Integrating Nuclear Criticality Safety into Design

Introduction

One of the more important tasks of a criticality safety engineer (CSE) is early design evaluation of proposed fissile material processes and facilities. The overall evaluation and selection of structures, systems, and components used for nuclear criticality safety (NCS) control purposes for a complex facility is a highly interactive and iterative process. Appropriate interaction with diverse engineering disciplines (chemical, process, radiological, structural, fire, MC&A, etc.) should be *balanced* to assure the established NCS control scheme is optimal for safety and operations and can be reliably maintained. Engineered control functionality and parameter selection and constraints can also affect process efficiency and facility operational cost structure. Therefore it is important that NCS practitioners engage project / process engineering management throughout the design process. NCS evaluations performed during *design evolution*[1] should establish appropriate subcritical limits and controlled parameters. NCS control types used (e.g, passive, active and administrative) on said parameters must assure that an acceptable margin of subcriticality is maintained during normal operations, maintenance, and credible accident conditions.

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 to promote and benefit development of expertise is the integration of nuclear criticality safety into *design* of fissile material processes.

An over-arching requirement of the ANSI/ANS-8.1 national consensus standard is the expectation for process analyses; "*Before a new operation with fissionable materials is begun or before an existing operation is changed, it shall be determined that the entire operation will be subcritical under both normal and credible abnormal conditions.*" Effective communication and iteration with process design engineers is vital to ensuring this fundamental precept is met.

Both DOE and NRC regulatory agencies provide high-level expectations[2,3] to integrate NCS into design of fissile material process equipment or facilities. The primary objective of this white paper is to clarify and present a generic "best practice" scheme which will control design evolution *independent of design stage* and assure nuclear criticality safety remains integral to overall facility safety bases documentation.

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[1] In the context of this paper, *design evolution* and NCS integration with facility design basis should be maintained throughout pre-conceptual, conceptual, preliminary, and final design phases. The corresponding process hazards analysis (PHA) for these stages may be summarized as follows:

- Preconceptual - scoping analysis of potential hazards should be performed
- Conceptual - disciplined evaluation of the potential facility hazards must be performed
- Preliminary - confirm and add detail to the conceptual design stage analyses, including developing functional requirements and performance criteria for safety structures, systems and components (SSCs) or items relied on for safety (IROFS)
- Final - The completed safety analysis demonstrates the adequacy of the design from the safety prospective. Use final SSCs / IROFS only.

[2] DOE-STD-1189, Integration of Safety Into the Design Process, March 2008.

[3] 10CFR70.64, Requirements for new facilities or new processes at existing facilities, 65 FR 56231, Sept. 18, 2000.

General Discussion

NCS Design Criteria

To assure proper NCS design control, a key recommended practice is to establish internal nuclear [criticality] safety design criteria for the protection of employees, the public, the environment, and company facilities from the potential hazards associated with fissile material operations. Facility management should endorse internal nuclear safety design criteria.

Established design criteria and nuclear criticality safety reviews should be applicable to all new processes, facilities or equipment that process, store, transfer or otherwise handle fissile materials, and any change in processes, facilities or equipment which may have an impact on the established basis for nuclear criticality safety. Nuclear safety design criteria should acknowledge applicable industry acceptable guidance set forth in applicable ANSI/ANS-8 series national consensus standards. ANSI/ANS-8.1 (2014) process analysis requirement is key to design of fissile processes and facilities (refer above background discussion). The double-contingency principle further states, “process designs should incorporate sufficient factors of safety to require at least two unlikely, independent, and concurrent changes in process conditions before a criticality accident is possible.” Other design considerations might include hydrogenous content of firefighting materials and mitigation of inadvertent unsafe acts by individuals. NCS evaluations should also clearly establish subcritical limits and controls on measureable parameters applicable to the design for each fissile material process or facility. The NCS evaluations should be independently reviewed by cognizant and qualified NCS staff familiar with the design.

NCS Controls

A criticality safety control is an attribute or capability of a structure, system or component, or an administrative requirement that is necessary to maintain identified control parameter(s) within a specified range that assures safety for each process, or item of equipment containing fissile material. Criticality safety controls are characterized as passive, active, or administrative in nature. The goal of the CSE is to incorporate safety into the design by relying on passive and active controls to the extent feasible. While some administrative control will always be necessary, it is the goal of the design effort to make the system or operations as safe as feasible without relying on operator action.

Each criticality safety control should be capable of performing its safety function independent of any other control. Controls should be so specified that any single realistically credible control failure, while other process conditions are at their most reactive credible values, will result in the system remaining subcritical.

