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Nuclear Criticality Safety in Practice

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Norann Calhoun

Nuclear Criticality Safety Division

Agenda

1. Requirements
2. How is Criticality Safety Practiced?
3. Criticality Safety Evaluations
4. Fissionable Material Operation Review
5. Procedures

Requirements

Flow of Requirements

High-Level Legal Requirement: 10 CFR 830, Section 830.204

- *Ensures that operations with fissionable material remain subcritical under all normal and credible abnormal conditions*
- *Identifies applicable nuclear criticality safety standards*
- *Describes how the program meets applicable nuclear criticality safety standards*

↓

Required by DOE Order 420.1C

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Captured in the LANL NCS Program Document, SD-130

(approved by DOE)

↓

Implemented for Each Facility (AP-522)

↓

Criticality Safety Evaluation Documents

ANSI / ANS Series 8 Categories

Administrative		Application Specific			Emergency
8.1	8.20	8.5	8.12	8.17	**8.3**
8.10	8.24	8.6	8.14	8.21	8.23
8.19	8.26	8.7	8.15	8.27	

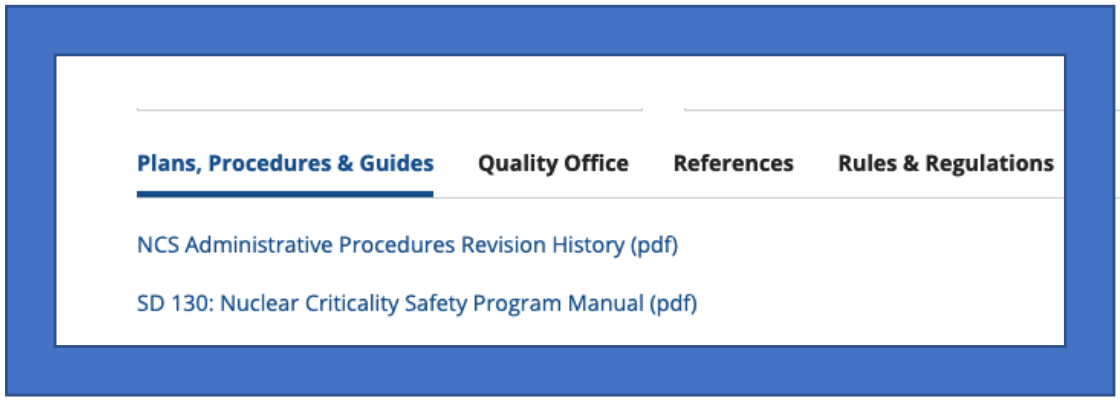
How Criticality Safety is Practiced?

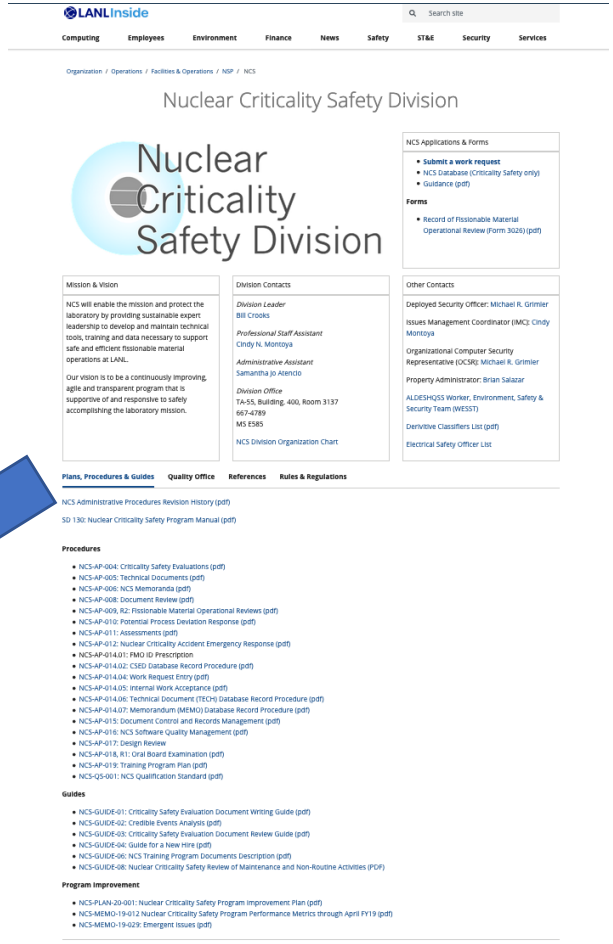
Where to Access References

SD130, DOE Order, DOE-STDs, LANL

Internal Page for Nuclear Criticality Safety Division:

