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Development of Dry Cask Risk Tools

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Development of a High-Level Risk Assessment Tool for Reviewal of License Amendment Requests

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ACRONYMS

CFR	Code of Federal Regulations
CoC	Certificate of Compliance
FSAR	Final Safety Analysis Report
HALEU	High-Assay Low-Enriched Uranium
HI STORM	Holtec International Storage Module
HI TRAC	Holtec International Transfer Cask
INL	Idaho National Laboratory
ISFSI	Independent Spent Fuel Storage Installation
LAR	License Amendment Request
MPC	Multi-Purpose Canister
PRA	Probabilistic Risk Assessment
SDP	Significance Determination Process
SER	Safety Evaluation Report
SSC	Structures, Systems, and Components
SNF	Spent Nuclear Fuel
SME	Subject Matter Expert
TS	Technical Specifications
U.S. NRC	United States Nuclear Regulatory Commission
U.S. NWTRB	United States Nuclear Waste Technical Review Board

Development of Dry Cask Risk Tools

1. INTRODUCTION

The Nuclear Regulatory Commission (NRC) has repeatedly expressed a desire to consider information on risk in its decision-making processes. The Probabilistic Risk Assessment (PRA) Policy Statement published in 1995 formalized the commission's commitment to risk-informed regulation through the expanded use of PRAs. While a great deal of work has been done to incorporate risk insights into the regulatory framework for at-power nuclear reactors, less progress has been made to risk-inform the dry casks and nuclear waste transportation areas of the nuclear fuel cycle.

Idaho National Laboratory (INL) was assigned by the NRC with a project that aims for the incorporation of information from completed dry cask PRAs and related available information into a tool that supports the commission with using those insights to identify levels of risk at various stages in the nuclear waste path. The project consists of three tasks:

Task 1: Evaluation of risk related to License Amendment Requests (LAR) for spent nuclear fuel (SNF) dry cask storage systems

Task 2: Expand the tool to SNF transportation systems

Task 3: Addresses eventual, additional, regulatory applications (e.g., oversite) for dry cask storage or transportation

This report is a working document. At the current stage, it provides an overview on INL's work on the first task, but eventually, the document is going to be further developed to cover INL's work on the remaining two tasks after completion in the future.

The first task of this project specifically asked to incorporate available risk insights into the process for determining and prioritizing reviews of LARs related to storage applications by outlining an NRC resource allocation strategy and by defining recommendations for the depth and breadth of the review. The NRC requested that the tool should be similar in design to their existing Significance Determination Process (SDP) notebooks/worksheets. The new tool would include quantitative, qualitative, and/or semi-quantitative approaches to assess the risk of a requested change (i.e., a LAR item). The final tool design that was selected by INL in consultation with NRC to be developed is a tree diagram including an associated rationale document. The structure of the tool allows NRC personnel to conduct an efficient, preliminary, high-level risk determination of typical LARs for example, system design changes or changes in the approved system content with the tool providing the user a rationale behind the risk categorization of each specific change. The risk categorization leads to specific, actionable review recommendations for each individual LAR item. This allows for a more consistent review process by the NRC as well as for an improvement of the overall efficiency of the review itself.

2. METHODOLOGY

The general approach to tackle the first task of this project was to develop a tree diagram that guides the user to a risk significance of a LAR item that has already been preliminarily analyzed at a high-level so that the reviewer can quickly identify the level of effort and resources required to properly assess this LAR for the applicant. The tree diagram comes with an associated rationale document that establishes the criteria according which the risk significance of a number of potential changes are analyzed so that the reviewer can assess whether the recommend guidance is adequate for a specific LAR item or if additional precautions should be taken to address any relevant characteristics of a specific change. The tool was designed for growth, and the tree diagram and the rationale document can be extended by additionally identified changes. Further, the design allows for risk levels to be changed to incorporate additional data.

Typically, LARs for dry storage casks, requested by the certificate of compliance (CoC) holder or licensee, submitted to NRC include requests for multiple individual changes. Each individual change must be reviewed on its own to assess the specific level of risk associated with the change. A set of common, individual LAR items are evaluated within this tool and each change has an associated risk categorization and rationale behind it. If the specific change is not identified and thus, not included in the tree diagram and rational document, the tool provides a general assessment approach to be followed that allows the user to manually identify the specific risk categorization using the same criteria that were used in the tool development.

