controls developed at the macro level are generally subject to critical reviews by DOE.

DOE-STD-3009-94 (U.S. Department of Energy, 1994) provides some clarification of DOE's expectations with regard to what should be included in TSRs as summarized below:

- It is important to develop TSRs judiciously. TSRs should not be used as a vehicle to ensure implementation of the many procedural and programmatic controls inherent in any operation. Excessive use of TSR limits to manage operations will result in distortion of the regulatory structure DOE is attempting to develop and dilute the intended emphasis on the most critical controls.

- TSRs assigned for defense in depth or safety-significant SSCs (i.e., not related to meeting evaluation guidelines) do not have safety limits and are not required to use operating limits (i.e., limiting control settings or limiting conditions for operations). They should, however, receive coverage in the administrative controls section of the TSRs at a minimum. Judgment should be exercised in determining which controls warrant the use of operational limits.

- Beyond safety-significant SSCs designated for worker safety, additional worker safety issues should be addressed in the administrative controls section of the TSRs by invoking safety management programs.

On April 12, 2000, DOE issued a clarifying memorandum (Englehart, 2000) on expectations for authorization bases with regard to criticality controls. This memorandum states that:

> A Safety Analysis Report (SAR) must treat all hazards, including inadvertent criticality, and TSRs must include the appropriate controls. The criticality safety evaluation (CSE) supports the SAR. It, including its resulting required controls, can be summarized and referenced in the SAR. A SAR also considers scenarios that may not be included in a CSE such as common cause failures, and additional controls might be identified as necessary. The TSR includes controls so identified, including a commitment to a Criticality Safety Program . . . . TSR level controls should be identified on a case by case basis and should be graded according to the guidance in DOE-STD-3009-94 with regard to the classification of controls.

These passages clearly indicate that it is not DOE's intent to have all criticality controls listed explicitly as individual TSRs. However, it is also clear that some criticality controls are expected to be captured as explicit TSRs. After consideration of the complexity of an operation, the available shielding, and other pertinent safety attributes, the engineering judgment of the criticality safety engineers and safety analysts will determine which subset of criticality controls warrant elevation to explicit TSRs. Prudence appears to dictate that design features, or SSCs, should be explicitly captured in the TSRs, since the associated surveillance and maintenance regimen will help ensure that the integrity of these controls is maintained over time. Conversely, most procedural administrative controls should be addressed under the programmatic TSR requiring the contractor to maintain a nuclear criticality safety program consistent with DOE Order 420.1 (U.S. Department of Energy, 1995) and the ANSI/ANS-8.x series of national consensus standards, and should not require explicit listing in the TSRs. It should be noted that the hierarchy of controls establishes a strong preference for design features over procedural administrative controls. Excessive use of procedural controls for the primary purpose of minimizing the number of explicit TSRs is unacceptable.

5. SUGGESTED IMPROVEMENTS

The recent complex-wide reviews of criticality safety performed by DOE and the Board's staff have revealed the need for improvement in certain areas of the current programmatic approach to criticality safety used by DOE's contractors. Some have argued for a complete shift in paradigm under which all criticality controls would be explicitly captured in the TSRs. The Board's staff believes a less onerous approach is appropriate, under which the weak elements of the contractors' criticality safety programs would be strengthened and augmented. The following sections outline suggested improvements that would revitalize weak elements of criticality safety programs and fill gaps that have to date been inadequately addressed.

5.1 ANALYZE THE HAZARDS AND DEVELOP CONTROLS

- Just as all environmental, safety and health groups must have competent people, criticality safety groups need to be staffed with highly competent, qualified nuclear criticality safety engineers. This statement is not intended as an indictment of the competency of current criticality safety engineers. Rather it is meant to focus attention on the uniquely important role of these engineers in ensuring nuclear criticality safety, and to challenge sites throughout the complex to maintain a high-caliber group of specialists to perform this central function.

- Criticality safety engineers need to continue to increase the time they spend on the floor with operational personnel. Time spent on the floor improves the criticality engineers' familiarity with the process systems for which they will be developing controls, and facilitates the gathering of operator input that is essential to the development of successful strategies for preventing criticality. Furthermore, once the criticality engineers have completed a NCSE for a process and controls have been implemented, increased time on the process floor makes it more likely that previously unanticipated criticality hazards, which often arise once operations have begun, will be detected and resolved expeditiously.

