Nuclear Criticality Safety Evaluations

Introduction

One of the more difficult, but important, tasks of a criticality safety engineer (CSE) is to develop the rationale for the establishment of controlled parameters and properly document the basis for subcritical limits derived using the controlled parameters. The documented basis is often referred to as a nuclear criticality safety evaluation (NCSE). In addition, clear specifications of associated control and functionality requirements needed to safely operate a process or facility involving fissile material must be clearly communicated to operating personnel.

Background

This white paper was identified by the ANS/NCSD Education Committee as important to meeting the overall mission statement of the NCSD, "To promote development of nuclear criticality safety expertise by providing opportunities that offer technical growth and recognition." An obvious area in which to promote development of nuclear criticality safety expertise is to define "best practices" on what constitutes proper development and documentation of a nuclear criticality safety evaluation, and the underlying logic used in the creation of that document.

General Discussion

Guidance provided in ANSI/ANS-8.19-2014 stipulates criteria for nuclear criticality safety evaluations and provides guidance on implementation and maintenance of nuclear criticality safety controls. The following principles are emphasized:

- It shall be determined and documented that the entire process will be subcritical for both normal and credible abnormal conditions.
- The evaluation shall be documented with sufficient detail, clarity, and lack of ambiguity to allow independent judgment of results.
- Established controls shall be implemented, maintained, and verified before start of operation.

To accomplish this, CSEs must be knowledgeable of operations with fissile processes and must have a means to compile conditions that could develop that might allow a criticality accident to occur. In addition, the CSEs must have a firm grasp of the analytic tools being used and their limitations, operating license conditions, and standards and regulations.

Content

Facility-specific administrative requirements ultimately dictate the format and content of a nuclear criticality safety evaluation. The format may be designed to facilitate operations understanding. A nuclear criticality safety evaluation should reflect the needs and characteristics of the system being analyzed and include the following elements as applicable to meet the *minimum acceptable* requirements:

- **Scope** - This element defines the stated purpose of the evaluation and the properties (e.g., maximum enrichment and isotopes) of the fissile material being processed.
- **General Discussion** - This element presents an overview of the process being evaluated (new operation, proposed change or installation) and includes a process description, flow diagrams, normal operating conditions, system interfaces, and other aspects important to design considerations.
- **Criticality Safety Hazards** – A key section of any nuclear criticality safety evaluation is the assessment of normal and credible abnormal conditions that could lead to a criticality. Justification why the prescribed control(s) are adequate should be provided.[1] The hazards evaluation section should consider the following:

    - Understand the normal operation of system being evaluated. To assess process upsets, it is important to convey the normal operating conditions. It is likewise important to identify expected upset conditions for the system being evaluated. Facility and equipment drawings should be reviewed as well as process flow sheets or descriptions. Direct observation is strongly recommended for existing operations. Ancillary safety analysis for the facility may also provide insight on proper identification of credible accident sequences that could affect nuclear criticality safety (e.g., seismic design, sprinkler activation, loss of containment).

    - Identify potential criticality accident scenarios. The analyst must describe in detail the suite of *credible* accident scenarios. There is normally a range of contingencies that needs to be considered and input from subject matter experts from multiple disciplines, including but not limited to: process specialists, operators, safety basis analysts, and other safety disciplines is required for a comprehensive collection. For most criticality safety specialists, formal process hazards analysis methods, usually involving a team (including participation from operations) prove helpful (e.g., logic trees, event trees, fault trees, HAZOP, FMEA, What-If). The method used and rationale for its selection need to be documented so that the results and conclusions of this part of the evaluation can be reviewed by operations, process engineers, and other criticality safety specialists. The initiating event, enabling events, and failure mode(s) of each identified control or barrier for a given accident sequence should be assessed. Where practical, walkthroughs of the process are encouraged to identify potential accident scenarios.

    - Control the risk. The risk of credible criticality scenarios must be controlled. The overall goal for each assessed nuclear operation is that the risk of a credible criticality accident is "highly unlikely." Protection of operating personnel and the public must be the dominant consideration. Implicit in the guidance of the ANSI/ANS-8 series criticality safety standards are concepts of process efficiency and economic considerations. Safety may be achieved using a graded approach. In Section 1, ANSI/ANS-8.1 states that "…extensive operations can be performed safely and economically when proper precautions are exercised", and the admonition that "good safety practices must recognize economic consideration…" stresses that the controls should be as cost effective as is reasonable. The preferred hierarchy of controls is 1) passive engineered controls, 2) active engineered controls, and 3) administrative controls. Each credible accident sequence analysis shall identify required control(s) necessary to render it "highly unlikely". Identified controls should be documented, implemented, and maintained in accordance with site or facility procedures.

[1] Refer ANSI/ANS-8.1-2014, Section 4.1.2, Process analysis requirement and technical practices Section 4.2.2, Double-contingency principle for basic expectations.

- **Methodology** – A description of analytic (hand calculation) method used; or validated computer code(s) and cross sections used to establish subcritical limits for the systems explicitly modeled. Where applicable, the upper subcritical limit (USL) shall be clearly defined for each Area of Applicability (AoA). The USL should include bias and associated bias uncertainty, arbitrary margin of subcriticality, and (if required) any additional Area of Applicability margin (AoA_m). Calculational model assumptions applicable to the fundamental process conditions and design features should also be included as appropriate in this section.

- **Calculations and Results** - The section includes a description of model constructs, how calculations were performed, what analytic tools or reference documents were used, and a summary of the calculational results and associated uncertainties in accordance with the facility approved methodology as a function of key parameter(s). Derived subcritical limits are based on the most reactive values of uncontrolled parameters or based on worst credible values of uncontrolled parameters with documented justifications.

- **Controls** – This section should (i) document the basis for derived subcritical limits for selected controlled parameters and establish the passive, active, and administrative controls necessary to maintain the process within applicable subcritical limits; (ii) be prepared or updated for each new or significantly modified process or facility in accordance with established internal configuration management (CM) procedures by qualified criticality safety staff.

  The limits and controls established in the evaluation should be developed in collaboration with operations and process engineering staff prior to initial implementation to ensure the requirements are clear and the potential costs and impacts on operations are adequately understood. The responsible CSE should also walkdown the process to assure the documented evaluation reflects as-built conditions, flow-down of control requirements are met, and operations personnel understand operating procedure control requirements.

- **Specifications and Requirements for Safety** - When applicable, this element presents both bounding design assumptions and the criticality safety requirements for correct implementation of established controls. The requirements are grouped according to passive, active, or administrative controls. Generic management measures and applicable elements of combustible material control (or other) programs may also be included in this element.

- **Conclusions** - This element concludes the analysis with pertinent summary statements and a statement regarding license compliance for process analysis.

- **Attachment/Appendices** - This element may include attachments/appendices as needed to support and assist the readability of the main body of the nuclear criticality safety evaluation. Attributes commonly included are materials used, tabulated results, atomic number densities, data trends, sample input file(s) and related geometric plots, sensitivity studies, equipment sketches, etc.

Reviews

ANSI/ANS-8.19 requires that each documented nuclear criticality safety evaluation be independently reviewed to confirm the adequacy of the evaluation by personnel familiar with the physics of nuclear criticality, facility operations, and associated nuclear criticality safety practices. These independent reviews should be performed by senior CSEs familiar with the facility and practices to confirm adequacy of the evaluation.

Conclusion

This white paper presents guidance for acceptable format/content elements that comprise a documented nuclear criticality safety evaluation.