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The Los Alamos National Laboratory Relative Risk Ranking and Expert Judgement Approach for Prioritization of Disposition of Legacy Nuclear Material Containers

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Abstract

The Los Alamos National Laboratory (LANL) incorporates results from a relative risk ranking (RRR) algorithm into a priority scoring (PS) algorithm to support risk-based prioritization decisions for legacy nuclear material container disposition and to report progress. Containers without an engineering design pedigree can present a risk for both workers and facility operations. Historically, there have been notable worker health impact incidents resulting in operational shutdowns and federal investigations. The RRR method utilizes both objective and subjective variables to assess the relative risk ranking of each container stored at LANL. These variables include measurable values such as container age, grams of nuclear material, dose conversion factors, respirable release fractions, etc.; along with expert judgement variables such as corrosivity, reactivity, pyrophoricity, and oxidative expansion potential. Los Alamos has been steadily addressing the disposition of legacy containers over time with continuous feedback and active management of relative risk. Recently, the risk ranking team identified 65 containers for accelerated repackaging, initially using the RRR method results and supplementing with expert judgement and information derived from container surveillance for similar container/content combinations. This assessment revealed opportunities for improving the RRR methodology, and identified several containers that the team viewed as equal or higher priority than those identified by RRR alone. The risk team concluded that although reduction in total RRR is a useful tool for reporting progress, additional considerations for prioritization should include other factors such as: 1) accounting for the polyvinyl chloride bag degradation, which off-gasses significant amounts of HCl for containers with high dose/heat load materials, 2) weighting older, non-pedigreed containers higher relative to younger pedigreed containers, and 3) researching details of containers and contents to supplement data from the nuclear material control and accountability database. An overview of the current RRR methodology, how it relates to the PS algorithm, and how it is used (including logistical and operational constraints) will be presented, along with the techniques used to assess and compile the 65 container list and how these may impact the RRR and PS methodology going forward.

1 – INTRODUCTION

In March of 2023, a memorandum was issued to responsible program and line organizations at the Technical Area (TA) 55 Plutonium Facility (PF, or the facility) identifying 65 elevated risk legacy containers prioritized for remediation by a team of subject matter experts on behalf of the Los Alamos National Laboratory's (LANL) Nuclear Materials Manager [1]. This memo carries the weight of an actionable directive given by the Nuclear Materials Manager, and requires each owning organization to schedule and remediate, by repacking, stabilization, and/or disposition, their respective elevated risk item(s) in the timeframe given. The timeframe was determined based on the relative risk between the 65 items and is intended to provide the greatest value in timely risk mitigation for the protection of the worker and facility operations.

The continued storage of legacy containers, or containers without an engineering design pedigree, poses risks to both worker safety and facility operations due a potential nuclear material release during routine handling and/or an accidental drop. Such a release, depending on the contents of the container, could result in both a worker intake (via inhalation) causing significant negative health effects and the contamination of a mission-critical operation within the facility. Depending on the intake amount, this leads to different investigative levels by the DOE into the conduct of operations (ConOps) at LANL, causing significant delays, costs, and a loss of trust from the DOE and the public.

In April 2003, a legacy Pu-238 container release during an MC&A inventory caused internal dose to workers sufficient to trigger the formation of a Federal Accident Investigation Board [2]. In December 2005, a legacy Pu-239 container release during an MC&A inventory also caused internal worker dose and resulted in a significant interruption in vault operations and an internal investigation [3]. It should be noted that neither of these events took place due to a container drop, but merely routine handling of legacy containers.

The memorandum requiring disposition of the 65 elevated risk containers is another significant event in a long history of legacy container identification and disposition efforts at LANL. Initial motivation for systematic legacy container disposition came from a 1994 Defense Nuclear Facilities & Storage Board (DNFSB) recommendation (94-1) with a follow on in 2000 (00-1). As a result, the Department of Energy (DOE) developed a complex-wide response via implementation plans from each site intended to remediate safety concerns related to nuclear material storage on a high priority basis. These plans included details for conversion, disposition, and stabilization of specific fissile materials for safe interim storage [4] [5]. The 94-1 recommendation also contained "guidance for interim safe storage of plutonium-bearing solid materials for a period of 20 years or less" and motivated the creation of the first "Standard" Nuclear Material Container (SNMC), a threaded lid vented nuclear material storage container designated as the "Hagan" [6] [7]. Additionally, these recommendations eventually led to the creation of the first risk-based prioritization algorithm in 2004 for high priority identification and disposition at LANL [8].

The recommendations evolved in response to progress and subsequent events into the issuance of DOE Manual 441.1-1, *Nuclear Material Packaging*, (or the Manual) in 2008, which is the primary regulatory driver of legacy container disposition today. With follow on improvements to the now named relative risk ranking (RRR) algorithm in 2007 [9], LANL responded to the Manual with an implementation plan in 2009 that was subsequently approved, which uses RRR in conjunction with the introduction of the SAVY-4000 nuclear material container series to achieve Manual compliance through the support of risk-based prioritization decisions and repackaging for legacy container disposition.

