Defense in Depth for Dry Cask Storage Systems (DCSS)

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U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Overview for Risk Informing DCSS

1. Collect Available Risk Information
2. Define Defense-in-Depth (DID) for DCSS

Completed and Updated

Goal for Today

3. Define Decision Metrics and Acceptable Risk Criteria DCSS
4. Develop the Preliminary Risk-Informing Approach for DCSS

Open to Discussion and Input

5. Apply Preliminary Risk-Informing Approach to a Pilot
6. Finalize Risk-Informing Approach
7. Develop Staff Training

Overview of Presentation

- Background on DiD
- Proposed Definition for DiD
- Example of DiD for DCSS

- Thoughts on a Possible Risk Assessment Framework
- Previously Proposed Metrics

- Presentation Review
- Q&A

Recommendation to Define DiD

NUREG-2150, "A Proposed Risk Management Regulatory Framework":

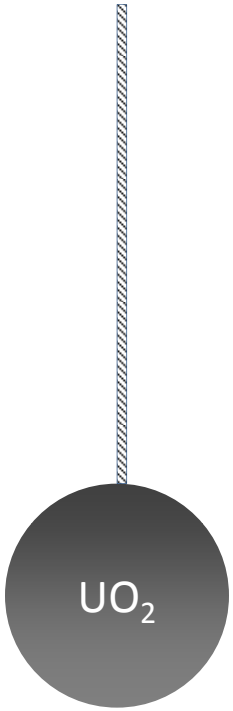
Recommendation S-R-2: As part of the implementation of the proposed risk management regulatory framework, the **NRC should more consistently consider the concept of defense-in-depth explicitly and evaluate its proper use in the SNF storage regulatory program**. The NRC should also improve appropriate parts of staff training to make this concept a central part of such training.

NRC Definition of DiD

The NRC Web site Glossary defines defense-in-depth as: "An approach to designing and operating nuclear facilities that prevents and mitigates accidents that release radiation or hazardous materials. **The key is creating multiple independent** and redundant **layers of defense** to compensate for potential human and mechanical failures so that **no single layer, no matter how robust, is exclusively relied upon**. Defense-in-depth includes the use of access controls, physical barriers, redundant and diverse key safety functions, and emergency response measures."

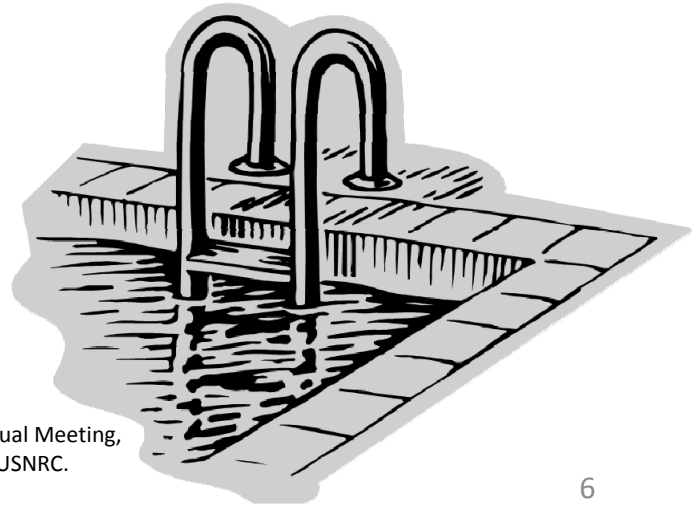
DiD and Margin

A mass of enriched uranium is hanging by a thread over a pool of water.
$K_{eff} < 1$ out of the pool.



If the thread were replaced by a steel cable, we increase margin but have not added a layer of DiD.

Adding a net between the UO_2 and the water would be adding DiD.



DiD and Margin - Fukushima

The Fukushima Daiichi disaster is an example of margin without DiD. The design basis tsunami was 5.7 meters.

The constructed sea wall was 10 meters high, but the tsunami was 14 to 15 meters high.

Not having the diesel generators in the basement would have been an example of DiD against a flooding event.

http://carnegieendowment.org/files/fukushima.pdf

DiD Described in IAEA (INSAG-10)

Levels of DiD	Objective	Essential means
Level 1	Prevention of abnormal operation and failures	Conservative design and high quality and construction and operation
Level 2	Control of abnormal operation and detection of failures	Control, limiting and protection systems and other surveillance features
Level 3	Control of accidents within the design basis	Engineered safety features and accident procedures **[Prevent Core Damage]**
Level 4	Control of severe plant conditions, including prevention of accident progression and mitigation of the consequences of severe accidents	Complementary measures and accident management **[Prevent Release]**
Level 5	Mitigation of radiological consequences of significant releases of radioactive materials	Off-site emergency response

http://www-pub.iaea.org/MTCD/publications/PDF/Pub1013e_web.pdf

Proposed Definition of DiD

Defense-in-depth (DiD) for interim dry storage consists of element(s) within multiple, independent layers of defense to achieve the three principle functions of a DCSS.