https://int.lanl.gov/org/ddops/aldfo/nuclear-safety/nuclear-criticality-safety/index.shtml



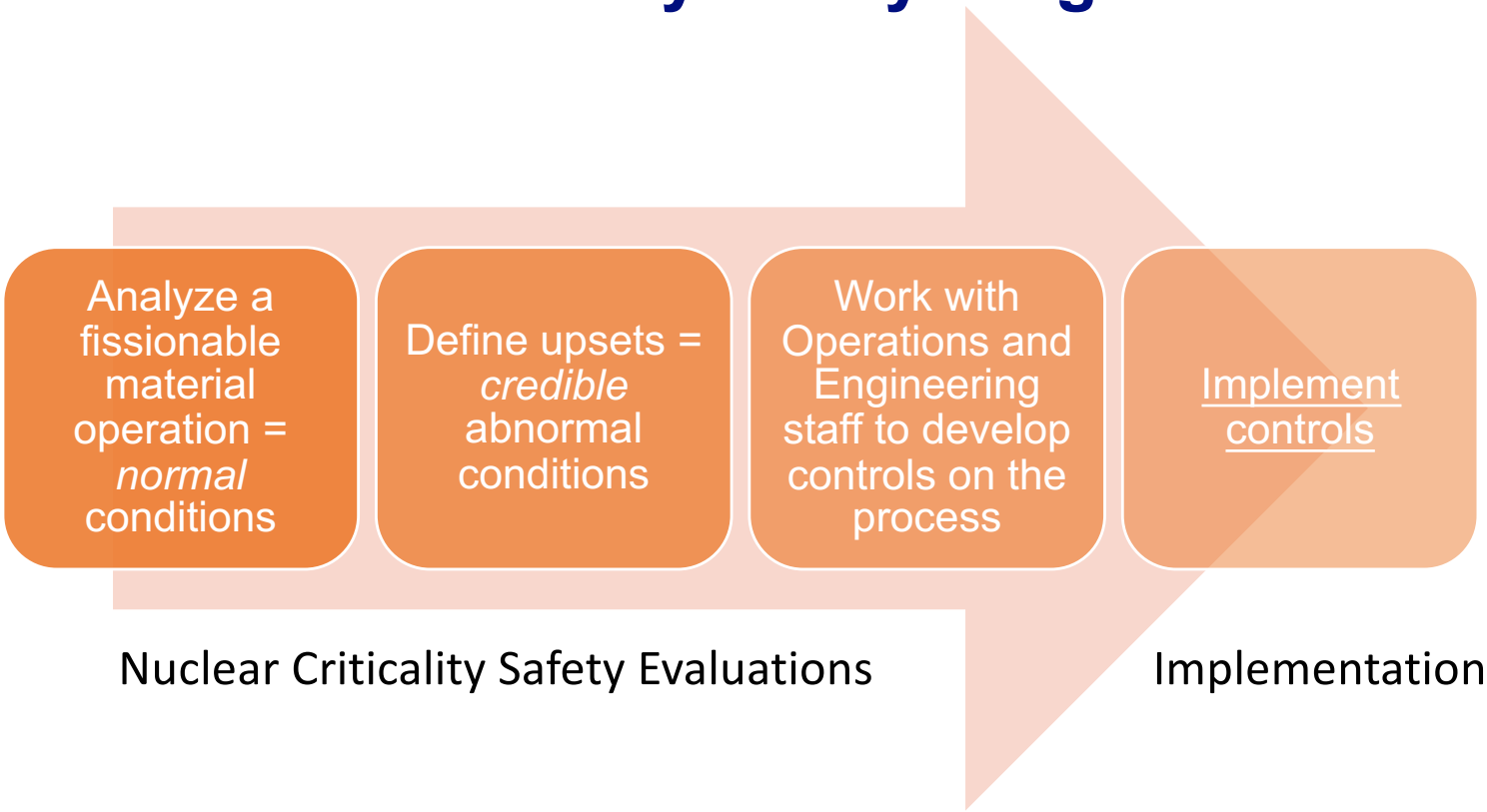


When is the Nuclear Criticality Safety Program Applied?