The SAVY-4000 nuclear material container series (or the SAVY) was introduced between 2008-2011 as the primary (of two, the other being the Fuel Storage Outer) Manually compliant nuclear material container for use in the facility for short term (interim) storage. The SAVY was designed specifically to meet Manual requirements to protect the worker from an airborne nuclear material release and currently has a design life of 15 years. Given the need to meet Manual requirements, containers at the facility were redesignated into two categories: standard containers and legacy containers. Standard containers include two sub-categories: Manually compliant containers (such as the SAVY) and Manually exempt containers (such as 3013s and some other container types that in the 2007-2014 timeframe were not candidates for disposition). Legacy containers also include two sub-categories: non-standard containers (such as taped slip lids, drums, paint cans, etc.) and Hagans, the previous SNMC. Hagans were considered "standard" containers until the introduction of the Manual and the SAVY. A significant number of the Hagans have associated non-conformance reports (NCRs) for quality deficiencies that occurred during manufacturing (i.e., weld and filter gasket), and are therefore split into normal Hagans (no NCRs, SNMC-1), Hagans with a filter gasket NCR (SNMC-2), and Hagans with a weld NCR (SNMC-3). The filter gasket NCR is the result of filter gasket material inhomogeneity, which causes early degradation. The weld NCR is due to improper helium leak testing of the tamper indicating device (TID) bar weld.

2 – THE RELATIVE RISK RANKING ALGORITHM

The RRR and the 2009 implementation plan are focused on reducing the risk to workers associated with the accident scenario of dropping a legacy container. RRR is based on the does to a worker from indoor airborne dispersion resulting from this drop from a specified height multiplied times a failure index (or failure probability). The equation for RRR is given below with conceptual equation following it.

$$RRR = RelativeDose * FailureIndex$$
$$(Risk = Consequence * Probability)$$

The failure index, introduced in 2007, is determined by multiplying $age/4$ times a reactivity index times a package factor (introduced in 2014).

$$FailureIndex = ReactivityIndex * \frac{Age}{4} * PackageFactor$$
$$(Probability = Material\ Reactivity * Age * Packaging\ Robustness)$$

The reactivity index is aimed to provide a relative rank of the likelihood of a release given a drop based on the material inside of a legacy container. It is based on subject matter expert scoring of the stored material based on the item's IDC and is not an absolute scoring, but a relative scoring for four material hazard characteristics - pyrophoricity, corrosivity, pressure, and oxidative expansion. An example is the compound plutonium chloride ($PuCl_3$) with an IDC of C19X, spill factor of 0.00006, reactivity of 5.19 based on scorings of 0.43, 2.57, 1.33, and 0.86 for pyrophoricity, corrosivity, pressure, and oxidative expansion respectively [9]. Age is divided by 4 so that containers with ages less than four get multiplied by a factor less than one. The package factor, introduced in 2014, is used to account for container type, which the reactivity index does not consider [10]. It is also based on expert judgment and is determined by the type of outer container.

The package factor is set to zero for Manually compliant containers (i.e., SAVYs) and Manually exempt containers (e.g., 3013s). Non-standards have a package factor of one and Hagans have a package factor of 0.4 unless they have an NCR. In that case they have a package factor of 0.6 or 0.8 for a filter gasket or weld NCR respectively.

The failure index is not actually a measure of probability and RRR is not an absolute, or "true" risk measure. It is a relative ranking based on dose and expert opinion as to a container's susceptibility to a release given the IDC (reactivity index) and an expert judgment ranking from zero to one based on outer container type (package factor). The dose calculation also depends on parameters determined by expert judgement. The RRR values are grouped into categories using the following scheme:

Table 1. RRR Category Thresholds

RRR Category	Lower Bound	Upper Bound
Low Risk	> 0	≤ 65.5
Medium Risk	> 65.5	≤ 377
High Risk	> 377	≤ 666
Very High Risk	> 666	N/A

It is unfortunate that these categories are labelled in terms of risk, they should be labeled as Low RRR, Medium RRR, High RRR and Very High RRR. These categories were also determined by experts based on the containers in the inventory at that time (circa 2014).

3 – DISPOSITION PROGRESS AND CURRENT PROCESS

The 2009 implementation plan focused initially on the "Very High Risk" RRR category results which consisted primarily of very old (>20 years) non-standard containers with highly respirable nuclear material contents (e.g., oxide). Using total RRR as a trackable metric for the overall health of the facility, the total RRR was reduced by approximately 30% through the disposition of non-standards over the course of five years (2009-2014) [11]. Today, there are no "Very High Risk" or "High Risk" containers remaining. However, to fully achieve Manual compliance, the facility must repackage or dispose of all legacy (not only non-standard) containers.