1) Maintain sub-criticality
2) Prevent radiation exposure from exceeding regulatory limits
3) Prevent release of radioactive materials from exceeding regulatory limits

Engineered, programmatic, and mitigating controls form the three layers of DiD for interim dry storage.

Proposed Definition of DiD

Three Safety Functions:

- Maintain Sub-Criticality
- Prevent Radiation Exposure from Exceeding Regulatory Limits
- Prevent Release of Radioactive Materials from Exceeding Regulatory Limits

Three Phases of Operation:

- Loading and Transfer
- Storage
- Transfer and Unloading

Three Layers of Defense:

- Engineered Controls
- Programmatic Controls
- Mitigating Controls

Dependent on DCSS Design

Example of DiD

Maintaining Sub-Criticality during Storage

DiD Level 1 Engineered Controls		
Element	**Description**	**Basis**
Siting	DCSS siting may minimize the potential for flooding	10 CFR 72.124(a)
Confinement boundary	Prevents moderator intrusion	10 CFR 72.124(a) 10 CFR 72.236(c)
Neutron absorbers	Neutron absorbers receive 75 – 90% for the amount of B^{10} present in the absorber	10 CFR 72.124(a) 10 CFR 72.124(b) 10 CFR 72.236(c)
Fuel Assembly Basket	Maintains analyzed fuel geometry	10 CFR 72.124(a) 10 CFR 72.124(b) 10 CFR 72.236(c)
Cladding	Maintains analyzed fuel geometry	10 CFR 72.124(a) 10 CFR 72.124(b) 10 CFR 72.236(c)
Fuel burn-up credit is limited	Burn-up credit is limited during the criticality analysis	10 CFR 72.124(a) 10 CFR 72.236(c)

DiD Level 2 Programmatic Controls		
Element	**Description**	**Basis**
Monitoring and Maintenance	Active pressure monitoring systems measure the pressure between seals of bolted cask systems	10 CFR 72.122(h)(4)
	Visual inspections and corrective action programs for the bolted cask identity and correct general corrosion degradation.	10 CFR 72.122(h)(4)
	Aging Management Programs identify and correct degradation of the cask/canister	10 CFR 72.122(h)(4)
DOE Cask Demonstration Program	The DOE cask demonstration program will identify any unexpected degradation to the neutron absorbers	10 CFR 72.124(a)
DOE Cask Demonstration Program	The DOE cask demonstration program will identify any unexpected degradation to the basket	10 CFR 72.124(b)
Site boundary monitoring	Site boundary monitoring may indicate an increase dose rate if configuration of the basket occurred	10 CFR 72.124(c)
Cask Demonstration Program	The DOE cask demonstration program will identify any unexpected degradation to the fuel cladding	10 CFR 72.124(b)
Site boundary monitoring	Site boundary monitoring may indicate an increase dose rate if configuration of the fuel occurred	10 CFR 72.124(c)

Did Level 3 Mitigating Controls		
Element	**Description**	**Basis**
Unloading or Transport	If siting is determined to be unacceptable the DSCC can be unloaded or moved	10 CFR 72.124(a)
Replace the seal	Unload the cask into the spent fuel pool and replace the seal	10 CFR 72.124(a) 10 CFR 72.236(c)
Restore confinement	Depending on the conditions, the assemblies may be returned to the pool and repackaged, or the current confinement may be repackaged	
Ensure moderator intrusion is not credible	Perform criticality analysis given new B^{10} credit Perform risk assessment of criticality during storage Unloading Repackaging	10 CFR 72.124(a) 10 CFR 72.124(b) 10 CFR 72.236(c)
Ensure moderator intrusion is not credible	Perform criticality analysis given new fuel geometry Perform risk assessment given new fuel geometry Unloading Repackaging	10 CFR 72.124(a) 10 CFR 72.124(b) 10 CFR 72.236(c)
Ensure moderator intrusion is not credible	Perform criticality analysis given new fuel geometry Perform risk assessment given new fuel geometry Unloading Repackaging	10 CFR 72.124(a) 10 CFR 72.124(b) 10 CFR 72.236(c)
Ensure moderator intrusion is not credible	Perform criticality analysis given correct fuel burn-up Perform risk assessment of criticality during storage Unloading Repackaging	10 CFR 72.124(a) 10 CFR 72.236(c)

Maintaining Sub-Criticality during Storage

DiD Level 1 - Engineered Controls (High-Level, Simplified View)		
Element of Defense	**Description**	**Basis**
Siting	ISFSI siting may minimize the potential for flooding	72.124(a)
Confinement boundary	Prevents moderator intrusion	72.124(a) 72.236(c)
Neutron absorbers	Neutron absorbers receive 75 – 90% credit for the amount of B^{10} present in the absorber	72.124(a) 72.124(b) 72.236(c)