2.1 Tree diagram

The tree diagram shown in Figure 1 is designed for ease of use and to allow the reviewer to quickly identify the significance of the change for a specific LAR item being reviewed by following a decision path until final resolution is determined.

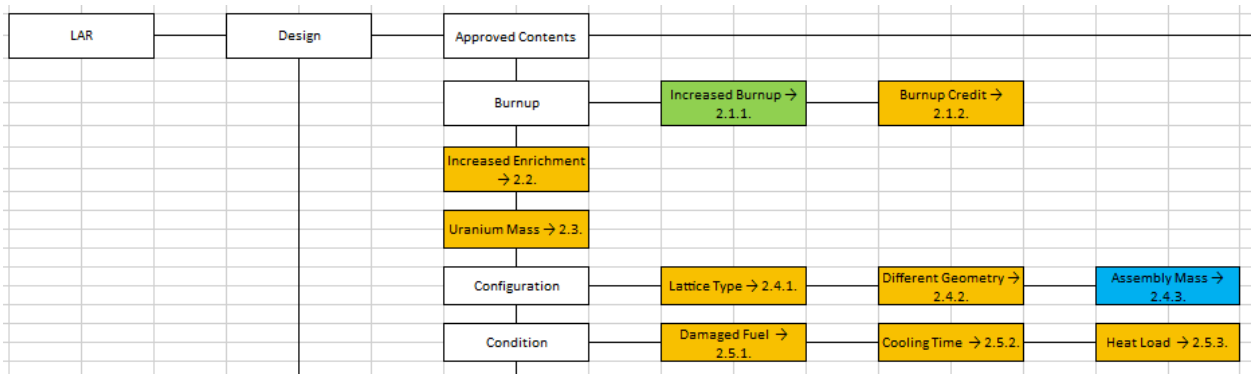

Figure 1: Example portion of Task 1 tree diagram.

The diagram is color coordinated and numbered to signal the correlated risk significance of the change to the user as well as to help the user to quickly identify the corresponding section number in the associated rationale document. This allows the user to review the argumentations and the specific reasons behind the risk classification.

The risk categorization key shown in Table 1 is color coded for easy recognition, and outlines the specific criteria according which change in the tree diagram is evaluated and categorized. The column “LAR Review Process” in Table 1 is designed to be modified or expanded as the NRC uses the tool and defines the level of review that would be adequate for the respective risk category.

Table 1: Risk Categorization Key

Risk Significance	LAR Review Process	Risk Significance Determination Criteria
Low	Efficient	→ Redundancy of preventive measures or multiple malicious conditions necessary for accident initiation in by LAR flawed system. Independent failure of the redundant systems, or independent concurrence malicious conditions for accident initiation. → If quantitative data is available: Insignificant increase (by a factor of less than one order of magnitude) of cancer risk theoretically possible, due to by LAR flawed system. → Standard reevaluation process of the system that requires only an adaption of new parameters. → Low chance of making a significant evaluation error during safety evaluations by the licensee and high chance of catching such an error by the reviewer. → No direct effect of LAR item on current operation procedures.
Medium	In Detail	→ Detection of evaluation error or flaw likely (e.g., due to surveillance). → No immediate danger to public or personnel due to by LAR flawed system due to significant safety margins. → If quantitative data is available: Medium increase (by a factor of less than two orders of magnitude) of cancer risk theoretically possible, due to by LAR flawed system.
High	Extensive, Thorough, Very Detailed	→ Error in LAR safety evaluations could directly lead to an accident that includes a release of radioactive material, criticality, or undetected, and significantly increased radiation exposure of the public or the operating personnel. → No reliable redundancy in the system. → If quantitative data is available: Significant increase (by a factor larger than two orders of magnitude) of cancer risk theoretically possible, due to by LAR flawed system.
See Rationale	Based on Extensive Risk Significance Determination	→ No risk significance estimation possible without consideration of additional factors.

