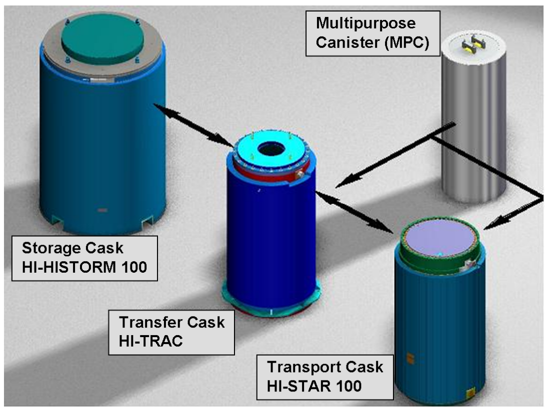
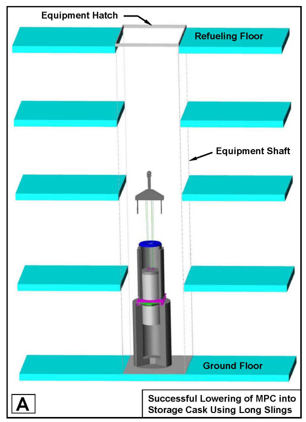
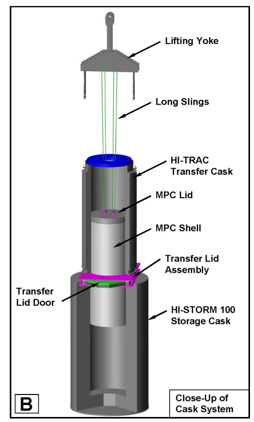
Qualitative Human Reliability Analysis of Dry Cask Storage Operations

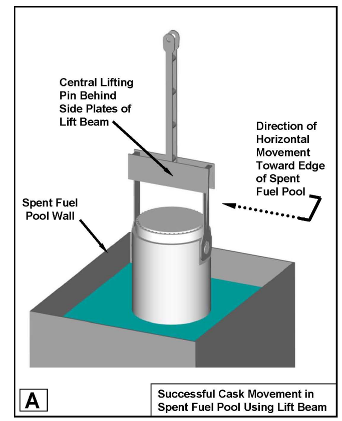
International Topical Meeting on Probabilistic Safety Assessment and Analysis (PSA 2011)

March 2011









SAND2011-xxxx

Jeffrey D. Brewer, Sandia National Laboratories

Stacey M. L. Hendrickson, Sandia National Laboratories

Susan E. Cooper, United States Nuclear Regulatory Commission

This work was funded by the U.S. Nuclear Regulatory Commission at Sandia National Laboratories. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Sandia National Laboratories

Overview

- Introduction
- Analysis Approach
- Cask Drop Scenarios
- Human Performance Vulnerabilities
- Mitigative Strategies
- Conclusion

Introduction

- Need for application of HRA to the assessment of risk of a cask drop in dry cask storage operations due to human performance
  - Increased opportunity for catastrophic drop of loaded fuel cask as more dry cask storage operations (DCSOs) are being conducted
  - Human involvement within DCSOs and the potential to lead to a cask drop is not well understood
- A Technique for Human Event Analysis (ATHEANA)
  - proposed for use in diverse applications outside the control room due to its particular approach for systematically examining the dynamic, contextual conditions influencing human performance

Focus of Study

- Application of ATHEANA to prospectively examine how unsafe actions may contribute to a cask drop and generate ideas for avoiding cask drops
- Develop cask drop scenarios including unsafe actions and error-forcing contexts
- Develop human performance vulnerabilities
- Provide insights into what can ‘set-up’ personnel for HFEs involving cask drops.
- Develop illustrative guidance for avoiding or mitigating human performance vulnerabilities

Analysis Approach

- Gathered information
  - Subject matter experts
  - Reviewed reports and previous analyses
- Generated cask drop scenarios
  - Hypothetical scenarios describing how and why cask drops may occur given current understandings of human performance
  - Identified unsafe actions, human failure events, contexts
- Generated recommendations for avoiding or mitigating cask drop human failure events

A new taxonomy of operations to facilitate examination of human performance ➡

Phases of Dry Cask Storage Operations

One proposed structure (NRC NUREG-1864)

1) **Handling**
   - cask lowered into the pit
   - MPC in storage cask is moved out of secondary containment

2) **Transfer**
   - as MPC in storage cask passes 2^{ndary} containment
   - storage cask on ISFSI pad

3) **Storage**
   - monitoring & surveillance for 20 years or more

Another proposed structure (EPRI report # 1009691)

1) **Cask Loading**
   - 1^{st} fuel assembly into cask
   - cask drained, dried, inerted & sealed

2) **Cask Transfer**
   - placement of cask on transport vehicle
   - storage cask on ISFSI pad