- The present overreliance on procedural administrative controls for criticality safety needs to be reevaluated and, where appropriate, design feature replacements should be identified. The preference for engineered controls is clearly stated in the supporting standards and guidance for criticality safety; however, this preference is not reflected in the makeup of the control sets extant in much of the complex. It is recognized that for some of the older facilities in the complex, retrofitting of engineered features may not always be practical. However, the degree of reliance on administrative controls still appears extreme. In new facilities, retrofitting is not an issue, and criticality safety should be emphasized early in the design process to ensure that engineered features are incorporated to the maximum extent practicable.

- The relationship between criticality controls developed in NCSEs and facility SARs and TSRs differs greatly from site to site, and in some cases from facility to facility within the same site. Some groups within the criticality community have suggested that all criticality controls should be captured in the TSRs while others maintain that none of the criticality controls should be included in the TSRs. DOE would be well served to promulgate guidance to the complex clarifying the expectations for the relationship between criticality controls and these safety documents.

5.2 IMPLEMENTATION OF CONTROLS

A robust process needs to be established for vertically tracing the criticality controls identified in the NCSEs to the procedures, postings, design drawings, and surveillance requirements in which they are implemented. Further, this process should be able to cross-reference criticality controls from a given NCSE to all other NCSEs where they are also credited. This will ensure consistency and integration of criticality controls.

5.3 FEEDBACK AND IMPROVEMENT - MAINTAIN CONTROLS

- DOE's oversight of contractors' criticality safety programs needs to be improved. DOE and the contractor's management should develop performance elements for criticality safety programs that, when met, will provide assurance that the contractor's criticality safety program will provide adequate protection from inadvertent criticality. These performance elements should be captured in the programmatic TSR administrative control that calls for establishment of the contractor's criticality safety program. DOE's Office of Environment, Health and Safety Workshop Handbook, *Your Mission... and Nuclear Criticality Safety* (U.S. Department of Energy, 1999), presents examples of acceptable performance elements. DOE's oversight plans need to be formalized and to be of sufficient rigor to ensure that the agreed-upon performance elements are being met. The importance of robust oversight on the part of DOE in ensuring the proper functionality of a contractor's criticality safety program cannot be overstated.

- Operators should continue to receive periodic training in the nuclear criticality safety aspects of their jobs and in proper conduct of operations, and procedural steps with criticality safety significance should continue to be uniquely marked. This will ensure that the maximum reliability of procedural administrative controls is maintained.

- Periodic self-assessments by contractors need to be formalized, with sufficient rigor and frequency to ensure that the program remains capable of developing adequate criticality controls and that any programmatic deficiencies are identified and corrected in a timely manner.

- Design features (e.g., structures, systems, and components) credited in the NCSEs as providing protection from inadvertent criticality need to be subject to periodic surveillance and configuration management to ensure that they do not degrade to the point that they can no longer be depended upon to perform their intended function. Criticality consequences are generally defined in DOE's Orders to be serious injuries or fatalities to workers. It is true that if the double contingency requirement is met, no single failure of an SSC should lead to a criticality. Still, prudence dictates that maintenance of the design features relied on for criticality control be accomplished by functionally classifying this equipment as safety-significant and invoking the appropriate authorization bases (TSR) mechanisms for surveillance and configuration management. Active engineered features should be covered under TSRs and LCO, while passive design features should be captured in the authorization bases as design features credited for safety. In determining the frequencies for surveillance, the likely failure modes and time frames of the specific SSCs should be considered. Conversely, the benefits of functionally classifying procedural administrative criticality controls and subsequently capturing them explicitly in the authorization bases (TSRs) are minimal, provided these controls are uniquely marked and double contingency is met. Thus, procedural administrative criticality controls do not need to be explicitly captured in the authorization bases (TSRs) unless they are the only control for a singly contingent abnormal operating condition.

- A robust and consistent process for reporting infractions needs to be developed. Reporting criteria should be neither overly sensitive so that they might lead to numerous reports of low-concern events, nor too insensitive such that important events are not reported externally. A clear link in the NCSEs between criticality controls and the abnormal operating conditions for which they provide protection would facilitate a more consistent and straightforward process for reporting infractions.