Finally Table 2 provides specific set of six rules that the user has to follow to ensure that the tool is properly used and that no change is screened out or goes unanalyzed by the tool.

Table 2: Dry Storage Cask Risk Tool Rules

Rule	Instructions
1	Choose the gate that matches the LAR item.
2	If more than one choice for a gate is possible, evaluate both gates independently.
3	Use color scale to evaluate risk significance.
4	Review rationale document if gate color is blue.
5	Review rationale document for general background information or if doubt.
6	Review rationale document if the gate is unevaluated.

The tree diagram itself, as well as the rationale document is designed to be expanded or modified as more scenarios are identified and incorporated, or as more information and data has been collected that allows for better risk assessments of the changes.

2.2 Rationale Document

The associated rationale document outlines the argumentation bases on which the determination of the risk significance of each evaluated LAR items is based on. The evaluation can be semi-quantitative (i.e., using available simulation or examination data, and sensitivity studies on PRA data), and qualitative [i.e., via conducting subject matter expert (SME) interviews, and engineering judgment] of the potential consequences of an LAR item (e.g., a

design change of a component), focusing on following core functions of a spent nuclear fuel (SNF) dry storage systems:

1.) Containment of radionuclides
2.) Shielding
3.) Subcriticality of contents

Further, the rationale document provides guidance for LAR items with ambiguous risk significance and provides a strategy to estimate the risk significance for currently unidentified items.

2.2.1 Evaluated Changes

The evaluated dry storage system LAR items listed in this document are a set of generic items and were selected from common, past LARs submitted to U.S. NRC, or were selected under coordination with the U.S. NRC.

The focus of the evaluations was put on dry storage design changes, changes regarding the chosen safety evaluation methods, editorial changes, and changes in the approved SNF content. However, it is impossible to develop (and evaluate) a complete set of LAR items, since future requests cannot be adequately predicted. Thus, a strategy, within the rationale document, is provided to evaluate LAR items that are not included within this document.

2.2.2 Risk Significance Evaluation Criteria

The risk significance of an LAR item was estimated via evaluating the question if, and under which circumstances, the requested change could lead to a release of radioactive material to the environment, lead to dry storage content criticality, or lead to a significant increase of radiation exposure to the public or operating personnel. The risk significance estimation included information on the level of redundancy of the system of preventing the initiation of such events, the number and likelihood of malicious conditions that need to concur, available risk data, and the complexity of the valuation and review process of a LAR item. Table 3 summarizes the qualitative criteria that were used to rate the risk significance of the generic LAR items.

It is important to note that the risk significant determination process did not consider regulatory thresholds, industry standards, or recommendations provided in guidance or regulatory documents. The emphasis was put on the dry storage core functions, which includes the protection of the public and personnel health. Other functions like, e.g., fuel retrievability, or functions related to system operations, besides other, were not considered.

Further, the risk evaluations are meant as a first, preliminary estimation of the risk associated with a LAR item and are intended to support the NRC reviewer in planning resource allocation when receiving a LAR. It is not meant to be a static risk estimate. During review, if the reviewer, or SME, gains the impression of a higher risk significance, the higher risk significance and the review process of the LAR item should be adapted accordingly.

Table 3: Evaluation criteria for risk significance estimation.

Risk Significance Estimate	Evaluation Criteria
Low	- Redundancy of preventive measures or multiple malicious conditions necessary for accident initiation in by LAR flawed system. Independent failure of the redundant systems, or independent concurrence malicious conditions for accident initiation. - If quantitative data is available: Insignificant increase (by a factor of less than one order of magnitude) of cancer risk theoretically possible, due to by LAR flawed system. - Standard reevaluation process of the system that requires only an adaption of new parameters. - Low chance of making a significant evaluation error during safety evaluations by the licensee and high chance of catching such an error by the reviewer. - No direct effect of LAR item on current operation procedures.
Medium	- Detection of evaluation error or flaw likely (e.g., due to surveillance). - No immediate danger to public or personnel due to by LAR flawed system due to significant safety margins. - If quantitative data is available: Medium increase (by a factor of less than two orders of magnitude) of cancer risk theoretically possible, due to by LAR flawed system.
High	- Error in LAR safety evaluations could directly lead to an accident that includes a release of radioactive material, criticality, or undetected, and significantly increased radiation exposure of the public or the operating personnel. - No reliable redundancy in the system. - If quantitative data is available: Significant increase (by a factor larger than two orders of magnitude) of cancer risk theoretically possible, due to by LAR flawed system.
Ambiguous	- No risk significance estimation possible without consideration of additional factors.

