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# MAKING RISK-INFORMED DECISIONS IN CASK DESIGN REVIEW

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## ABSTRACT

This paper presents how the Risk Tool, developed for use by the US nuclear regulatory reviewers of spent fuel casks amendments, informs the reviewer regarding the review risk significance of spent fuel cask components and assists in determining the level of analytical detail necessary to provide reasonable assurance that the integrity of the spent fuel cask will be maintained under normal, off normal and accident conditions. The paper explains how the quantitative estimates, from a probabilistic risk assessment of the process followed to transfer spent fuel from the fuel pool to an interim spent fuel storage installation, are used to scale the risk associated with a license amendment request. This initial risk is then further modified by the qualitative understanding of the safety significance of the affected components to arrive at the revised review risk significance in the Risk Tool. The risk scale along with a tree diagram which identifies cask components based on their function are the essential features of the Risk Tool. Examples are provided on how the Risk Tool assists in the risk-informed assessment of licensee amendment requests. The Risk Tool has improved the efficiency of staff reviews by directing resources based on the review risk significance of the amendment being reviewed. The Risk Tool can increase staff awareness of the benefit of using risk information in support of safety decisions including an improved understanding of design margins in design.

## INTRODUCTION

The Probabilistic Risk Assessment Policy Statement, (Use of Probablistic Risk Assessment Methods in Nuclear Regulatory Activity;Final Policy Statement, 1995)formalized the Commission's commitment to risk-informed regulation through the expanded use of probabilistic risk assessments (PRAs). The statement reads, "*The use of PRA technology should be increased in all regulatory matters to the extent supported by the state of the art in PRA methods and data, and in a manner that complements the NRC's deterministic approach and supports the NRC's traditional defense-in-depth philosophy.*"

To implement this commitment, different offices within NRC undertook programmatic initiatives to encourage the use of PRA in their findings and in regulatory decision making. The programs serve as platforms for staff collaboration on the use of risk insights to support decision making during the development of safety evaluation reports (SERs) for licensing actions. The programmatic effort augments staff decisions by using the risk insights revealed from PRA's developed for the design. The PRA's ability to evaluate a

wide range of scenarios along with their parametric uncertainties is a powerful tool to provide insights on the vulnerabilities of structures, systems, and components, enhancing the confidence to the staff's decisions that were made previously using only the results of a deterministic analysis. Such actions support the goal of making the agency a modern risk-informed regulator.

The Office of Nuclear Material Safety and Safeguard (NMSS) at the NRC contracted Idaho National Laboratory (INL) to develop a methodology (later identified as the "Risk Tool") to encourage the use of PRA results and other qualitative information about the performance of spent nuclear fuel (SNF) dry storage casks (DSCs) in estimating the appropriate review effort for license amendment requests (LARs). The methodology defined a term "review risk significance" which denotes the relative risk associated with the NRC review process of an LAR item (Eidelpes et.al; 2022). The Risk Tool methodology established a risk criterion matrix, described later, to estimate the integrated review risk and its significance.

The significance of the integrated review risk is estimated using a hybrid approach which includes quantitative risk estimates (estimates of exposure risk from the Pilot PRA - NUREG-1864) and risk modifiers (qualitative risk information) identified in the risk criterion matrix. The review risk significance is used to estimate the most appropriate level of review effort required for evaluating the LAR in consideration of all the elements that contribute to the review risk.

**THE PILOT PRA**

The pilot PRA (NUREG-1864) assessed the risk to the public and identified the dominant contributors to risk associated with the operation of a Dry Cask Storage System (DCSS). It involved a specific cask at a specific boiling-water reactor (BWR) site using site-specific lifting and transportation devices. Although the study results cannot be directly applied to all cask systems and sites, it does provide a general understanding of the risk significance of cask safety functions and the components that support that function. The operational phases of all DCSS are essentially the same, hence the risk estimates from the pilot PRA provide a reasonable approximation of the risk associated with DCSS operations. The Risk Tool uses this applicability of the PRA results in its development.

The cask system considered in the PRA consists of three major components, a canister containing the SNF, a transfer overpack, and a storage overpack. The SNF is moved from the pool into the submerged canister within the transfer overpack which shields workers from radiation. For onsite storage the canister is transferred from the transfer overpack to the storage overpack. Commonly the canister with the transfer overpack is called the transfer cask (TC) and the storage overpack is called the storage cask. These terms are used in this paper henceforth.