6. CONCLUSIONS

Based on a review of both criticality safety requirements as outlined in the national consensus standards and relevant DOE directives, and current practices for developing, implementing, and maintaining criticality controls, the Defense Nuclear Facilities Safety Board's staff has formulated the following conclusions which reflect the views as to the most important changes that can be made:

- *No imminent criticality hazards were identified in the DOE complex*. During the course of the staff's reviews, no imminent criticality safety hazards were found, though several issues were noted. A specific issue that warrants increased attention is the large accumulation of enriched uranium solutions in the H-Area outside storage tanks at the Savannah River Site.

- *A properly structured programmatic approach to criticality safety can provide adequate protection for operations with fissile material.* The programmatic approach commonly taken can provide acceptable protection from inadvertent criticality in operations with fissile material, and need not be supplanted by a more restrictive paradigm. Nevertheless, several aspects of that approach need to be strengthened, including oversight by DOE Field Offices, maintenance of design feature controls, presence of criticality engineers on the process floor, infraction reporting, and the extent of reliance on procedural controls.

- *More formalized and robust oversight of contractors' criticality safety programs by DOE Field Offices is necessary*. DOE's performance expectations for those programs need to be clearly articulated, and effective oversight programs instituted to ensure that these expectations are being met. A strong DOE oversight function is essential to the success of the programmatic approach to criticality safety.

- *Extant guidance on maintaining the integrity and reliability of criticality-related design features is incomplete.* The national consensus standards for criticality safety and relevant DOE directives address the development and implementation of criticality controls in detail. Such complete treatment is not provided for maintenance of the integrity of design feature criticality controls.

- *Criticality-related design features need to be covered by a formalized maintenance and configuration management program*. Both passive and active engineered design features credited for preventing or mitigating inadvertent criticality should be subject to a formalized maintenance and configuration management program. Capturing these design features explicitly in the Technical Safety Requirements with concomitant surveillance and maintenance requirements is appropriate for ensuring that these controls do not degrade such that they can no longer be relied upon to perform their intended function.

- *Consistent criteria for reporting of criticality infractions need to be established*. There is significant variability throughout the complex with regard to such criteria. Because this feedback information is quite useful for catching potential problems early, it is imperative that the thresholds for reporting be neither oversensitive nor too insensitive.

- *Criticality engineers must continue to increase their presence on the process floor*. Time spent on the floor makes criticality safety engineers more familiar with the relevant fissile material processes; facilitates operator input with regard to criticality control strategies, which ultimately translates into safer operations; and makes it more likely that a criticality safety engineer will identify potential problems at an early stage.

- *The current overreliance on procedural administrative controls for criticality safety needs to be addressed*. Both national consensus standards and relevant DOE directives clearly communicate a preference for design feature controls over procedural administrative controls. This preference is rooted in the fact that the human element associated with procedural controls makes them much more vulnerable to failure than design features. Unfortunately, this preference is not reflected in the criticality control sets extant in much of the complex. Opportunities for replacing procedural controls with more robust design features should therefore be explored.

- *DOE needs to clarify its expectations for the relationship between the criticality controls and the SAR and TSRs*. Currently, there is confusion regarding the relationship between the criticality controls and facility safety documents. DOE should issue guidance to the field that clarifies the expectation for which criticality controls, if any, are most appropriately captured in the facility SAR and TSRs.

APPENDIX A

ANALYZE THE HAZARDS AND DEVELOP CONTROLS: REQUIREMENTS AND GUIDANCE

A.1 PROGRAM STRUCTURE, ROLES, AND RESPONSIBILITIES

! Management shall provide personnel skilled in the interpretation of data pertinent to nuclear criticality safety and familiar with operations to serve as advisors to supervision. These specialists should be, to the extent practicable, administratively independent of process supervision. (Section 4.1.1 ¶2, American National Standards Institute/American Nuclear Society-8.1-1983)

! Management shall provide personnel familiar with the physics of nuclear criticality and with associated safety practices to furnish technical guidance appropriate to the scope of operations. This function should, to the extent practicable, be administratively independent of operations. (Section 4.4, American National Standards Institute/American Nuclear Society-8.19-1996)