3) **Cask Storage & Monitoring**
   - monitoring & surveillance for 20 years or more

Previous analyses did not focus on human performance contexts in which human failure events may occur

CA ⟹ particularly helpful for consequence analysis

Phases used in this analysis

1) **Fuel Load Planning**
   - generate fuel move plan
   - dependent upon previous outages

2) **Cask ops. pers. & equip. prep.**
   - training, staffing, inspection, test, maintenance,

3) **Cask prep. & positioning**
   - cask brought into plant
   - cask into loading pit

4) **Cask Loading (CA)**
   - 1^{st} fuel assembly into cask
   - cask drained, dried, inerted & sealed

5) **Loaded cask transfer w/in structure (CA)**
   - move from cask prep. area
   - cask coupled to transporter

6) **Loaded cask transfer outside structure (CA)**
   - cask coupled to transporter
   - cask emplaced at ISFSI pad

7) **Loaded Cask Storage & Monitoring (CA)**
   - ends when cask contents are moved off-site (20++ years)

Cask Types

- HI-STORM 100 System at Mark I Boiling Water Reactor
  - Uses the canister as the confinement boundary and uses a separate structure to provide shielding and thermal protection
  - Loaded canister must be transferred to the storage structure/container
- Transnuclear (TN)-40 at Pressurized Water Reactor
  - Uses a directly loaded, bolted-closure storage cask to provide confinement, shielding, and thermal protection
  - May be placed directly on the independent spent fuel storage installation

Cask Drop Scenarios

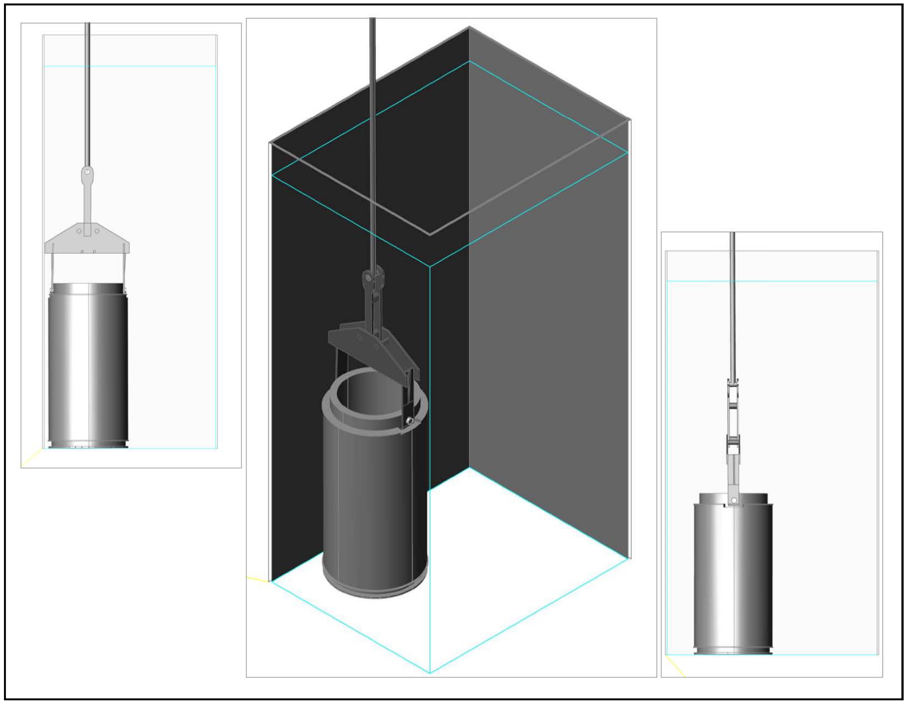
- Scenarios constructed within NUREG-CR/7016 for the following movements:
  - Cask movement from spent fuel pool to preparation area (HI-STORM 100 & TN-40)
  - Cask movement from preparation area to transfer pit (HI-STORM 100)
  - Multipurpose canister (MPC) movement from transfer cask down to storage cask (HI-STORM 100)
- Scenarios constructed within NUREG-CR/7017 for additional movements
  - Before and during fuel loading
  - During MPC and transfer cask sealing operations
  - During storage cask movement from the transfer pit to the ISFSI pad
  - During cask monitoring and storage at the ISFSI

Cask Hang–Up and Drop
(example scenario)