Table 1. Significant Quantity Thresholds	
Standard Conditions (as specified in ANSI/ANS-8.1-2014)	
Material	**Mass (grams)**
^{239}Pu	450
^{235}U	700
^{233}U	500
Combinations of nuclides	Use Sum of Ratios Method (Section 2.2.4) or ^{239}Pu Fissile Gram Equivalent Method (Section 2.2.5)
Pu ≥ 65% ^{238}Pu	5000
Pu ≥ 75% ^{242}Pu	5000*
Actinides not listed above	Per ANSI/ANS-8.15-2014, *Nuclear Criticality Safety Control of Selected Actinide Nuclides*, Single Parameter Limits, and/or consult with the NCS Division
Special Conditions	
Any Fissionable Material with a Special Condition (see Section 2.2.6)	Consult with the NCS Division

"The NCS Program applies to Laboratory employees, guests, visitors, and others who perform work at or for LANL (within contractual agreements of the Prime Contract and subcontracts) who participate in operations (e.g., storage, in processing, transport, etc.) in LANL-owned facilities which the amount of fissionable material may exceed, under normal or credible abnormal conditions, a significant quantity threshold as defined in Table 1." (SD130 Section 2.2)

How is the Nuclear Criticality Safety Program Practiced?



Criticality Safety Evaluations

Criticality Safety Evaluations

Purpose:

- Evaluate fissionable material operations in terms of criticality safety

- Document the completion of the ANSI/ANS 8.1 (*Nuclear Criticality Safety In Operations with Fissionable Material Outside Reactors*) requirement for Process Analysis (Section 4.1.2):

"Before a new operation with fissionable material is begun, or before an existing operation is changed, it shall be determined that the <u>entire process will be subcritical under both normal and credible abnormal conditions</u>. Normal and credible abnormal conditions shall be determined with input from operations or other knowledgeable individuals."

When is a Criticality Safety Evaluation Required?

Table 2. Nuclear Material Not Requiring Criticality Safety Evaluation or Controls	
Material	**Mass***
Pu- 239, 240, 241	≤ 1 g
Enriched U (U-233 or U-235)	≤ 1 g
Combinations of ^{239}Pu/^{235}U/^{233}U	≤ 1 g
Pu ≥ 65% ^{238}Pu	≤ 10 g
Pu ≥ 75% ^{242}Pu	≤ 10 g
Np-237	≤ 1 g
Am-241	≤ 1 g
Am-242m	≤ 0.1 g
Am-243	≤ 1 g
Cm-243	≤ 0.9 g
Cm-245	≤ 0.3 g
Cm-247	≤ 1 g
Cf-249	≤ 0.1 g
Cf-251	≤ 0.05 g
Cf-252	≤ 1 g
Depleted or Natural U	ANY

"Nuclear material movements or operations involving fissionable material quantities lower than the de minimis values in Table 2 do not require a formal criticality safety evaluation, even when the facility inventory exceeds the corresponding significant quantity threshold. This exception does not apply to the movement or storage of combinations or accumulations which total more than the corresponding Table 2 quantity." (SD130 Section 2.2.7)