Maintaining Sub-Criticality during Storage

	DiD Level 2 - Programmatic Controls (High-Level, Simplified View)		
Level 2 Element	**Element of Defense**	**Description**	**Basis**
Siting			
Confinement boundary	Monitoring and Maintenance	Active pressure monitoring systems measure the pressure between seals of bolted cask systems	72.122(h)(4)
		Visual inspections and corrective action programs for the bolted cask identify and correct general corrosion degradation.	72.122(h)(4)
		Aging Management Programs identify and correct degradation of the cask/canister	72.122(h)(4)
Neutron absorbers			

Maintaining Sub-Criticality during Storage

	DiD Level 3 - Mitigating Controls (High-Level, Simplified View)		
Level 3 Element	**Element of Defense**	**Description**	**Basis**
Siting	Unloading or Transport	If siting is determined to be unacceptable the DCSS can be unloaded or moved	72.124(a)
Confinement boundary	Replace the seal	Unload the cask into the spent fuel pool and replace the seal	72.124(a) 72.236(c)
	Restore confinement	Depending on the conditions, the assemblies may be returned to the pool and repackaged, or the current confinement may be repackaged or repaired	
Neutron absorbers	Ensure moderator intrusion is not credible	Perform criticality analysis given new B^{10} credit Perform risk assessment of criticality during storage Unloading Repackaging	72.124(a) 72.124(b) 72.236(c)

Possible Risk Assessment Approach

- Operational Phase [Storage]
  - Safety Function [Confinement]
    - Layer of Defense [Engineered]
      - Element [Primary Confinement]
        - Sub-element [Lid-to-Shell Weld]
          - Data

1) **Expert Opinion**
2) **Operating Experience**
3) **PRAs/HRAs**

Failure Mechanism	Failure Frequency	Failure Detection	Consequence	Risk
Delayed Hydrogen Cracking	L	H	L	L

Possible Risk Assessment Approach [with Data]

- System Vendor [NuWaste Inc.]
- System Name [NuStor-100]
- System Type [Canister]
- System Orientation [Vertical]
- Confinement Material [Carbon Steel]
- System Elevation [Above Ground]
- Sub-element [Lid-to-Shell Weld]

1) **Expert Opinion**
2) **Operating Experience**
3) **PRAs/HRAs**

Failure Mechanism	Failure Frequency	Failure Detection	Consequence	Risk
Delayed Hydrogen Cracking	Number / cask	H	L	L

Potential Risk Assessment Approach

1) Qualitative / Semi-Quantitative
2) Flexible to become progressively more quantitative as our knowledge base grows.

Question: Can user group data inform the risk assessment approach?

May need specific quantitative analyses:

1) Stress Corrosion Cracking
2) Canister Examination Frequencies
3) Risk of Unloading a Canister

Metrics

We are in listening mode, not decision mode.

What are appropriate metrics?

- Fatalities
- Public-dose
- Worker-dose
- Unacceptable degradation
- Tech spec violations
- Regulatory violations
- Probability of canister breach

Risk-Informed Decision making for Nuclear Material (RDIM) and Waste Applications

The RIDM guidance document, published in 2008, was a high-level, document providing guidance to NMSS/FMSE staff on appropriate risk-informed decisions for nuclear material and waste.

The document suggested quantitative health guidelines (QHGs) for acute and latent fatality and injury for both individual members of the public and workers.

Risk-Informed Decision making for Nuclear Material and Waste Applications, Rev. 1 2008

Metrics - RDIM

- Public individual *risk* of acute fatality (QHG 1) is negligible if ≤ $5x10^{-7}$ /yr;
- Public individual *risk* of latent cancer fatality (QHG 2) is negligible if ≤ $2x10^{-6}$ /yr or 4 mrem/year;
- Public individual *risk* of serious injury (QHG 3) is negligible if ≤ $1x10^{-6}$ /yr;
- Worker individual *risk* of acute fatality (QHG 4) is negligible if ≤ $1x10^{-6}$ /yr;
- Worker individual *risk* of latent cancer fatality (QHG 5) is negligible if ≤ $1x10^{-5}$ /yr or 25 mrem/year; and
- Worker individual *risk* of serious injury (QHG 6) is negligible if ≤ $5x10^{-6}$ /yr.

Metrics - PRAs

Risk of Latent Cancer Fatalities

Storage Phase	EPRI-1009691 TN-32, bolted lid, (PWR)	NUREG-1864 HI-STORM 100, welded lid, (BWR)
Cask Loading/Handling	6.3×10^{-14}	1.77×10^{-12}
Cask Transfer	3.3×10^{-13}	≈ 0
Cask Storage	1.7×10^{-13}	3.23×10^{-14}
Sum of First Year	5.6×10^{-13}	1.8×10^{-12}

There are orders of magnitude between the recommended NMSS qualitative health goals and the risks indicated in the pilot PRAs.