The movement of SNF from the pool to the storage cask is accomplished in three distinct phases: handling, transfer, and storage. The PRA evaluates the risk associated with the initiating events involved in each phase. In the handling phase, SNF assemblies are placed in the submerged canister within the TC. After the canister is sealed, dried and inerted, it is transferred in the TC to the storage cask. In the transfer phase, the storage cask is moved from the secondary containment to the storage pad. In the storage phase, the storage cask is

set down on the storage pad of the ISFSI. A storage period of 20 years is considered in the PRA.

To better characterize the risk, the three operational phases were divided into 34 stages in the PRA. A comprehensive list of initiating events was developed, and the risk associated with each initiating event was evaluated. Analyses were performed to determine the cask response to mechanical and thermal loads under each initiating event. This informed the probability estimate of a release risk conditioned by the probability of occurrence of an event. The study assessed the risk to the public in terms of prompt fatalities (there were none) and latent cancers within 16 km (10 miles) of the site. The PRA considered the core safety functions of a cask to be to provide containment, criticality safety and radiation protection. These functions are essential to prevent the exposure of the operating personnel and public to the harmful effects of ionizing radiation.

The results showed that the risk is dominated by drop accident sequences in the handling phases of the operation. Specially, the risk was dominated by operations when the canister is not sealed, and the TC cover is not in place. The regulatory containment boundary for a vast majority of the cask system designs uses a welded canister while a few are bare fuel casks with bolted inner lids (Cater and Peters,2020). The lid to the overpack serves as a radiation shield and a defense-in-depth feature of the cask by serving as an additional confinement boundary. The breach of the containment boundary would lead to a release of radioactive isotopes, noble gases, and crud (a mixture of corrosion particles on SNF rods) with harmful effects on public health.

The PRA considered the risk of release from a criticality event and determined it is not a significant contributor to release risk in the absence of a moderator, as the canister is dried and filled with inert gas. The PRA considered the risk of public exposure from a loss of shielding event and found it is not a significant contributor to release risk and any loss in the effectiveness of the shielding can be compensated by time and distance.

Hence the aggregate release risk was stated as: $R_r = \Sigma( H_{ri} + T_{ri} + S_{ri} )$ which is the sum over all events of the risk from each phase of the operation. Where $R_r$ is the release risk from all events; $H_{ri}$ is the release risk during a handling accident; $T_{ri}$ is the release risk during a transfer accident and $S_{ri}$ is the release risk from a storage accident.

Any change in the computed exposure risk was taken to be solely the result of release from a breach in the containment boundary from drops during handling where $H_{ri} = P_{ai} * P_{ar}$ where $P_{ai}$ is the probability of an accident event occurring and $P_{ar}$ is the probability of a release from the accident.

The Risk Tool uses this aggregation of exposure risk associated with drop sequences as the quantitative estimate of potential exposure risk that may result from the implementation of the amendments to the cask Structures, Systems and Components (SSCs) that support the cask safety functions: containment, criticality control and radiation protection.

**THE RISK TOOL**

The Risk Tool developed by INL for NMSS uses the potential for change in the PRA estimated risk of release as one of the inputs to determine the review risk significance of a LAR. An increase in the release risk by a factor of two or below was selected as defining a low risk modification. An increase in release risk greater than two but less than 10 was

defined as a medium-risk modification and a change in release risk greater than 10 was defined as a high-risk modification. The above color code is used in the Risk Tool Tree diagram to identify the risk significance of the component being evaluated.

Table 1: Risk Significance Categories

| Risk Significance |
|---|
| Low |
| Medium |
| High |
| See Rationale |
| Unevaluated |

In addition to the risk scale of the modification, the review risk significance is established considering the following additional qualitative measures.