Design Iteration

Fundamentally, NCS control design during the maturation of a given fissile process incorporates five major process elements that are consistent with integrated safety management philosophies:

- Define the scope of the system/process to be evaluated
- Identify and analyze the associated criticality hazards
- Develop subcritical limits and parameter controls to assure safe operation
- Perform the design activity to implement the limits and controls
- Evaluate the design against credible abnormal conditions and feedback/iterate with design engineers and/or operators until the design assures subcriticality.

It is emphasized that the above process steps are iterative. In some cases, it may be sufficient to modify the design to ensure criticality safety. In other cases, it may be necessary to modify the design criteria or limits for the operation/system. Regardless of how the design, limits, and controls change, it is an expectation throughout the design life cycle to maintain integrated safety basis documentation alignment per internal configuration management practices to reflect current operations.

Design Considerations

NCS design considerations of a given fissile material process are numerous and depend on the scope of the process being evaluated. Hugh Paxton[4] outlined practical nuclear criticality safety [design] fundamentals as follows:

- Safety is an acceptable balance of risk against benefit; it is meaningless as a concept isolated from other goals. It follows that safety should be considered one of the goals of design and operation instead of something superposed.

- Accident prevention depends upon responsibility for safety implementation and commensurate authority at the supervisory level closest to operation, under the general direction of policies set by higher management. Attempts to control detail at a remote level are misguided.

- Other things being equal, simple convenient safety control provisions are more effective than complex or awkward arrangements. Similarly, “free” (e.g., no cost) contributions to safety should be nurtured (e.g., make proper operation convenient and maloperation inconvenient).

Additional high-level NCS design considerations include evaluation of credible *internal* events and credible *external* events such as seismic and natural phenomena events for the given facility. International safeguards may also be factored into the facility / process design. Finally, nuclear criticality safety design considerations should permit inspection, testing, and maintenance, to ensure established NCS controls remain available and reliable to perform their intended function.

Conclusion

Integrating nuclear criticality safety into design from pre-conceptual to final design stages can be effectively managed. Establishment of internal nuclear safety design criteria, a clear understanding of what constitutes a NCS control, and a well-defined iterative design control process can assure control reliability and availability. Proper interdisciplinary reviews and integration across technical disciplines involved in the initial fissile material process design can assure successful transition to operations. Development and revision control both NCS evaluations and integrated safety basis documentation must be systematically integrated into facility configuration management and integrated safety management practices.

Successful transition from design and construction to fissile material process operations must be grounded first through integration of NCS staff involvement in the design process itself. Facility design criteria Documented NCS evaluations must provide the basis for passive, active, and administrative controls on identified parameters. Identified NCS controls must be fully implemented into facility design and written operating procedures, and maintained per internal configuration management practices.

Supplemental Reading List

- ANSI/ANS-8.1 (2014), Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors, and sub tier ANSI/ANS-8 series national consensus standards.
- 10 CFR Part 70, Domestic Licensing of Special Nuclear Material [USNRC]
- 10 CFR 70.64 Requirements for new facilities or new processes at existing facilities.
- NUREG-1520, Standard Review Plan for the Review of a Licens Application for a Fuel Cycle Facility
- 10 CFR Part 830, Nuclear Safety Management [USDOE]

[4] “Criticality Control in Operations with Fissile Material,” HC Paxton, LASL report LA-3366, January 1966 [Revised 1972].

- INL/EXT-09-16907 Safeguards Guidance for Designers of Commercial Nuclear Facilities: International Nuclear Safeguards Requirements and Practices for Uranium Enrichment Plants, USDOE INL Report, October 2009.
- DOE Order 420.1B, *Facility Safety*
- DOE G 420.1-1, *Nonreactor Nuclear Safety Design Criteria and Explosive Safety Guide* for use with DOE O 420.1 Facility Safety
- DOE G 420.1-2, *Guide for the Mitigation of Natural Phenomena Hazards for DOE Nuclear Facilities and Nonnuclear Facilities*
- DOE G 421-1-2, *Implementation Guide for Use in Developing Documented Safety Analyses to Meet Subpart B of 10 CFR 830*
- DOE-STD-1020-2002, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*
- DOE-STD-1021-93, *Natural Phenomena Hazards Performance Categorization Guidelines for SSCs*
- DOE-STD-1189-2008, Integration of Safety into the Design Process
- DOE-STD-3009-94, Preparation Guide for U.S. DOE Nonreactor Nuclear Facility Safety Analysis