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QUALITATIVE HUMAN RELIABILITY ANALYSIS OF DRY CASK STORAGE OPERATIONS

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ABSTRACT

Human reliability analysis (HRA) methods have been developed primarily to provide information for use in probabilistic risk assessments of nuclear power plant control room operations. The HRA method of A Technique for Human Event Analysis (ATHEANA) has been 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. This paper describes aspects of a recently completed project in which the qualitative analysis within ATHEANA was successfully used to prospectively examine how unsafe actions may contribute to a cask drop and generate ideas for avoiding cask drops. Through the investigation of previous analyses as well as discussion with subject matter experts, cask drop scenarios were generated that might occur within dry cask storage operations. The development of these scenarios led to the development of human performance vulnerabilities meant to describe performance shaping factors as well as plant conditions that generate a context that may ultimately contribute to human failure events (HFEs). After analyzing the human performance vulnerabilities, illustrative guidance was developed for avoiding or mitigating them so that HFEs involving cask drops may be avoided or mitigated. This paper provides a description of the qualitative HRA process followed, a listing of HFE scenario groupings, discussion of selected human performance vulnerabilities, and illustrative approaches for avoiding or mitigating human performance vulnerabilities that may contribute to dropping a spent fuel cask.

Key Words: Human Reliability Analysis (HRA), Spent Fuel Handling, Cask Drops, Human Performance

1 INTRODUCTION

The storage of spent fuel at nuclear power plants (NPPs) has come under increasing scrutiny as the number of dry casks stored at US NPPs has grown. As plans for a geologic repository have gone unrealized, many NPP sites have begun storing spent fuel at independent spent fuel storage

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installations (ISFSIs) located at or near the plant. It is anticipated that all (or the vast majority of) U.S. NPPs will have implemented dry cask storage by 2025. The risks associated with these dry cask storage operations (DCSOs) have received some attention, but failures due to human error have largely been unexplored. The potential consequences resulting from the drop of a loaded fuel cask within a plant are of particular concern due to the possibility of damage to the plant, injury to personnel, and in some plant types, the possibility of initiating a reactor accident and simultaneously damaging equipment required for mitigating the accident. Human reliability analysis (HRA) can be used in this instance to more fully understand how human performance of DCSOs can plausibly lead to a cask drop. Furthermore, a qualitative HRA helps provide the start to building a technical basis for potential improvements to procedures and practices in order to keep cask movements safe.

HRA methods have been developed primarily to provide information for use in probabilistic risk assessments (PRAs) of NPP control room operations. The HRA method of A Technique for Human Event Analysis (ATHEANA) has been 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. This paper describes one successful test of this proposition by presenting portions of a recently completed study [1, 2] in which qualitative HRA activities were performed to prospectively examine how unsafe actions may contribute to a cask drop and generate ideas for avoiding cask drops. This application was aided by the investigation of previous analyses and discussion with subject matter experts. Through this analysis, cask drop scenarios including unsafe actions and error-forcing contexts were generated that might occur within DCSOs.

The development of the cask drop scenarios led to the development of *human performance vulnerabilities*, this terminology refers to a spectrum of performance shaping factors and plant conditions, including the past history of both latent and active unsafe actions, which generate a context that may ultimately contribute to human failure events (HFEs). The vulnerabilities were derived from a review of process descriptions, relevant incidents (e.g., heavy load drops, crane problems, cask component problems) and from interviews with subject matter experts (SMEs) who have hands-on experience with the processes. In addition to examining cask movement activities for vulnerabilities, various planning, preparation, equipment configuration, and related quality assurance activities were analyzed to provide insights into what can 'set-up' personnel for HFEs involving cask drops. After analyzing the human performance vulnerabilities, illustrative guidance was developed for avoiding or mitigating them so that HFEs involving cask drops may be avoided or mitigated.