2.2.3 Available Data and Literature

Figure 2 shows a summary of an original PRA of a Holtec International Storage Module (HI STORM) 100 System (Malliakos, 2007). In the scope of this PRA, the quantitative data on risk is defined as the probability of latent cancer fatality of an individual within 10 miles of the dry storage system, considering a 20-year dry storage operation. The probabilistic data of Malliakos (2007) is used to study the risk sensitivity on applicable LAR items.

Phase	Stage	Activity	Event	Initiating Event Frequency	Probability of Release from Canister and Rod	Released Material Type	Probability of Release to Environment	Consequen
Handling	1	Load SNF in Canister	Fuel Assembly Drop	2.20E-03	6.40E-02	Noble Gas	1	1.50E-12
Handling	3	Lifting Transfer Cask out of Cask Pit	Transfer Cask Drop into Cask Pit	5.60E-05	1	Noble Gas	1	1.00E-12
Handling	4	Lifting Transfer Cask over Railing	Dropping Transfer Cask, Height less than 1 ft	5.60E-05	1.00E-06	All	1.50E-04	3.60E-04
Handling	5	Moving Transfer Cask to Preparation Area, 1st Section	Dropping Transfer Cask, Height less than 1 ft	5.60E-05	1.00E-06	All	1.50E-04	3.60E-04
Handling	6	Moving Transfer Cask to Preparation Area, 2nd Section	Dropping Transfer Cask, Height less than 1 ft	5.60E-05	1.00E-06	All	1.50E-04	3.60E-04
Handling	7	Moving Transfer Cask to Preparation Area, 3rd Section	Dropping Transfer Cask, Height less than 1 ft	5.60E-05	1.00E-06	All	1.50E-04	3.60E-04
Handling	8	Lowering Transfer Cask onto Preparation Area	Dropping Transfer Cask, Height less than 1 ft	5.60E-05	1.00E-06	All	1.50E-04	3.60E-04
Handling	11	Lifting the Transfer Cask	Dropping Transfer Cask, Height less than 1 ft	5.60E-05	1.00E-06	All	1.50E-04	3.60E-04
Handling	12	Moving Transfer Cask to Bottom Lid Exchange Area, 1st Section	Dropping Transfer Cask, Height less than 1 ft	5.60E-05	1.00E-06	All	1.50E-04	3.60E-04
Handling	13	Moving Transfer Cask to Bottom Lid Exchange Area, 2nd Section	Dropping Transfer Cask, Height less than 1 ft	5.60E-05	1.00E-06	All	1.50E-04	3.60E-04
Handling	14	Replacing Pool Lid by Transfer Lid	Dropping Transfer Cask, Height less than 1 ft	5.60E-05	1.00E-06	All	1.50E-04	3.60E-04
Handling	15	Moving Transfer Cask in Direction Equipment Hatch	Dropping Transfer Cask, Height less than 1 ft	5.60E-05	1.00E-06	All	1.50E-04	3.60E-04
Handling	16	Holding the Transfer Cask	Dropping Transfer Cask, Height less than 1 ft	5.60E-05	1.00E-06	All	1.50E-04	3.60E-04
Handling	17	Moving Transfer Cask to Equipment Hatch	Dropping Transfer Cask, Height less than 1 ft	5.60E-05	1.00E-06	All	1.50E-04	3.60E-04
Handling	18a	Lowering Transfer Cask onto Overpack (a)	Dropping Transfer Cask, Height 100 ft	5.60E-04	2.00E-02	Noble Gas	1.00E+00	1.00E-10
Handling	18b	Lowering Transfer Cask onto Overpack (b)	Dropping Transfer Cask, Height 100 ft	5.60E-05	2.00E-02	Other than Nobel Gas	1.50E-04	3.60E-04
Handling	20a	Lifting Canister and Opening Transfer Lid (a)	Dropping Canister, Height 5.9 ft	5.60E-05	2.80E-01	Noble Gas	1.00E+00	1.00E-10
Handling	20b	Lifting Canister and Opening Transfer Lid (b)	Dropping Canister, Height 5.9 ft	5.60E-05	2.80E-01	Other than Nobel Gas	1.50E-04	3.60E-04
Handling	21a	Transfering Canister to Overpack (a)	Dropping Canister, Height 5.9 ft	5.60E-05	2.80E-01	Noble Gas	1.00E+00	1.00E-10