! Management shall establish the criteria to be satisfied by nuclear criticality safety controls. (Section 4.1.1 ¶3, American National Standards Institute/American Nuclear Society -8.1-1983)

! Management shall formulate a nuclear criticality safety policy and make it known to all employees involved in operations with fissile material. (Section 4.2, American National Standards Institute/American Nuclear Society-8.19-1996)

! The nuclear criticality safety staff shall provide technical guidance for the design of equipment and processes and for the development of operating procedures. (Section 6.1, American National Standards Institute/American Nuclear Society-8.19-1996)

! The staff shall maintain familiarity with the current developments in nuclear criticality safety standards, guides, and codes. Knowledge of current nuclear criticality information should be maintained. (Section 6.2, American National Standards Institute/American Nuclear Society-8.19-1996)

! The staff should consult with knowledgeable individuals to obtain technical assistance as needed . (Section 6.3, American National Standards Institute/American Nuclear Society-8.19-1996)

- The staff shall maintain familiarity with all operations within the organization requiring nuclear criticality safety controls. (Section 6.4, American National Standards Institute/American Nuclear Society-8.19-1996)

A.2 PROCESS ANALYSES

- The nuclear criticality safety program . . . shall include: Nuclear Criticality Safety Evaluations for normal and credible abnormal conditions that document the parameters, limits, and controls required to ensure that the analyzed conditions are subcritical (Section 4.3.2 ¶2 [i], DOE Order 420.1). (U.S. Department of Energy, 1995)

- Before a new operation with fissionable materials is begun or before an existing operation is changed, it shall be determined that the entire process will be subcritical under both normal and credible abnormal conditions. Care shall be exercised to determine those conditions that result in the maximum effective multiplication factor (k_{eff}). (Section 4.1.2, American National Standards Institute/American Nuclear Society-8.1-1983)

- Before starting a new operation with fissile materials or before an existing operation is changed, it shall be determined that the entire process will be subcritical under both normal and credible abnormal conditions. (Section 8.1, American National Standards Institute/American Nuclear Society-8.19-1996)

- The nuclear criticality safety evaluation shall determine and explicitly identify the controlled parameters and their associated limits upon which nuclear criticality safety depends. (Section 8.2, American National Standards Institute/American Nuclear Society-8.19-1996)

- The nuclear criticality safety evaluation shall be documented with sufficient detail, clarity, and lack of ambiguity to allow independent judgment of results. (Section 8.3, American National Standards Institute/American Nuclear Society-8.19-1996)

- Where applicable data are available, subcritical limits shall be established on bases derived from experiments, with adequate allowance for uncertainties in the data. In the absence of directly applicable experimental measurements, the limits may be derived from calculations shown by comparison with experimental data to be valid. (Section 4.2.5, American National Standards Institute/American Nuclear Society-8.1-1983)

- There are many calculational methods suitable for determining the k_{eff} of a system or for deriving subcritical limits. The methods vary widely in basis and form, and each has its place in the broad spectrum of problems encountered in the nuclear criticality safety field.

However, the general procedure to be followed in establishing validity is common to all. (Section 4.3, American National Standards Institute/American Nuclear Society-8.1-1983)

! Bias [of a calculational method] shall be established by correlating the results of criticality experiments with the results obtained for these same systems by the method being validated. Commonly the correlation is expressed in terms of the values of k_{eff} calculated for the experimental systems, in which case the bias is the deviation of the calculated values of k_{eff} from unity. However, other parameters may be used. The bias serves to normalize a method over its area(s) of applicability so that it will predict critical conditions within the limits of the uncertainty in the bias. Generally, neither bias nor uncertainty is constant; both should be expected to be functions of composition and other variables. (Section 4.3.1, American National Standards Institute/American Nuclear Society-8.1-1983)

! The area(s) of applicability of a calculational method may be extended beyond the range of experimental conditions over which the bias is established by making use of the trends in the bias. Where the extension is large, the method should be supplemented by other calculational methods to provide a better estimate of the bias in the extended area(s). (Section 4.3.2, American National Standards Institute/American Nuclear Society-8.1-1983)

! A margin in the correlating parameter, which margin may be a function of composition and other variables, shall be prescribed that is sufficient to ensure subcriticality. This margin of subcriticality shall include allowances for the uncertainty in the bias and for uncertainties due to any extensions of the area(s) of applicability. (Section 4.3.3, American National Standards Institute/American Nuclear Society-8.1-1983)