2 ANALYSIS APPROACH

The analysis activities performed during this study were chosen to generate insights into how human performance aspects of DCSOs can plausibly lead to a cask drop and ways to reduce human contributions to cask drops. To achieve this aim, qualitative HRA activities were carried out that allowed the construction of detailed cask-handling scenarios showing various types of human performance vulnerabilities contributing to hypothetical cask drops. These activities also enabled the development of mitigating measures, closely associated with specific scenarios, which might reduce the potential for a cask drop due to human actions. Given that human actions are major determinants of the success or failure of cask movements, the analysis focused on both direct human involvement in cask movement operations and relevant pre-initiator latent error conditions that could “set up” personnel for the unsafe actions (UAs) that become the proximate/immediate/direct contributors to or causes of a cask drop.

The analysis generally involved an iterative process of gathering information from multiple sources; processing that information to develop credible, hypothetical cask drop scenarios involving UAs and HFEs; and inferring potential techniques for avoiding or mitigating the impact of human actions that could contribute to the events described in the scenarios. To generate cask drop scenarios that enable an understanding of human performance contributions, it was necessary to perform qualitative HRA activities using a method suitable to the spent fuel handling (SFH) domain. However, most HRA methods developed in the past for use in NPPs focused predominantly on human actions in NPP control room settings, with less emphasis on activities outside the control room such as DCSOs or equipment inspection, maintenance, and repair activities. The ATHEANA method was developed with a task, person, and environment-analysis approach, based on the latest behavioral science research circa 2000, which facilitated the discovery of particular situations and contexts that would challenge individuals and crews with particular types of knowledge, skills, experience, attitudes, and working styles in correctly executing goal-directed behavior. Fortunately, while the ATHEANA documentation is tailored to NPP operations, much of the methodology is easily applied to non-control room applications. Therefore, this study includes many qualitative HRA tasks adapted from NUREG-1792, *Good Practices for Implementing Human Reliability Analyses (HRA)* [3], NUREG-1624, Rev. 1, *Technical Basis and Implementation Guidelines for A Technique for Human Event Analysis (ATHEANA)* [4], and NUREG-1880, *ATHEANA User’s Guide* [5].

The basic ATHEANA process involves performing the following tasks in the general sequence listed (defining the HFEs is usually an iterative process):

1. Define and interpret the issue being analyzed
2. Define the resulting scope of the analysis
3. Describe the base case scenarios
4. Define HFEs and UAs of concern
5. Identify potential vulnerabilities
6. Search for deviations from base case scenarios
7. Identify and evaluate complicating factors
8. Evaluate the potential for recovery
9. Resolve issue (including quantification)
10. Incorporate into the PRA (if necessary)

In the current study, ATHEANA tasks 1–9 were adapted to generate detailed cask drop scenarios that identify and explain the potential impact of human performance vulnerabilities, and to infer techniques for improving human performance. Qualitative HRA tasks are typically performed in the context of a plant-specific PRA study. However, this study was performed without the benefit of a larger PRA study, and it was not plant-specific. Consequently, this analysis investigated somewhat generic HRA issues relevant to SFH and DCSOs.

3 CASK DROP SCENARIOS

The starting point for developing scenarios that involved important HFEs for DCSOs was to review scenarios identified in previous PRA-type activities performed on DCSSs, such as the studies by EPRI [6] and NRC [7]. The authors' understanding of nominal DCSOs, recent concerns, and emerging issues grew over time. The scenarios evolved slowly as initial scenarios were formulated and subsequently refined as more insights were obtained. HFE scenario groupings were progressively developed along with the increasing understanding of the potential use or usefulness of job aids, plausible variations in context, potential error mechanisms for cask-handling-specific failures, and other performance shaping factors (PSFs) and vulnerabilities that could influence the likelihood and consequence of particular HFEs.

The DCSO categorization scheme used in the analysis was divided into the following seven phases of operation:

1. Fuel Load Planning – This phase of operation involves activities by the appropriate engineering department to generate a fuel move plan, incorporating proper review and approval with subsequent transmission to the fuel handlers who will carry out the operation. This activity depends upon proper configuration management practices such that an accurate record of the history and specific location of every fuel assembly in the spent fuel pool (SFP) is maintained.
2. Cask Operations Personnel and Equipment Preparation – This phase of operation involves training and appropriate staffing of personnel for DCSOs as well as inspection, test, maintenance, recertification, upgrading, etc., of all structures, systems, and components that are required for executing DCSOs. An example of this phase would include assigning trained personnel to conduct detailed structural inspections of auxiliary or refueling building crane supports and interfacing building structures to insure that no cracks, deformations, or other aberrations threaten crane operations. This activity would be immediately accompanied with thorough inspection, test, and maintenance of crane systems and components before any critical heavy lifts are attempted (e.g., lifting a fuel-loaded and water-filled cask from the spent fuel pool).
3. Cask Preparation and Positioning – This phase of operation represents the beginning of actual DCSOs as the cask is brought into the plant for loading preparation activities which culminate with the placement of the empty cask/canister system into the cask loading pit of the SFP in advance of fuel loading.
4. Cask Loading – This phase of operation begins with placement of the first fuel assembly in the cask or canister and ends with the cask or cask and canister being properly drained, dried, inerted, and sealed.
5. Loaded Cask Transfer Within Structure – This phase of operation begins with preparations to transfer the loaded, sealed cask from the reactor, auxiliary, or fuel building and ends with the cask coupled to the cask transporter.
6. Loaded Cask Transfer Outside Structure – This phase of operation begins with a loaded cask, coupled to the cask transporter and ready for movement to the ISFSI and ends with cask emplacement at the ISFSI.
7. Loaded Cask Storage and Monitoring – This phase of operation begins with cask emplacement at the ISFSI and ends when the cask contents (i.e., the SF) are transferred to an off-site storage and/or processing location.

The seven phases of operation were used to group detailed descriptions of SFH and DCSO and to help guide the search process for potential HFEs and related human performance vulnerabilities. For NUREG/CR-7016 [1], four group categories were then developed to separate HFE scenarios that link to the taxonomy of operations. The HFE scenario descriptions were organized by the following four HFE scenario group categories:

1. Scenarios during cask movement from spent fuel pool to preparation area (HI-STORM 100 System at Mark I Boiling Water Reactor [BWR])
2. Scenarios during cask movement from preparation area to transfer pit (HI-STORM 100 System at Mark I BWR)
3. Scenarios during multipurpose canister (MPC) movement from transfer cask down to storage cask (HI-STORM 100 System at Mark I BWR)
4. Scenarios during cask movement from spent fuel pool to preparation area (TN-40 at Pressurized Water Reactor [PWR])

It should be recalled that HFEs are defined as events that would be modeled as basic events in the logic models of a PRA, therefore the scenario groups above do not map directly to the phases of operation in a one-to-one fashion. For example, the first group—*scenarios during cask movement from spent fuel pool to preparation area* is a subset of phase 4—*cask loading* that includes the major cask movement actions of raising the fuel and water-laden cask out of the pool and transfer to the preparation area since this covers a relatively continuous sequence of activities in which a cask drop, i.e., an event that would be modeled in a dry cask PRA,[3] may occur. The 2nd and 3rd scenario groups represent a decomposition of relatively continuous sequences of activities within phase 5—*loaded cask transfer within structure*. The increasing detail for the HFE scenario groupings for those two phases of operation allows for a better logical separation of conceivable/credible HFEs. Furthermore, the specific terminology (e.g., MPC, transfer pit, etc.) used in HFE groups 2 and 3 is intentionally directed toward the Holtec International HI-STORM 100 cask system and a boiling water reactor plant design whereas the 4th scenario involves the TN-40 DCSS at a PWR. PRAs focused on different cask systems and/or plant designs would be expected to have slightly different HFE scenario group categories, while the DCSO categories would remain the same.

NUREG-CR/7017 [2] included four additional group categories that covered more of the seven phases of operation:

1. Scenarios occurring before and during fuel loading
2. Scenarios during MPC and transfer cask sealing operations
3. Scenarios during storage cask movement from the transfer pit to the ISFSI pad
4. Scenarios during cask monitoring and storage at the ISFSI

4 HUMAN PERFORMANCE VULNERABILITIES

This section discusses human performance vulnerabilities that may affect cask-handling activities. Human performance vulnerabilities refer to a spectrum of PSFs and plant conditions,

[3] Given typical PRA practice, this could be considered the first operation in which a HFE involving a cask drop is anticipated to potentially result in a radiological incident or accident even though one or more UAs during previous operations may also contribute to the "consequential" event.