Criticality Safety Evaluation Team

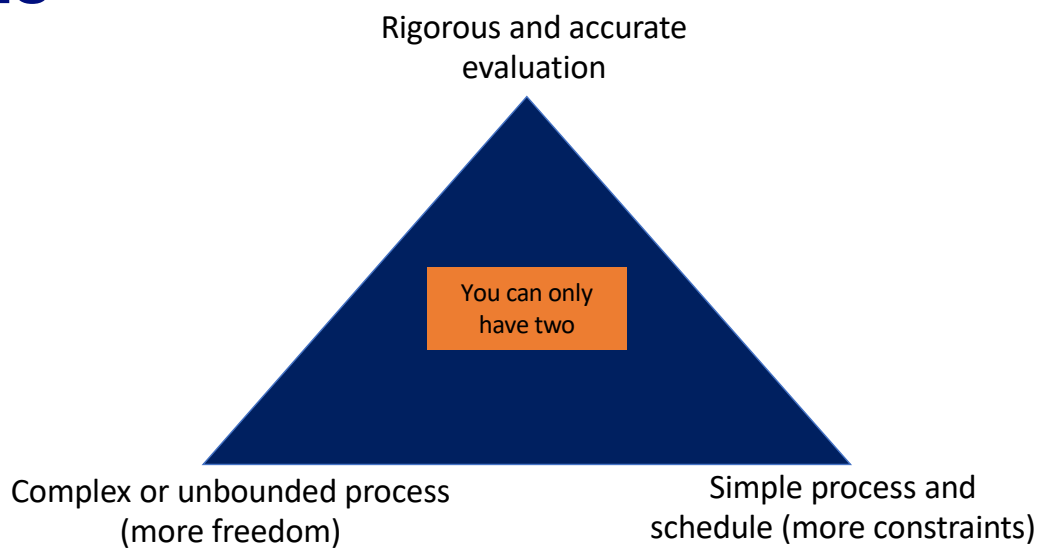
- Establish an evaluation team
  - Two Criticality Safety Engineers/Analysts
    - Author of the evaluation
    - Independent peer reviewer
  - Operations Responsible Supervisor
  - Operators
    - Knows more about the reality of operations
    - Involvement leads to better controls and better implementation
  - Additional Experts as needed
    - System engineers, seismic engineers, fire engineers, chemists, metallurgists, etc.
- Team works through evaluation steps (next slide)

Steps of a Criticality Safety Evaluation

1. Define the process normal conditions (team)
2. Define the credible abnormal conditions (team)
3. Analyze the normal and credible abnormal conditions (NCS engineer)
4. Develop an appropriate criticality safety control set (team)
5. Iterate as necessary on all four of these aspects until the process will remain subcritical when operated (team)
6. Document the evaluation (NCS engineer)
7. Review the evaluation (team)
8. Iterate as necessary (team)
9. Approve the evaluation (supervisor)
10. Implement the control set (team)

Criticality Safety Evaluations

- What operations want?
  - More freedom in operations
  - An evaluation as soon as possible
- What NCS engineers want?
  - A well defined, constrained process
  - Rigorous and accurate evaluation
- What is required?
  - Rigorous and accurate evaluation



- This means:
  - Complex process + rigor = Longer time to produce evaluation
  - Complex process + scheduling = Inaccurate evaluation (not enough detail)
  - Rigor + simplicity = Faster evaluation but more constraints

Process Description

General Location Description

- Physical boundary of the operation
- Separation distances
- Neighboring operations
- Facility Systems
- Fire suppression

Specific Location Description

- Facility systems (e.g. gases, water, electrical, waste etc.),
- Integrity of the structure,
- Major instruments, or machinery,
  - Those that significantly affect criticality safety parameters
- Instruments and tooling not of substantial construction
  - Can be described generally (e.g. hand tools)

Process Description

Material Form, Type, and Handling

- How is material introduced/manipulated/removed
- Where does it come from?
- Where does it go?
- Containers or holders
- Physical and/or Chemical form of fissionable material, and potential form changes

Operations

- Details of the primary activity
- Starting Physical, as well as chemical form, of the fissionable material,
  - Soluble and 'non-soluble'
- Other Materials that may affect MAGIC MERV
  - (e.g., epoxy, aluminum, copper, stainless steel, etc.),
- Any changes of physical/chemical form of material due to processing

Maintenance, Housekeeping, and Holdup

Hazard Analysis

Purpose

- Provide a systematic process by which to identify process conditions that will subsequently be analyzed in a Criticality Safety Evaluation Document (CSED).