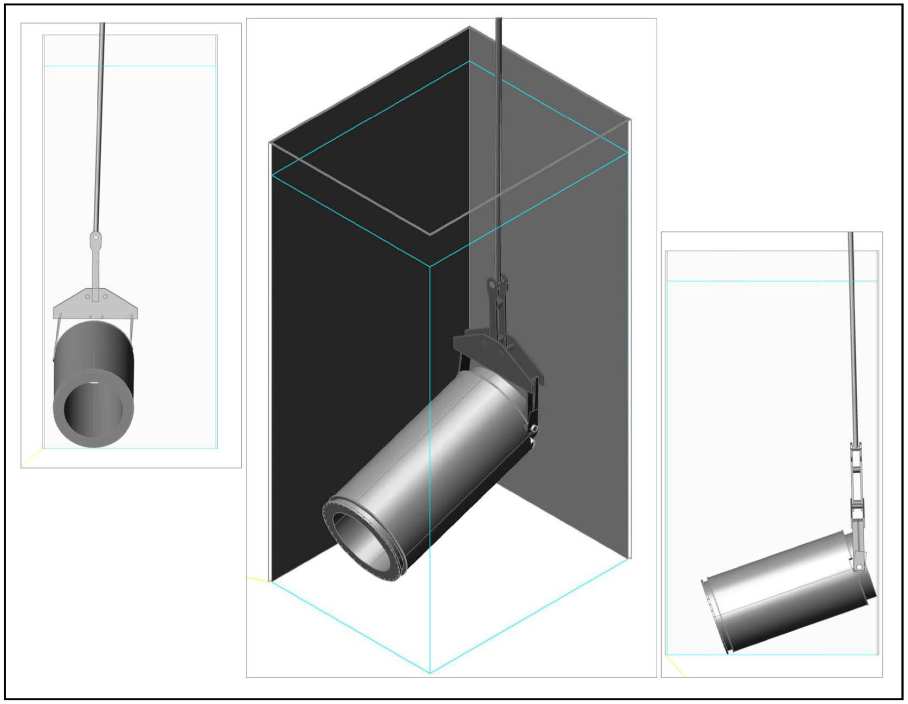
<u>4th Phase of Operation</u>: Cask loading

<u>1st HFE Scenario Group</u>: Cask movement from spent fuel pool to preparation area (HI-STORM 100 System at a Mark I BWR)

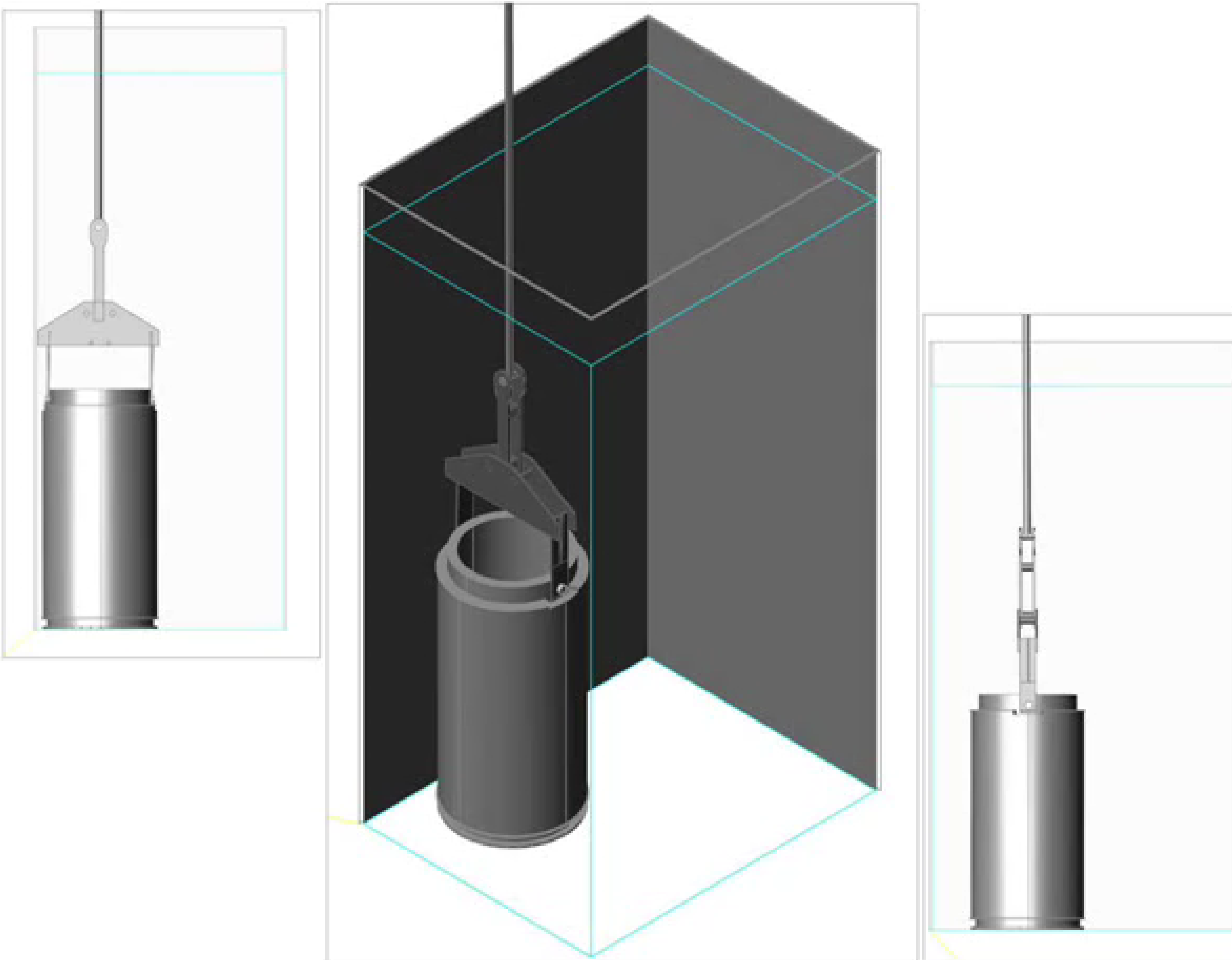
<u>3rd Scenario</u>: Crane operator hangs-up cask on structure in the spent fuel pool, crane is overstressed, cable is broken & cask is dropped