including the past history of both latent and active UAs, which may ultimately contribute to HFEs during cask movement activities. The context, emerging from a combination of human performance vulnerabilities, integrates the individual, task, situation, and environment in such a way that the connection between actions and undesirable consequences is apparent. While a positive context can improve human performance, a negative context (i.e., an error forcing context [EFC]) can set up personnel to commit UAs and HFEs. The following is a summary of some potential human performance vulnerabilities that were derived from process descriptions, review of relevant incidents and accidents related to spent fuel handling (e.g., heavy load drops, crane problems, cask component problems, other incidents during spent fuel handling and dry cask storage operations), and interviews with subject matter experts (SMEs) who have hands-on experience with the processes. An additional motivation for selecting and developing the vulnerabilities was to generate a set of terms that provide human performance distinctions that are readily understood by those who are knowledgeable of dry cask storage operations (DCSOs), but who may have limited knowledge of human factors (HFs) and human reliability analysis (HRA). That is, one goal was to avoid HF/HRA jargon by generating and describing terms useful for a broad audience of people interested in improving human performance in DCSOs.

1. *Inadequate procedures* – Procedures that are found to be deficient, possibly by discovering that a situation once thought to be unusual or rare is actually more common and deserves to be explicitly addressed in procedures. A deficiency in procedures may also exist when an important situation was not previously considered at all. Other deficiencies in procedures can include omissions in detail that are important for reducing the likelihood of UAs and HFEs. For example, procedures may not explicitly state the maximum height at which to stop lifting the cask from the spent fuel pool (SFP). This may increase the likelihood of a cask drop, for example, due to interactions of cask height and time available to avoid a two-block event caused by equipment failure or a UA.
2. *Limited reliance on procedures* – In general, many spent fuel operations are skill-based and may not be guided by detailed procedures. However, even if detailed procedures do exist, they may rarely be referenced because skills, informal rules, and heuristics guide task execution. For example, procedures specifying how to move a cask from the SFP to the decontamination/sealing area in great detail may not be regularly referred to, given the perception that the associated crane operation skills are "simple." This lack of reliance on procedures may lead to latent UAs, and over time could progressively lead to an increased potential for an HFE.
3. *Inapplicable procedures* – These are procedures, or significant portions of a procedure, that do not apply to a unique or unusual (i.e., off-normal/emergency) situation. This may result from a conscious decision by system designers and managers to avoid changing a procedure to explicitly deal with an unusual situation (because it might confuse or distract personnel dealing with many more commonly encountered situations). To handle the unusual situation, personnel need to know when to deviate from the documented procedures and rely on other factors such as training, knowledge-based problem solving, or engineered-feature response to avoid an HFE. Inapplicable procedures may also result from not considering a particular situation; however, upon discovery of this omission, it may still seem appropriate to avoid explicitly addressing some aspects of the situation in the procedure. The presence of inapplicable procedures may distract and delay personnel if they do not realize the procedures do not apply to current plant conditions.