Handling	21b	Transfering Canister to Overpack (b)	Dropping Canister, Height 5.9 ft	5.60E-05	2.80E-01	Other than Nobel Gas	1.50E-04	3.60E-04
								Risk Handling
Transfer	26a	Lifting Storage Overpack from Helman Rollers with Overpack Transporter (a)	Dropping Overpack	0.00E+00	0.00E+00	Noble Gas	0.00E+00	1.00E-10
Transfer	26b	Lifting Storage Overpack from Helman Rollers with Overpack Transporter (b)	Dropping Overpack	0.00E+00	0.00E+00	Other than Nobel Gas	0.00E+00	3.60E-04
Transfer	27a	Moving Storage Overpack to Preperation Area (a)	Dropping Overpack	0.00E+00	0.00E+00	Noble Gas	0.00E+00	1.00E-10
Transfer	27b	Moving Storage Overpack to Preperation Area (b)	Dropping Overpack	0.00E+00	0.00E+00	Other than Nobel Gas	0.00E+00	3.60E-04
Transfer	28a	Holding Storage Overpack (a)	Dropping Overpack	0.00E+00	0.00E+00	Noble Gas	0.00E+00	1.00E-10
Transfer	28b	Holding Storage Overpack (b)	Dropping Overpack	0.00E+00	0.00E+00	Other than Nobel Gas	0.00E+00	3.60E-04
Transfer	29a	Moving Storage Overpack away from Prepration Area (a)	Dropping Overpack	0.00E+00	0.00E+00	Noble Gas	0.00E+00	1.00E-10
Transfer	29b	Moving Storage Overpack away from Prepration Area (b)	Dropping Overpack	0.00E+00	0.00E+00	Other than Nobel Gas	0.00E+00	3.60E-04
Transfer	30a	Transfering Storage Overpack on Asphalt to Storage Pad (a)	Dropping Overpack	0.00E+00	0.00E+00	Noble Gas	0.00E+00	1.00E-10
Transfer	30b	Transfering Storage Overpack on Asphalt to Storage Pad (b)	Dropping Overpack	0.00E+00	0.00E+00	Other than Nobel Gas	0.00E+00	3.60E-04
Transfer	31a	Transfering Storage Overpack on Gravel to Storage Pad (a)	Dropping Overpack	0.00E+00	0.00E+00	Noble Gas	0.00E+00	1.00E-10
Transfer	31b	Transfering Storage Overpack on Gravel to Storage Pad (b)	Dropping Overpack	0.00E+00	0.00E+00	Other than Nobel Gas	0.00E+00	3.60E-04
Transfer	32a	Moving Storage Overpack above Storage Pad (a)	Dropping Overpack	0.00E+00	0.00E+00	Noble Gas	0.00E+00	1.00E-10
Transfer	32b	Moving Storage Overpack above Storage Pad (b)	Dropping Overpack	0.00E+00	0.00E+00	Other than Nobel Gas	0.00E+00	3.60E-04
Transfer	33a	Lowering Storage Overpack onto Storage Pad (a)	Dropping Overpack	0.00E+00	0.00E+00	Noble Gas	0.00E+00	1.00E-10
Transfer	33b	Lowering Storage Overpack onto Storage Pad (b)	Dropping Overpack	0.00E+00	0.00E+00	Other than Nobel Gas	0.00E+00	3.60E-04
								Risk Transfer
Storage	34.1a	Storage	Overpack Tip-over due to Seismic Event	7.00E-07	1.00E-06	Noble Gas	1.00E+00	1.00E-10
Storage	34.1b	Storage	Overpack Tip-over due to Seismic Event	7.00E-07	1.00E-06	Other than Nobel Gas	1.00E+00	3.60E-04
Storage	34.2a	Storage	Overpack Struck by Aircraft	6.30E-09	1.40E-02	Noble Gas	1.00E+00	1.00E-10
Storage	34.2b	Storage	Overpack Struck by Aircraft	6.30E-09	1.40E-02	Other than Nobel Gas	1.00E+00	3.60E-04
Storage	34.3a	Storage	Overpack Struck by Meteorite	3.50E-14	1.00E+00	Noble Gas	1.00E+00	1.00E-10
Storage	34.3b	Storage	Overpack Struck by Meteorite	3.50E-14	1.00E+00	Other than Nobel Gas	1.00E+00	3.60E-04
Storage	34.4a	Storage	Overpack Headed by Aircraft Fuel	3.70E-09	0.00E+00	Noble Gas	1.00E+00	1.00E-10
Storage	34.4b	Storage	Overpack Headed by Aircraft Fuel	3.70E-09	0.00E+00	Other than Nobel Gas	1.00E+00	3.60E-04
								Risk Storage Ph Year)
								Risk 20 Yea