Before Loading



After Drop



Human Performance Vulnerabilities

1	Inadequate procedures	Omission of detail in procedures
2	Limited reliance on procedures	Many operations are skill-based and may not be guided by written procedures
3	Inapplicable procedures	Procedures don’t apply to a unique or unusual situation (off-normal; emergency)
4	Inadequate training/experience	Individual & team factors (e.g., between plant personnel and temporary contractor personnel)
5	Communication difficulties	Noise, hand signals, confusion using RF headsets with many people
6	Limited indicators and job aids	Lack of engineered reference tools or administrative controls (variable execution of skills)
7	Visual challenges	Large distances, viewing casks in water, obstructions
8	Unchallenging activities	Slow-paced tasks, monotonous, easy to get distracted
9	Time pressure	Approaching outage can increase pressure

Human Performance Vulnerabilities

10	Time of day & shift work challenges	Double shifts, variable shift schedules, filling in for sick colleagues
11	Inadequate verification	Incorrect “redundant” checking: common-mode failures, social shirking, overcompensation
12	Quality assurance problems	Structures, systems, components, materials, etc.
13	Decision making bias error	In particular: confirmation bias, loss aversion, overconfidence
14	Inadequate team coordination	Undesirable variability within and between teams, e.g., different assumptions for task execution
15	Improper or uneven task distribution	Missed opportunities for checking, workload imbalance
16	Large number of manual operations	More opportunities for unsafe actions and human failure events
17	Other ergonomic issues	Cramped work spaces, noise, hot or cold conditions, cumbersome clothing

Mitigative Strategies

1	Procedures	More detailed procedures & practice reliance on procedures
2	Training & experience	Value safety first, questioning attitude, recognize unsafe situations, team training, lessons learned
3	Communication	Standardized hand signals, radio procedures, 3-part communication, redundancy
4	Indicators and job aids	Positive measures for constant, accurate feedback and engineered controls to prevent failures
5	Visibility	Eliminate blind spots, multiple spotters, crane control pendants to keep operator close to moving load
6	Adequately engaging activities	Task balancing to increase vigilance and decrease stress or monotony
7	Avoiding time pressure	Proper scheduling; healthy safety culture
8	Time of day and shift work	Train personnel to recognize and respond to fatigue appropriately (within themselves and among others)

Mitigative Strategies

9	Independent verification	Train on effective search & detection strategies; techniques to avoid social shirking & overcompensation
10	Quality assurance	Processes, procedures, & training to inspect and maintain all relevant elements of system
11	Avoiding decision making bias errors	Training on types of biases and mitigation approaches, strong safety culture
12	Team coordination	Ensure appropriate skills, attitudes, knowledge, and working styles for team members
13	Task distribution among team members	Balance workload, clear lines of responsibility, train to adapt to changing situations (e.g., halt operations and achieve a safe state when significant deviation is encountered)
14	Reasonable number of manual operations	Limit number of operations per individual, provide job aids to reduce memory loads
15	Minimize ergonomic issues	Eliminate the issue, reduce exposure time, provide special training and/or equipment

Conclusion

- Introduced the analysis process allowing development of:
  - Cask drop scenarios including unsafe actions and error-forcing contexts
  - Human performance vulnerabilities representing performance shaping factors and plant conditions that generate a condition that may contribute to human failure events
  - Illustrative guidance for avoiding or mitigating the human performance vulnerabilities
- ATHEANA & Good Practices for HRA have proven valuable for uncovering the dynamic, contextual conditions influencing human performance in cask handling
- Building a technical basis for potential improvements to procedures and practices involving Dry Cask Storage Operations – e.g., to avoid cask drops