! If the method involves a computer program, checks shall be performed to confirm that the mathematical operations are performed as intended. Any changes to the computer program shall be followed by reconfirmation that the mathematical operations are performed as intended. (Section 4.3.4, American National Standards Institute/American Nuclear Society-8.1-1983)

! Nuclear properties such as cross-sections should be consistent with experimental measurements of these properties. (Section 4.3.5, American National Standards Institute/American Nuclear Society-8.1-1983)

! A written report of the validation shall be prepared. This report shall: (1) describe the method with sufficient detail, clarity, and lack of ambiguity to allow independent duplication of results; (2) state computer programs used, the options, recipes for choosing mesh points where applicable, the cross-section sets, and any numerical parameters necessary to describe the input; (3) identify experimental data and list the parameters derived therefrom for use in the validation of the method; (4) state the area(s) of applicability; and (5) state the bias and the prescribed margin of subcriticality over the area(s) of applicability. State the basis for the margin. (Section 4.3.6, American National Standards Institute/American Nuclear Society-8.1-1983)

- Before the start of operation, there shall be an independent assessment that confirms the adequacy of the nuclear criticality safety evaluation. (Section 8.4, American National Standards Institute/American Nuclear Society-8.1-1983)

- DOE-STD-3007-93, *Guidelines for Preparing Criticality Safety Evaluations at Department of Energy Non-Reactor Nuclear Facilities* (U.S. Department of Energy, 1993). This document provides specific guidance on acceptable formats for nuclear criticality safety evaluations.

- DOE-STD-1135-99, *Guidance for Nuclear Criticality Engineer Training and Qualification* (U.S. Department of Energy, 1999). This document provides specific guidance on the acceptable structure and content of training programs for qualification of contractor nuclear criticality safety engineers.

A.3 ADEQUACY CRITERIA FOR CONTROLS

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- Nuclear criticality safety is achieved by controlling one or more parameters of the system within subcritical limits. Control may be exercised administratively through procedures, by physical restraints, through the use of instrumentation, by chemical means, by relying on the natural or credible course of events, or by other means. All controlled parameters and their limits shall be specified. (Section 4.2.1 ¶2, American National Standards Institute/American Nuclear Society-8.1-1983)

- Process design should, in general, incorporate sufficient factors of safety to require at least two unlikely, independent, and concurrent changes in process conditions before a criticality accident is possible. (Section 4.2.2, American National Standards Institute/American Nuclear Society-8.1-1983)

- 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 is possible. Protection shall be provided by either (1) the control of two independent process parameters (which is the preferred approach, when practical, to prevent common-mode failure), or (2) a system of multiple controls on a single process parameter. The number of controls required on a single controlled process parameter shall be based upon control reliability and any features that mitigate the consequences of a control failure. In all cases, no single credible event or failure shall result in the potential for a criticality accident . . . . (Section 4.3.3d [1], DOE Order 420.1). (U.S. Department of Energy, 1995)

- Where practicable, reliance should be placed on equipment design in which dimensions are limited rather than on administrative controls. Full advantage may be taken of any nuclear characteristics of the process materials and equipment. (Section 4.2.3, American National Standards Institute/American Nuclear Society-8.1-1983)

- Where a significant quantity of fissionable material is being processed and criticality safety is a concern, passive engineered controls such as geometry control shall be considered as a preferred control method. Where passive engineered control is not feasible, the preferred order of controls is: active engineered controls, followed by administrative controls. The double contingency analysis shall justify the chosen controls. Full advantage may be taken of any nuclear characteristics of the process materials and equipment (Section 4.3.3 d (2), DOE Order 420.1). (U.S. Department of Energy, 1995)

- Reliance may be placed on neutron-absorbing materials, such as cadmium or boron, that are incorporated in process materials or equipment, or both. (Section 4.2.4, American National Standards Institute/American Nuclear Society-8.1-1983)

APPENDIX B

IMPLEMENTATION OF CONTROLS: REQUIREMENTS AND GUIDANCE

B.1 RESPONSIBILITIES

- The nuclear criticality safety program . . . shall include: Implementation of limits and controls identified by the nuclear criticality safety evaluations (Section 4.3.2 ¶2 [ii], DOE Order 420.1). (U.S. Department of Energy, 1995)