Goal

- Document the completion of the ANSI/ANS 8.1 (*Nuclear Criticality Safety In Operations with Fissionable Material Outside Reactors*) requirement for Process Analysis (Section 4.1.2):

"Before a new operation with fissionable material is begun, or before an existing operation is changed, it shall be determined that the <u>entire process will be subcritical under both normal and credible abnormal conditions</u>. Normal and credible abnormal conditions shall be determined with input from operations or other knowledgeable individuals."

Hazard Analysis

- Failure space vs success space

- Review the boundaries of the fissionable material operation.
- Review fissionable material operation(s) directly adjacent to the location of concern.
- Review all of the activities to be performed at the location:
- Review the equipment/supplies to be used
- Review the adjacent activities and whether they could interact with the subject location

- Identify **credible** abnormal conditions for each activity and determine their credibility. Identify the NCS parameters would be affected (e.g., mass, interaction, etc.)

What are Credible Abnormal Conditions?

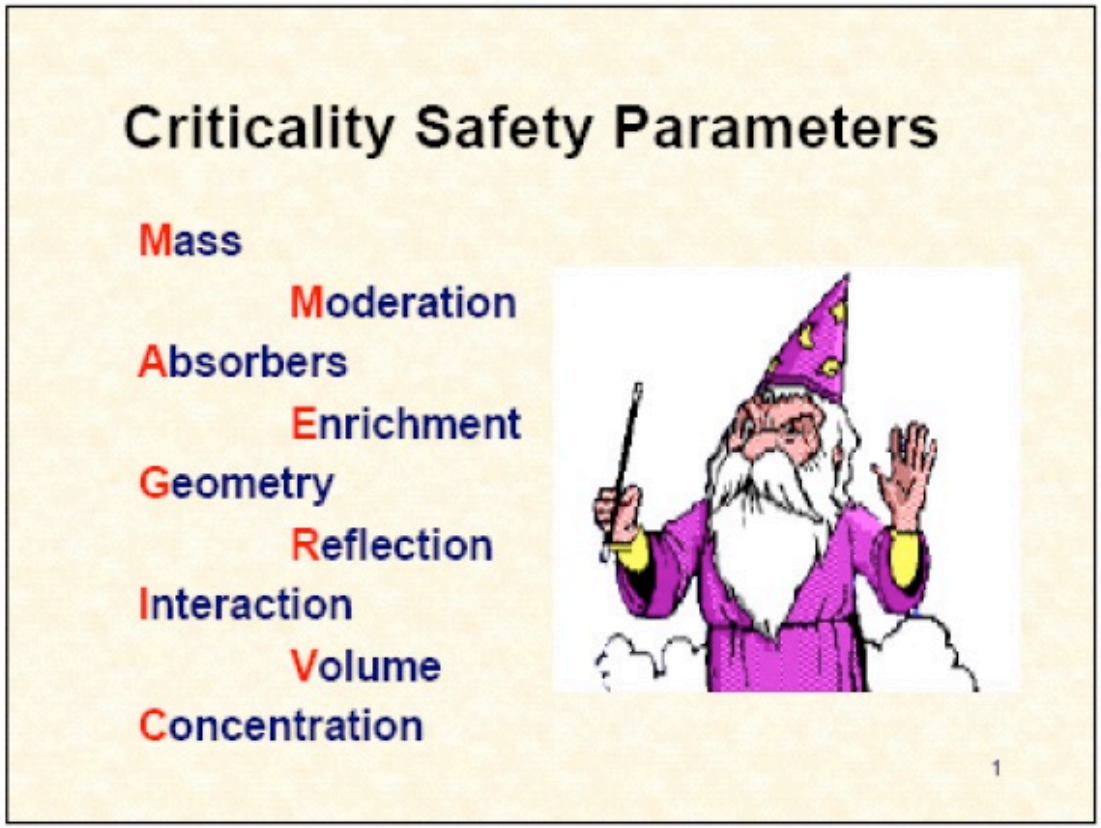
- Abnormal Conditions are everything that is credible to occur outside the normal process.