Table 2: Review Risk Criterion Matrix

| **Criterion** | | | | | | **Review Risk Significance** |
|---|---|---|---|---|---|---|
| **Quantitative Data - Factor of Risk Increase** | **Impact** | **Redundancy** | **Safety Margins** | **Evaluation Complexity** | **Error Detection and Correction Probability** | |
| < 2 | Yes or no | Exists | Small (if redundancy exist) to large | Simple | High | Low |
| 2 ≥ and < 10 | Yes | Nonexistent | Large | Simple to complex | Medium to high | Medium |
| ≥ 10 | Yes | Nonexistent | Small | Simple to complex | Low to high | High |

Adapted from INL/JOU-20-60011-Revision-0

The initial review resource estimate is based on the factor of risk increase estimate and can be further modified by the above stated qualitative criterion. The impact criteria allow the consideration of information on whether the amendment influences current or future operations. The presence or absence of such impact is then associated with the appropriate risk significance, which can range from low to high. The redundancy criteria allow the incorporation of a defense-in-depth feature that is available as an additional layer

for providing a core safety function. For example, a LAR that impacts a redundant level of a safety function can be considered as low risk significance. The evaluation complexity criteria include the availability of test data or experience data used in the evaluation of similar amendments and the level of subjectivity that is used in the evaluation of the LAR. The error detection and correction probability criteria account for the identification of flaws or errors that could be caused by the implementation of the LAR. The higher the chance of error or flaw detection, the lower is the review risk significance. Finally, are the criteria to address safety margins. The presence of safety margin in redundant or non-redundant SSCs can be used to modify the review risk. For example, for a non-redundant safety system with high margins of safety a moderate risk can be considered but not a low risk.

This hybrid approach is expected to provide the reviewers an insight to the review risk associated with the proposed amendment. The tool will, therefore, allow the reviewer to direct resources for the evaluation of the amendment commensurate with the review risk significance of the cask functions affected by the LAR and modifications to components that support these safety functions. With the criterion matrix presented a reviewer can evaluate the review risk significance of amendments as high, medium, or low. This evaluation can then be used to allocate resources to the LAR review.

To further facilitate the use of the tool, the methodology for determining the review risk of an amendment process to be followed is presented in a tree structure. The tree structure provides a visual of the logic followed and uses the risk scale use the PRA information. It is color coded in red, yellow, and green to signify high, medium, and low review risk. The tree uses a gate numbering system to associate each of the decision points with the component with the rational for the estimated risk at that gate.
The following applications of the Risk Tool in determining the Review Risk illustrate the application of the Risk Tool.

Example 1: A License Amendment Request (LAR) changes the material for a finned cask from Alloy A to Alloy B. Alloy B has a thermal conductivity that is 2 % less than that of Alloy B. The available margin in the cladding temperature is $50^0$ F. This is an issue of heat transfer. The Risk Tool leads the user to Gate 1.2.2.1 which is designated as “medium review risk” based on the rationale that is incorporated in the Risk Tool. Use Additional information to modify the initial estimate of review risk: Thermal analysis considered fins and results showed $50\ ^0$ F margin in cladding failure temperature. No increase in decay heat. The 2 % decrease in thermal conductivity would not significantly affect this margin– hence review risk is low as little additional effort will need to be expended to reach a safety conclusion.

Example 2: A LAR changes the poison material for the fuel basket. The fuel basket provides structural support to fuel assemblies and aids in maintaining the geometry of the fuel assemblies. The Risk Tool places this amendment to gates 1.1.2.1 and 1.1.2.2 and assigns the basket structure and neutron poisons as “Low review risk.” This initial risk assessment is further evaluated using case specific information to modify initial estimate of review risk. The new poison material will need a review of performance data or test data to illustrate expected performance. The new poison impregnated basket components may have a structural capacity different from the original basket. These new reviews will need additional time, thereby raising the review risk significance for this amendment to medium.

## CONCLUSIONS

The staff finds the Risk Tool to be an effective and rationale approach to help the staff assess the level of the review effort. The optimization of the time needed for the review effort will in the long run be a savings for the applicant. The tool provides a valuable aid to future staff as more and more gates are evaluated, and rationales are further developed as review information continues to expand and designs evolve. The tool in addition, provides an effective means for knowledge management both as a reference document for current staff use and providing a platform for updating of information in the Risk Tool with continued review experience, new information, and evolving designs – a 'living' document. The authors conclude that the Risk Tool could be improved by further development, including sensitivity and uncertainty studies of closure bolt design, welding process inconsistencies, strain rate effects on stainless steel material, and characterization of the gap between the fuel basket and the canister as a source of secondary effects and the resulting canister response.

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