The PRAs are for a single DCSS

1) Fabricated and loaded as described in the SAR
2) No materials degradation

Presentation Review

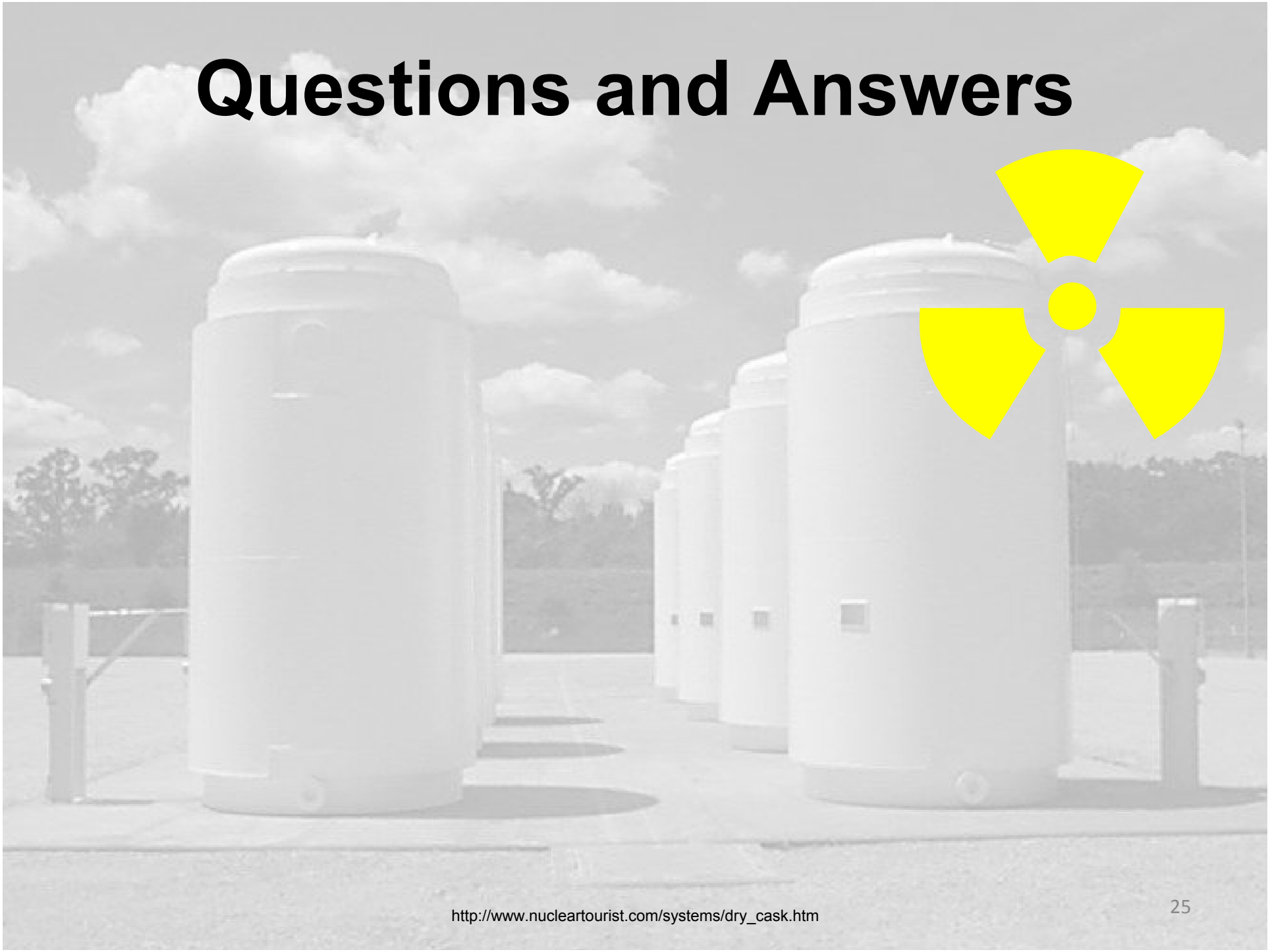
- General Description of DiD
- Working definition of DiD for dry storage
- Example of how DiD may be considered
- Potential risk-assessment framework for Part 72 activities
- Presented previously documented proposed risk metrics and insights

Presentation Review

- Defined DID
- 3 phases of operation
- 3 safety functions
- 3 levels of DiD

- Presented a preliminary, risk-assessment framework for Part 72 activities
- Presented previously documented proposed risk metrics and insights

Questions and Answers



http://www.nucleartourist.com/systems/dry_cask.htm