- DOE-STD-3007-2007 defines credible as:
  - "*the attribute of being <u>believable on the basis of commonly acceptable engineering judgment</u>. Due to the general lack of statistically reliable data, assigning numerical probabilities to events is not usually justifiable and when used should be backed up with references.*"

- Is this credible?
  - Has it happened before?
  - Is it reasonable to occur?
  - Justify why an event is credible or not credible

MAGIC MERV

Implement controls / limits / requirements on parameters …



Introduce materials with large **Absorption** cross-section

Limit fissile M**ass**

Only use tanks with favorable **Geometry**

Increase spacing between tanks to reduce **Interaction**

Limit the fissile **Concentration** of the solution

Avoid optimal **Moderation**

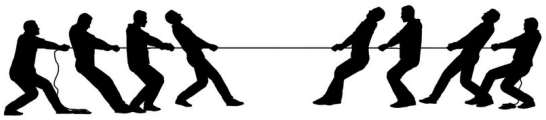
Decrease **Enrichment**

Limit **Reflection**

Control **Volume** of solution

Tips and Tricks

- Iterate and review the process description as a team
  - Without ALL relevant information, it is impossible to evaluate a process properly
  - Requires regular, ***effective*** communication
- The complexity of an evaluation is inversely proportional to the level of process constraints
  - Constraints on the process translate directly into constraints on the relevant parameters and ranges of the parameters
  - There is a natural tension here between operations and criticality safety Operations wants freedom to operate, NCS wants constraints



Fissionable Material Operation Review

Where to Access More References

Annual Review Form, Request Database
Internal Page for Nuclear Criticality Safety Division:

https://int.lanl.gov/org/ddops/aldfo/nuclear-safety/nuclear-criticality-safety/index.shtml

Fissionable Material Operation Reviews (FMORs)

Purpose

- Ensure fissionable material operations (FMOs) are adhering to their approved procedures, criticality safety requirements and the process conditions remain within the envelope considered by the operation's criticality safety evaluation.

- Document the completion of the ANSI/ANS 8.1 (*Nuclear Criticality Safety In Operations with Fissionable Material Outside Reactors*) requirement for Process Analysis (Section 4.1.2):

"Before a new operation with fissionable material is begun, or before an existing operation is changed, it shall be determined that the <u>entire process will be subcritical under both normal and credible abnormal conditions</u>. Normal and credible abnormal conditions shall be determined with input from operations or other knowledgeable individuals."

Fissionable Material Operation Reviews (FMORs)

- Team: Operational Responsible Supervisor (ORS), Criticality Safety Officer (CSO), Criticality Safety Engineer / Analyst (CSA), Operators
- Review: criticality safety evaluation, operating environment, equipment, support systems, process description, criticality safety controls, procedures

- If practical, the review should include
  - Field observation of the activity being performed.
  - Recommendations
  - Noteworthy Practices
  - Detailed notes

Administrative Review – What Is Reviewed?

FMO ID:	Date of Review:

Part 1: Administrative Review

Documents Reviewed	
Procedures	
Evaluations:	
Posting(s):	
Emergent Issues Memo:	
Previous Events/Corrective Actions:	

Administrative Review – What Is Reviewed?

Process, Procedure, Posting	Yes	No	NA	Comments
1. Are the activities described in the criticality safety evaluation document(s) consistent with those described in the operating procedure(s)?				
2. Have the procedure(s) been changed since the last operational review? If yes, provide the date of the NCS review.				
3. Have the posting(s) been revised since the last operational review? If yes, provide the date of the NCS review.				
Criticality Safety Controls				
4. Are the administrative criticality safety controls properly implemented in the operating procedure(s)/postings?				
5. Is the wording of the criticality safety posting(s) consistent with the wording in the operating procedure(s)?				
6. Are the engineered criticality safety controls properly implemented? If yes, provide evidence from the configuration management system (e.g., equipment tag or other unique identifier) or alternative.				
Previous Corrective Actions, Issues, Recommendations				
7. Have previous corrective actions been addressed?				
8. Have recommendations from previous operational reviews been addressed?				
9. Do any concerns exist regarding emerging issues pertaining to this operation? (Refer to the most current Emergent Issues memo.)				