4. *Inadequate training/ experience* – Many of the operations performed by the team may be skill-of-the-craft activities that lack a high level of formality both in terms of documented procedures and structured training programs. For example, there may be a lack of training in the immediate responses necessary given indications of a two-block event or a rigging failure in which a crew member is seriously injured and a loaded cask undergoes a freefall drop (e.g., assignment of responsibilities, order of emergency response actions). There may also be a lack of training in critical latent error conditions; for example, training in how to inspect crane support structures or inspect the state of rigging slings for signs of excessive strain loading and/or thermal damage. Inadequate training/experience may be present among:
    a. *Individuals*—individuals may not be adequately trained due to omissions or incorrect aspects of training as described above.
    b. *Teams*—inadequate training/experience among team members may not necessarily consist of large omissions or incorrect task-relevant training, but their training and experience may not have sufficiently prepared them to work together effectively with multiple people; this vulnerability may be particularly prevalent among hybrid teams consisting of both plant personnel and temporary contractor personnel.
5. *Communication difficulties* – The working environment of DCSOs is noisy, making verbal communication difficult. Headsets may cause confusion over who is speaking. Hand signals may be misinterpreted or not seen. For example, a spotter at floor level may shout warnings that go unheard by the crane operator; the spotter may also be unable to catch the attention of the crane operator with hand signals.
6. *Limited indicators and job aids* – Processes are generally controlled by unsystematic visual inspection instead of by positive safety measures such as engineered reference tools or other administrative controls. For example, lifting the cask out of the SFP is primarily guided by visual inspection without the additional safety features of proximity alarms (with auditory, tactile, or visual indicators) or objective reference tools (e.g., a reference scale indicating distance from the cask to the wall). That is, the avoidance of a cask hang-up or impact with items in the SFP may rely on the interpretation of visual cues selected and sampled in a subjective fashion by one or a very small number of people. In addition, for tasks involving numerous steps or for infrequently performed or unusual activities, there may be insufficient job aids to ensure that slips, lapses, and mistakes do not occur (e.g., due to distractions or memory limitations).
7. *Visual challenges* – Given the immense size of the cask as well as the placement of the workers, the line of sight for tasks may often be blocked or distorted. In addition, the operation of captivating and moving the cask while in the SFP may involve visual distortions from viewing the process through over 20 feet of water. Viewing the cask using underwater cameras may greatly reduce distortion from refraction of light; however, the difference in the perspective of the cask shown by the video system and the body positions of the crane operator and spotters may also lead to UAs. Furthermore, in some plants the crane operator is perched high above the cask movement operations and has an unclear view of the travel path and nearby obstructions. Visual challenges are identified as a distinct vulnerability given the prime importance of visually derived information for influencing human behavior.
8. *Unchallenging activities* – In general, DCSOs are slow-paced and they can be monotonous. Therefore, personnel may become easily distracted. For example, after progressing through

several successful loads within a campaign, the crane operator may become distracted while slowly moving the cask and miss a warning from a spotter below of an impending collision.

9. *Time pressure* – The time pressure felt by the workers during a DCSO may vary considerably. In general, the operations are slow-paced. However, missing scheduled milestones can increase the pressure felt. For example, as a cask loading campaign (CLC) nears completion and a scheduled outage approaches, along with the presence of hundreds of contractors arriving on site, the cask loading crew may rush to finish the last two loads of the campaign. Time pressure can arise from the tension generated by the often conflicting goals of "productivity and safety". However, time pressure can also arise from trying to achieve a specific safety goal; for example, pressure to complete rigging operations quickly to reduce radiation exposure to the riggers per the as low as reasonably achievable (ALARA) principle. Note that the safety culture among personnel can significantly affect the degree to which the perception of time pressure leads to rushed task performance.
10. *Time-of-day and shift-work challenges* – Workers are more likely to commit errors when fatigued, such as when they have performed a double shift or have been unable to sleep sufficiently between shifts. This problem of fatigue may be especially acute when personnel work an occasional night shift; for example, when a day shift worker fills in for a sick colleague one night.
11. *Inadequate verification* – Inadequate verification results from factors that lead to incorrect checking or overestimation of independence between checks. Key factors include common-mode failures, social shirking, and overcompensation [8, 9]:
    a. *Common-mode failures*—these include failures in redundant checks due to inadequate items (e.g., training, tools, equipment). For example, multiple inspectors incorrectly checking for defects will create latent error conditions.
    b. *Social shirking /misplaced trust*—a phenomenon in which individuals or groups reduce their reliability in checking by assuming that others will "take up the slack." The probabilities of error for a checker of another's work will be much higher than the probability of error for the original performer because the checker usually does not expect to find many errors when evaluating another's performance [10]. Crew members must trust each other to thoroughly review their work and catch any mistakes. A supervisor's cursory check of an "excellent" subordinate's work would violate that proper trust. Use of the term "misplaced trust" does not to imply that someone is generally "untrustworthy" if they succumb to this behavior—it highlights a subtle yet unsafe behavior that may occur among those who are "trusted." Also, mixed (hybrid) crews composed of plant personnel and contractors may not have the same understanding regarding the amount of verification needed or relied upon by others, thereby increasing the occurrence of social shirking.
    c. *Overcompensation*—a phenomenon in which the addition of extra items (intended to be redundant) encourages individuals or groups to increase production or engage in riskier behavior. An example would be greatly increasing throughput of newly manufactured crane components at an inspection station after providing additional inspectors. Overcompensation is a distinct action that often compounds the problem of failing to understand and account for dependencies due to social shirking and common mode failures.
12. *Quality assurance (QA) problems* – Careful verification that all structures, systems, and components (SSC) related to DCSOs meet appropriate conformance requirements may be