- Management shall assign responsibility and delegate commensurate authority to implement established policy. Responsibility for nuclear criticality safety should be assigned in a manner compatible with that for other safety disciplines. (Section 4.3, American National Standards Institute/American Nuclear Society-8.19-1996)

- Management shall clearly establish responsibility for nuclear criticality safety. Supervision should be made as responsible for nuclear criticality safety as for production, development, research or other functions. Each individual regardless of position, shall be made aware that nuclear criticality safety in his work area is ultimately his responsibility. This may be accomplished through training and periodic retraining of all operating and maintenance personnel. Nuclear criticality safety differs in no intrinsic way from industrial safety, and good managerial practices apply to both. (Section 4.1.1, American National Standards Institute/American Nuclear Society-8.1-1983)

- Each supervisor shall accept responsibility for the safety of operations under his control. Management shall assign responsibility and delegate commensurate authority to implement established policy. Responsibility for nuclear criticality safety should be assigned in a manner compatible with that for other safety disciplines. (Section 5.1, American National Standards Institute/American Nuclear Society-8.19-1996)

- Each supervisor shall be knowledgeable in those aspects of nuclear criticality safety relevant to operations under his control. Training and assistance should be obtained from the criticality safety staff. Management shall assign responsibility and delegate commensurate authority to implement established policy. Responsibility for nuclear criticality safety should be assigned in a manner compatible with that for other safety disciplines. (Section 5.2, American National Standards Institute/American Nuclear Society-8.19-1996)

- Each supervisor shall provide training and shall require that the personnel under his supervision have an understanding of procedures and safety considerations such that they may be expected to perform their functions without undue risk. Records of training activities and verification of personnel understanding shall be maintained. (Section 5.3, American National Standards Institute/American Nuclear Society-8.19-1996)

- The [Nuclear criticality safety] staff shall assist supervision, on request, in training personnel. (Section 6.5, American National Standards Institute/American Nuclear Society-8.19-1996)

- This industry consensus standard provides detailed guidance on appropriate criticality safety training for operators. (American National Standards Institute/American Nuclear Society 8.20-1991)

- Supervisors shall develop or participate in the development of written procedures applicable to operations under their control. (Section 5.4, American National Standards Institute/American Nuclear Society-8.19-1996)

- Supervisors shall verify compliance with nuclear criticality safety specifications for new or modified equipment before its use. Verification may be based on inspection reports or other features of the quality control system. (Section 5.5, American National Standards Institute/American Nuclear Society-8.19-1996)

- Each supervisor shall require conformance with good safety practices including unambiguous identification of fissile material and good housekeeping. (Section 5.6, American National Standards Institute/American Nuclear Society-8.19-1996)

- The [Nuclear criticality safety] staff shall examine reports of procedural violations and other deficiencies for possible improvement of safety practices and procedural requirements, and shall report findings to management . (Section 6.7, American National Standards Institute/American Nuclear Society-8.19-1996)

B.2 OPERATING PROCEDURES

- Operations to which nuclear criticality safety is pertinent shall be governed by written procedures. All persons participating in these operations shall understand and be familiar with the procedures. The procedures shall specify all parameters they are intended to control. They should be such that no single, inadvertent departure from a procedure can cause a criticality accident. (Section 4.1.3, American National Standards Institute/American Nuclear Society-8.1-1983)

- The purpose of operating procedures is to facilitate the safe and efficient conduct of the operation. Procedures should be organized and presented for convenient use by operators and be conveniently available. They should be free of extraneous material. (Section 7.1, American National Standards Institute/American Nuclear Society-8.19-1996)

- Procedures shall include those controls and limits significant to the nuclear criticality safety of the operation. (Section 7.2, American National Standards Institute/American Nuclear Society-8.19-1996)

- Supplementing and revising procedures as improvements become desirable shall be facilitated. (Section 7.3, American National Standards Institute/American Nuclear Society-8.19-1996)

- New or revised procedures that have an impact upon nuclear criticality safety shall be reviewed by the nuclear criticality safety staff. (Section 7.5, American National Standards Institute/American Nuclear Society-8.19-1996)