Figure 2. HI STORM 100 PRA data, adapted from Malliakos (2007)

2.2.3.1 General Assumptions

For evaluations based on sensitivity studies considering the probabilistic data of Malliakos (2007), the following assumptions are made:

1.) The integrity of the canister of the inspected dry storage system is comparable to the integrity of the Multi-Purpose Canister (MPC) that is part of HI STORM 100 system analyzed in the PRA (Malliakos, 2007).
2.) The integrity of the transfer cask of the inspected dry storage system is comparable to the integrity of the Holtec International Transfer Cask (HI TRAC) of the system analyzed in the PRA (Malliakos, 2007).
3.) The integrity of the storage overpack of the inspected dry storage system is comparable to the integrity of the overpack of the HI STORM 100 system analyzed in the PRA (Malliakos, 2007).

Other references used in the scope of the risk evaluations as presented within this document

include the PRA for a TN-32 dry storage cask (Canavan, 2004), a human reliability analysis for spent fuel handling (J. D. Brewer, 2012), and the classification of systems, structures, and components (SSCs) according to their importance to safety as outlined in NUREG/CR-6407 (J. W. McConnell, 1996) (Table 4), besides other.

Table 4: Categorization of SSCs according to safety (J.W. McConnell 1996)

Category	Criteria
A – Critical to safety	Failure of SSC could directly lead to loss of containment, shielding, or criticality control.
B – Major importance to safety	Failure of SSC in conjunction with failure of another item could lead to loss of containment, shielding, or criticality control.
C – Minor importance to safety	Failure of SSC likely does not affect the public health and safety adversely.

3. CONCLUSION

The combination of rationale document and tree diagram should provide the user (e.g., an NRC reviewer) with enough information to assess a requested changes to the dry cask storage and should improve the efficiencies in the review process as it makes LAR reviews more consistent in terms of resource allocation, depth, and breadth of the review.

4. FUTURE OPPORTUNITIES

There are multiple ways that have the potential to improve this tool. The primary steps for improving this tool would be to complete the next two tasks to incorporate the risks associated with transportation and other regulatory actions. Building experience will help improve the workflow when using this tool. Having NRC reviewers identify typical expectations from the utilities for varying risk categories will allow them to narrow down the expectations for both the review and the utility. Finally, the research activity that could lead to significant improvement in the tool would be the construction of additional dry cask PRAs and the gathering of more data on failures of the corresponding components and failures in operator actions and procedures associated with spent fuel loading, dry cask storage, and transportation. This could allow for a less conservative approach when assessing the risks inherent to dry cask storage. Probabilistic Risk Assessments could be designed for all portions of the used fuel cycle including wet storage, cask loading, and onsite dry cask storage, as well as transportation of the dry casks, to fully assess the areas of elevated risk to the general public.

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