lacking, which may lead to latent error conditions. QA verification should extend as far back into the manufacturing and procurement stages as possible. For example, a QA problem could allow a control pendant for remotely operating a crane to malfunction when it is unexpectedly dropped during a cask movement. In this case, when a control pendant was purchased, it may have been assumed, but not been suitably verified, that the manufacturer tested it for impacts of this nature. Another QA problem could be failure to detect a material property defect in a load-bearing component.

13. *Decision-making bias error* – Bias and heuristic errors may mislead personnel and lead to HFEs during DCSOs. Three biases emphasized in this report include: confirmation bias, loss aversion, and overconfidence.
    a. *Confirmation bias*—the tendency to seek out evidence that confirms one's current position and to disregard conflicting evidence. *Example:* After several successful cask loads within a campaign, workers will likely require greater evidence (i.e., stronger cues and signals) to suspect that anything is wrong during cask movement.
    b. *Loss aversion*—the individual-specific way of mentally accounting for the concept of loss in a given situation provides a strong biasing factor toward information and actions that enable the person to steer away from incurring that loss. *Example:* During movement of a cask, a loud metal-on-metal sound momentarily captures the attention of workers observing the cask movement. The source of the sounds may be movement of the yoke arm on the trunnion; however, the personnel attribute the noise to nearby machinery instead of focusing on the loss-threatening possibility that a cask drop is imminent, so they continue the cask movement.
    c. *Overconfidence*—overestimating one's level of knowledge or abilities relative to making a decision or executing a task. *Example:* A crane operator is overconfident in his ability to closely align the cask to the edge of the SFP when raising it to facilitate access for personnel who will decontaminate and partially secure the cask lid. A cask hang-up occurs. The operator's overconfidence was fueled by ample experience in operating the crane and participating in several successful CLCs.
14. *Inadequate team coordination* – There may be undesirable variability within and between teams involved in DCSOs, especially during predominantly skill-based operations in which there is limited reliance on procedures, new or hybrid teams have been assembled, or responsibilities are handed off between teams (e.g., shift changes or specialized teams for different operations). While team member variability in skills, attitudes, knowledge, and working styles is beneficial in many situations, it can also mask differences in understanding abilities and assumptions guiding others' performance, such that task performance is inadequate for particular situations. Hybrid teams of plant personnel and temporary contractor personnel may be particularly vulnerable to inadequate team coordination. For example, an experienced team member from the plant, overly confident in his ability to perform a task, completes the task quickly and misses a step. Another team member, a temporary contractor who is more slow and methodical by nature, notices the co-worker's rapid task performance and suspects a potential UA. However, he comes from a safety culture that discourages challenging others' work performance; thus, he does not attempt to verify the task was performed correctly. As another example, the second worker in the same scenario assumes that the rapid task performance simply demonstrates the first worker's

tremendous skill—casting doubt on the possibility of an UA; thus, no verification is performed.