- Procedures should be supplemented by posted nuclear criticality safety limits or limits incorporated in operating check lists or flow sheets on automatic inventory control systems. (Section 7.6, American National Standards Institute/American Nuclear Society-8.19-1996)

- Deviations from operating procedures and unforseen alterations in process conditions that affect nuclear criticality safety shall be documented, reported to management, and investigated promptly, corrected as appropriate, and documented. Action shall be taken to prevent a recurrence. (Section 7.7, American National Standards Institute/American Nuclear Society-8.19-1996)

- Deviations from procedures and unforseen alterations in process conditions that affect nuclear criticality safety shall be reported to management and shall be investigated promptly. Action shall be taken to prevent a recurrence. (Section 4.1.5, American National Standards Institute/American Nuclear Society -8.1-1983)

- The movement of fissionable materials shall be controlled. Appropriate materials labeling and area posting shall be maintained specifying material identification and all limits on parameters that are subjected to procedural control. (Section 4.1.4, American National Standards Institute/American Nuclear Society-8.1-1983)

- The movement of fissile materials shall be controlled as specified in documented procedures. (Section 9.1, American National Standards Institute/American Nuclear Society-8.19-1996)

- Appropriate material labeling and area posting shall be maintained specifying material identification and all limits and parameters that are subject to procedural criticality control. (Section 9.2, American National Standards Institute/American Nuclear Society-8.19-1996).

- Access to areas where fissile material is handled, processed, or stored shall be controlled. (Section 9.4, American National Standards Institute/American Nuclear Society-8.19-1996)

- Control of spacing, mass, density, and geometry of fissile material shall be maintained to assure subcriticality under all normal and credible abnormal conditions. (Section 9.5, American National Standards Institute/American Nuclear Society-8.19-1996)

- Emergency procedures shall be prepared and approved by management. Organizations, local and offsite, that are expected to respond to emergencies shall be made aware of conditions that might be encountered, and they should be assisted in preparing suitable procedures governing their responses. (Section 4.1.7, American National Standards Institute/American Nuclear Society-8.1-1983)

- Emergency procedures shall be prepared and approved by management. Organizations, on and off-site, that are expected to provide assistance during emergencies shall be informed of conditions that might be encountered. They should be assisted in preparing suitable emergency response procedures. (Section 10.2, American National Standards Institute/American Nuclear Society -8.19-1996)

APPENDIX C

FEEDBACK AND IMPROVEMENT - MAINTAIN CONTROLS: REQUIREMENTS AND GUIDANCE

- The nuclear criticality safety program . . . shall include: Reviews of operations to ascertain that limits and controls are being followed and that process conditions have not been altered such that the applicability of the nuclear criticality safety evaluation has been compromised (Section 4.3.2 ¶2 [iii], DOE Order 420.1). (U.S. Department of Energy, 1995)

- Management shall accept overall responsibility for safety of operations. Continuing interest in safety should be evident. (Section 4.1, American National Standards Institute/American Nuclear Society-8.19-1996)

- Management shall establish a way to monitor the nuclear criticality safety program. (Section 4.5, American National Standards Institute/American Nuclear Society-8.19-1996)

- Operations shall be reviewed frequently (at least annually) to ascertain that procedures are being followed and that process conditions have not been altered so as to affect the nuclear criticality safety evaluation. These reviews shall be conducted, in consultation with operating personnel, by individuals who are knowledgeable in nuclear criticality safety and who, to the extent practicable, are not immediately responsible for the operation. (Section 4.1.6, American National Standards Institute/American Nuclear Society-8.1-1983)

- Operations shall be reviewed frequently (at least annually) to ascertain that procedures are being followed and that process conditions have not been altered so as to affect the nuclear criticality safety evaluation. (Section 7.8, American National Standards Institute/American Nuclear Society-8.19-1996)

- Active procedures shall be reviewed periodically by supervision. (Section 7.4, American National Standards Institute/American Nuclear Society -8.19-1996)

- Management shall periodically participate in auditing the overall effectiveness of the nuclear criticality safety program (ANSI/ANS). (Section 4.6, American National Standards Institute/American Nuclear Society-8.19-1996)

- The [nuclear criticality safety] staff shall conduct or participate in audits of criticality safety practices and compliance with procedures as directed by management. (Section 6.6, American National Standards Institute/American Nuclear Society-8.19-1996)