Field Review - What information is gathered?

FMO ID:	Date of Review:

Part 2: Field Review

	Yes	No	NA	Comments
10. Is the process, as demonstrated/described by operations personnel, adequately documented in the criticality safety evaluation document(s)?				
11. Are the activities stated in the criticality safety evaluation document(s) still correct and representative of operational conditions (e.g., staging)?				
12. Is the "as-found" configuration consistent with expectations established in the operating procedure(s) and criticality safety evaluation document(s)?				
13. Is the process being performed in a location identified in the criticality safety evaluation document(s)?				
14. Are the operating procedures available at the location in accordance with the facility requirements?				
15. Are criticality safety postings available in accordance with the facility requirements?				
16. Is the "as-found" inventory compliant with the location's material limits and additional restrictions?				
17. Are the dimensions, volumes, or other parameters associated with the engineered criticality safety controls compliant with the criticality safety evaluation document(s)?				
18. With input from the ORS, do operations personnel understand the criticality safety controls for the process?				

Field Review – What information is gathered?

document(s)?				
18. With input from the ORS, do operations personnel understand the criticality safety controls for the process?	☐	☐	☐	
19. Have any support systems for the operation changed?	☐	☐	☐	
20. Has any equipment not discussed in the criticality safety evaluation document(s) been added to the operation (e.g., shielding)?	☐	☐	☐	
21. Has any equipment required by the criticality safety evaluation document(s) been removed from the operation?	☐	☐	☐	
22. Is any fixed facility equipment in close proximity to the operation (e.g., large water tanks/lines, heat exchangers with significant coolant volumes, sinks) not documented in the criticality safety evaluation document(s)?	☐	☐	☐	
23. Is there any out-of-service equipment within or nearby the operation that may affect the criticality safety of the operation?	☐	☐	☐	
24. Since the last operational review, has any equipment been modified in a way that affects the criticality safety evaluation?	☐	☐	☐	

Procedure Reviews

Procedure Review – Why?

Purpose:

- Verify that the process description in CSED and/or posted criticality safety limits bounds the work described in the procedure,
- Verify that the administrative controls and limits significant to the nuclear criticality safety of the operation are appropriately incorporated into the document.
- For documents that are not operating procedures or postings, verify that administrative requirements significant to nuclear criticality safety are appropriately incorporated into the document with respect to the requirements in SD130 and local facility criticality safety program implementing procedures.

Procedure Review - Requirements

Excerpts from ANSI/ANS-8.19, Section 7

- 7.1 The purpose of written operating procedures is to facilitate and to document the safe and efficient conduct of the operation. Procedures should be organized for convenient use by operators and be conveniently available. They should be free of extraneous material.

- 7.2 Procedures shall include those controls and limits significant to the nuclear criticality safety of the operation. Procedures should be written such that no single, inadvertent departure from a procedure can cause a nuclear criticality accident.

- 7.3 Supplementing and revising procedures as improvements become desirable shall be facilitated.

Procedure Review – When is it needed?

- Is this a new procedure or a non-Editorial Change (see Note below) to a procedure for a process that requires a CSED?
- Is this a maintenance procedure involving, or potentially involving, solutions of fissile material (e.g., liquid hold-up in piping)?
- Is this a maintenance or modification procedure affecting operations or processes that require a Criticality Safety Evaluation?
- Is this a maintenance or modification procedure to a facility or system that could potentially impact the introduction of moderator (e.g., water, oil) into a process that requires a Criticality Safety Evaluation?
- Does this procedure need Nuclear Criticality Safety review in the judgment of the Operational Responsible Supervisor?

Common Issues in Procedures

- Ambiguous or vague steps
- Technically inaccurate information
- Mismatch between procedural steps and the order in which tasks need to be performed
- Critical information that is missing
- Lack of graphics for complex steps
- References to other procedures
- More than one instruction in a step
- Overuse of critical steps

Questions?

Homework

- When is a Criticality Safety Evaluation Required?
- What is the difference between the normal and credible abnormal conditions?
- Who is responsible for defining the normal and credible abnormal conditions?
- What are 3 common issues in operating procedures?