15. *Improper or uneven task distribution* – The distribution of tasks and responsibilities may not be clearly defined, which may lead to missed opportunities for independent verification. Also, an uneven workload can increase the stress on some employees while allowing others to become bored and easily distracted. For example, consider the crane operator who is tasked with lifting the cask. The crane operator's position within the cab limits his/her view of the travel path. It may be beneficial for decontamination personnel at ground level to act as spotters responsible for verifying that a clear travel path exists throughout the movement (i.e., being the eyes for the crane operator's hands) instead of resting in place until it is time to decontaminate the cask. This additional assignment of responsibilities to decontamination personnel may keep them more engaged in the CLC activities, reducing boredom and increasing vigilance.
16. *Large number of manual operations* – As the number of manual operations increases, personnel must exercise increased vigilance in performing them correctly. This caution is especially important when the operations must be completed quickly. For example, imagine that a rigger is pressured to quickly execute all of the manual rigging steps while positioned on top of a loaded cask due to the ALARA principle and to reduce heat stress. In general, as the speed of task execution increases the likelihood of latent or active unsafe actions also increases.
17. *Other ergonomic issues* – The noise level in the work environment is quite high. In addition to impairing communication, excessive noise levels can exacerbate the effects of fatigue. Other issues may also arise within the work environment such as cramped (or even inaccessible) working spaces (e.g., for inspection), high or low temperatures, high radiation levels (encouraging rapid and/or awkward maneuvers), cumbersome clothing, etc. Of particular concern may be the high temperatures that riggers encounter when positioned on top of a cask. An additional ergonomic issue involves fatigue, distraction, or other impairment due to the onset of illness or upon return to work during recovery or following an illness.

5 MITIGATIVE STRATEGIES

This section provides illustrative guidance on how to avoid or mitigate the human performance vulnerabilities identified in the previous section and thus avoid or mitigate human failure events (HFEs) involving cask drops. It should be emphasized that the material in this section is not complete or exhaustive; it is merely illustrative and tied to the human performance vulnerabilities. It is common for a significant number of active failures or unsafe actions (UAs) to occur within any complex system. Thus, it is reasonable to assume that multiple UAs will also occur during DCSOs. It may be true in most scenarios that multiple equipment failures and UAs must occur simultaneously or in a particular sequence for a cask drop to occur. The intent of this section is to provide illustrative guidance on ways to reduce UAs and HFEs resulting in latent error conditions and active failures involving cask drops. It is likely that substantial knowledge and experience with a specific cask system and personnel at a specific plant are needed to appropriately adapt these illustrative recommendations into practical guidance for that plant.

1. *Procedures*

   a. *More detailed procedures*—Increase the comprehensiveness and detail of procedures, and include response to low-likelihood events. The procedure will remind the crew of the occasional occurrence of such or similar events and serve as training material for less-experienced personnel. Detailing actions for responding to a particular emergency such as a dropped cask will remind personnel of this possibility and may assist them in adapting the procedures to fit a similar emergency if it ever occurs. Greater detail could include incorporating checklists, specifying roles for personnel, and specifying measureable criteria.
   b. *Reliance on procedures*—Require more reliance on procedural direction by instituting checklists to be completed during multi-step operations and by specifying confirmation requirements to be met during inter-crew communications or measurement criteria to be met during cask movement. . Develop and maintain a "work-to-procedure" culture in which, if documented procedures deviate significantly from the actions that appear to be needed in an operation, all equipment is placed in a safe configuration and work is stopped until the procedures can be corrected. However, avoid overly prescriptive procedures or a "work-to-procedure" culture that does not allow personnel to respond appropriately to an abnormal situation. Write procedures that give personnel many cues for determining whether the procedure matches the situation encountered and for deciding when it is appropriate to deviate from a portion of a procedure. Procedures should contain many pre-determined "hold" and "exit points" so that if a task in the procedure is ambiguous or unworkable, a clear path for achieving a safe, sustainable state of equipment is provided until a solution for successfully completing the operation is generated. Developing detailed procedures, yet avoiding overly prescriptive procedures, requires careful consideration of the potential consequences associated with deviating from portions of the procedure.
2. *Training/experience* – Train employees to value safety first and feel comfortable questioning, without fear of retribution, a situation they feel may be unsafe. In addition to emphasizing safety, train personnel in how to recognize specific unsafe or aberrant situations and how to respond. Continually enhance training by incorporating lessons learned from previous accidents or incidents.
3. *Communication* – To help prevent miscommunication or missed communications, have personnel use standardized hand signals and three-way communication. It is also advised that more than one method of communication be used to ensure messages are received.
4. *Indicators and job aids* – Implement positive safety measures and job aids that provide feedback pertinent to the situation, or engineered controls to prevent catastrophic failures or collisions.
5. *Visibility* – To avoid or mitigate accidents due to poor visibility, train personnel to accurately detect blind spots, and assign multiple crew members to act as spotters. Use of a crane control pendant can allow the crane operator to move around and have the flexibility to find better vantage points.
6. *Adequately engaging activities* – Assign personnel extra tasks to engage them during particularly slow or monotonous work. Personnel should also be trained to scan ongoing tasks (under their responsibility as well as under others' responsibility) to see if they can assist in other areas.