- [Instilling responsibility and good conduct of operations] . . . may be accomplished through training and periodic retraining of all operating and maintenance personnel . . . . (Section 4.1.1 ¶1, American National Standards Institute/American Nuclear Society-8.1-1983, 1983)

- Maintenance of these procedures to reflect changes in operations shall be a continuing supervisory responsibility. (Section 5.4, American National Standards Institute/American Nuclear Society-8.19-1996)

- [For geometry controls] All dimensions and nuclear properties on which reliance is placed shall be verified prior to beginning operations, and control shall be exercised in maintaining them. (Section 4.2.3, American National Standards Institute/American Nuclear Society-8.1-1983)

- [For neutron absorber controls] Control shall be exercised to maintain their continued presence with the intended distributions and concentrations. Extraordinary care should be taken with solutions of absorbers because of the difficulty of exercising such control. (Section 4.2.4, American National Standards Institute/American Nuclear Society-8.1-1983)

- If reliance for criticality control is placed on neutron absorbing materials that are incorporated into process materials or equipment, procedural control shall be exercised to maintain their continued presence with the intended distributions and concentrations. (Section 9.3, American National Standards Institute/American Nuclear Society-8.19-1996)

- Subsequent to initial use, periodic verification shall assure that required physical and chemical properties of the Rashig rings are maintained. (Section 3(3), American National Standards Institute/American Nuclear Society-8.5-1996)

- The extent and frequency of the verification of physical and chemical properties [of Rashig rings] may be determined from a documented history of trends in these properties of Rashig rings in the particular environment in which they are used. Otherwise the frequencies specified in [Section] 7.4, Inspection Intervals, shall apply at all times. (Section 3[4], American National Standards Institute/American Nuclear Society-8.5-1996)

- The top surface of the Rashig rings within a vessel shall be inspected periodically to detect settling through time and use. (Section 5.3, American National Standards Institute/American Nuclear Society-8.5-1996)

- Rashig rings shall be inspected periodically to demonstrate their continued criticality control properties. These tests shall include ring settling, solids accumulation, and physical properties of the glass. The interval for inspection of rings shall not exceed: (a) 13 months for rings not subjected to agitation; or (b) 7 months for rings subjected to agitation. (Section 7.4, American National Standards Institute/American Nuclear Society-8.5-1996)

! After the installation [of the neutron absorbers], there shall be verification to ensure that the neutron absorber system is in place as intended. The extent and frequency of verification shall be dictated by the impact on the environment in which the absorbers are placed, on the absorber material properties, and on the configuration. (Section 4 ¶1, American National Standards Institute/American Nuclear Society-8.21-1995)

! The operation of the neutron absorber system and its maintenance shall be verified to conform to the safety evaluation requirements. (Section 5.3.2.4, American National Standards Institute/American Nuclear Society-8.21-1995)

! DOE-P-450.5, *Line Environment, Safety and Health Oversight* (U.S. Department of Energy, 1997). This policy obligates the DOE field element line management, in coordination with contractor line management, to develop performance objectives for safety (including criticality safety), incorporate these objectives into the contract, and provide oversight to assure that these objectives are being met.

! DOE Department-wide Functional Area Qualification Standard, *Criticality Safety*. This document provides specific guidance on the acceptable structure and content of training programs for qualification of DOE nuclear criticality safety staff.

GLOSSARY OF ACRONYMS

Abbreviation	Definition
ANS	American Nuclear Society
ANSI	American National Standards Institute
Board	Defense Nuclear Facilities Safety Board
CSE	Criticality Safety Evaluation
DOE	Department of Energy
EH-2	Department of Energy Deputy Assistant Secretary for Oversight
ISM	Integrated Safety Management
k_{eff}	Effective Multiplication Factor
LCO	Limiting Condition for Operation
LMES	Lockheed Martin Energy Systems
NCSE	Nuclear Criticality Safety Evaluation
PFP	Plutonium Finishing Plant
RFETS	Rocky Flats Environmental Technology Site
SAR	Safety Analysis Report
SRS	Savannah River Site
SSCs	Structures, Systems, and Components
TSR	Technical Safety Requirement
WSRC	Westinghouse Savannah River Company

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