7. *Avoiding time pressure* – Similar to training personnel to focus on safety, emphasize the need to avoid rushing work processes to ensure a strong safety culture. Organize work processes so they can be completed efficiently.
8. *Time-of-day and shift-work* – The effect of fatigue is a primary concern in working atypical shifts or long hours. Train personnel to recognize the signs of fatigue in themselves and others. Encourage personnel to be aware of other signs indicating an employee may not be fit for duty. If work is required during atypical times of day, take other precautions such as scheduling more breaks and ensuring adequate staffing.
9. *Independent verification* – To assist in recognizing defects, train personnel in effective search and detection strategies. Train and warn personnel of the social shirking phenomenon and ways to overcome such tendencies. Strategies might include keeping the identity of the checkers anonymous and spacing the checks over appropriate time spans. To help ensure the proper functioning of equipment, check components well before use and near the time of use.
10. *Quality assurance* – To ensure the proper function and operability of equipment and components, inspect them regularly. Thoroughly train personnel performing the inspection on how to detect problems.
11. *Avoid decision-making bias errors* – To counteract the negative effect of a bias error which leads the decision maker to the wrong conclusion and an inappropriate decision, train the crew on the types of biasing errors that may exist. Establish an organizational culture in which personnel feel safe in reporting unsafe circumstances or safety concerns. Have a diverse team design procedures and training so that a wide array of options and situations are considered and planned for. Ensure personnel are trained on these situations and mentally guided through appropriate responses.
12. *Team coordination* – To help a team work together effectively, team members should have appropriate and suitably similar skills, attitudes, knowledge, and working styles for the particular operations. Experts or suitable trainers should be available to probe for and recognize gaps in these attributes relative to the specific operations to be performed. Ensure that hand-offs between teams have been analyzed for gaps in capabilities. Try to avoid assembling a hybrid team of plant personnel and temporary contract personnel shortly before execution of a CLC.
13. *Task distribution among team members* – The proper distribution of tasks will help alleviate the stress felt by over-burdened employees and engage personnel tasked with light and easy tasks. Train employees to scan the situation for ways they can contribute if they are working on an insufficiently engaging or low-stress task. Tasks should also be clearly defined so that each worker knows who is ultimately responsible for completing each task. If a task is particularly stressful or complex, assign multiple employees for redundancy and verification.
14. *Reasonable number of manual operations* – An employee can easily feel overwhelmed with a large number of manual tasks needing to be completed. Furthermore, it is easy for one of these operations to be inadvertently skipped or missed. Design tasks such that individuals are not responsible for an overwhelmingly large number of operations. Provide job aids to aid employees' memory while they complete tasks so they do not accidently miss steps or subtasks.
15. *Minimize ergonomic issues* – To effectively cope with a stressful environment (e.g., due to high temperatures, slippery surfaces, cramped locations) identify the ergonomic stressors

within those environments and eliminate or reduce them where possible. If not possible to eliminate the issue, limit exposure time. The employee working in such conditions may need special training or special equipment.

6 CONCLUSIONS

This project applied the qualitative analysis portion within ATHEANA to prospectively examine how unsafe actions may contribute to a cask drop. Through this application, cask drop scenarios were generated including unsafe actions and error-forcing contexts that might occur within DCSOs. The development of the cask drop scenarios led to the development of human performance vulnerabilities representing performance shaping factors and plant conditions which generate a context that may contribute to HFEs. Following the development of the human performance vulnerabilities, illustrative guidance was provided for avoiding or mitigating them so that HFEs involving cask drops may be avoided or mitigated. This paper provides a description of the qualitative HRA process followed and discussion of the human performance vulnerabilities and mitigative strategies. It is anticipated that the results of this qualitative analysis will begin a process that may lead to improvements in guidance for conducting and monitoring the performance of DCSOs.

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