As of August of 2022, legacy containers remaining at the facility include 668 non-standards, 2649 Hagans (no NCRs, SNMC-1), and 85 Hagans with an NCR. Of the Hagan containers without an NCR, over 18% (more than 500) have been in storage beyond their original design life intent of 20 years and another 20% (approximately 530) are believed to be not fully sealed at the O-ring as suggested by design review, testing, and surveillance data [12].

Table 2. Legacy Container Types Remaining in the Plutonium Facility

Container Type	Current Total (As of August 2022)
Non-standards (non-Hagan)	668
Hagan (SNMC-1)	2649
Hagan with Filter Gasket NCR (SNMC-2)	14
Hagan with Weld NCR (SNMC-3)	71
Total	3402

As approved in the implementation plan, after the repackaging and/or disposition of the Very High Risk items the facility has transitioned to a more routine programmatically influenced disposition schedule [13]. This consists of the repackaging and disposition of legacy items during maintenance, disposition, and routine programmatic work. Additionally, the program presently uses a priority scoring (PS) algorithm for the disposition of legacy items based on the product of the following worker (W) and programmatic (P) impact parameters per container in the equation:

$$PS = A * B * C * D * E$$

$$A = RRR\ (W)$$
$$B = Location\ Type\ (P)$$
$$C = Non - standard\ vs. Standard\ Package\ (W)$$
$$D = Container\ Size\ (P)$$
$$E = Packaging\ Efficiency\ (P)$$

As shown above, PS includes RRR but emphasizes operational and programmatic needs providing flexibility for effective item disposition planning during changing facility conditions such as paused processing lines, unavailability of discard capability, and opportunities for increased throughput in specific operating lines. Therefore, a combination of the PS, operational efficiency, and programmatic work primarily influence current legacy item disposition, except for occasional high priority disposition memos influenced significantly by the RRR.

In recent years, high priority disposition memos have prioritized worker safety by identifying those containers that have a RRR exceeding the "High Risk" threshold score (>377) for disposition. A 2019 memo took a more proactive approach using RRR to predict and identify nine containers that would graduate to "High Risk" in the upcoming years (2019 through 2021). The memo put the responsibility on the owning organization to report the planned quarter for disposition and the planned method (e.g., repackaging, discard, stabilization) [14]. Then, a review of the RRR methodology in 2021 resulted in the concern that RRR alone was not adequate for identifying all of the highest disposition priority containers and that a more comprehensive assessment was needed [15]. Therefore, following the review of the 2019 memo with the 2021 assessment in mind, in 2022 the Nuclear Material Container Committee (NMCC) tasked the nuclear material container management, safety, and engineering team with updating the memo by identifying elevated risk containers for disposition in the upcoming year with the following expectations for the team's assessment: identify all containers with RRR exceeding the "High Risk" threshold as of April, 2022; identify containers that would exceed the "High Risk" threshold within the next five years; form a committee of experts (CoE) to review "Medium" RRR category containers for "High Risk" consideration; and include three non-standard containers exceeding the "High Risk" RRR threshold that were targeted for disposition in 2022. A total of 65 containers were identified as "elevated risk" and were placed on the draft 2022 memo that was issued on March 27th of 2023.

4 – THE 65 ELEVATED RISK LEGACY CONTAINERS

The CoE identified 65 containers as elevated risk for high priority disposition. The CoE consisted of 20 members, each with varying expertise in hands-on nuclear material processing, packaging, storage, shipping, disposition, and program/project management. Four approximately two hour meetings were held in April and May of 2022 where details about the entire LANL inventory of nuclear material could be shared, reviewed, and discussed. With such a large inventory, the containers were first screened and down selected using an augmented version of the RRR in conjunction with knowledge gleaned from in-depth item identification techniques and expert insight into each item's history.

Modifications to the RRR (or the augmented RRR) were based on the remediation of known limitations from the 2021 RRR assessment [15]. These modifications included: consideration of graduation date from "Medium" to "High" RRR; weighting of molten salt extraction (MSE) salts higher due to their high americium (Am) content; adjusting packaging factors of Hagans to better assess the relative importance of containers with and without an NCR; and considering the likelihood of bag out bag failure using a "Bag Degradation Factor" (BDF). The BDF uses the following equation:

$$BDF = power * \frac{Age}{(Container\ Radius)^2}$$

This weighs older, higher wattage, and smaller (radially) containers much higher than younger, lower wattage, and especially larger containers due to the presumed closer proximity of a bag out bag to the container content in the smaller containers. Surveillance data has shown that the degradation of bag out bags either by heat and/or radiolysis causes significant amounts of corrosion of the outer storage container, sometimes indicated by a corroding TID wire outside of the containment boundary, or white powder gathering around the external filter vent.

Additional item identification techniques were used to better understand the actual form and state of the items in question along with their packaging configuration. An item description code (IDC), used as a shorthand in the nuclear material control and accountability system, is given for each item and isn't always the most accurate at describing the actual material form due to incorrect entry, complexity of the material, etc. Therefore, in order to better understand the actual material form, the team first utilized the remarks section of the accountability system, followed by item history traces, non-destructive assay (NDA) reports, and even simply reviewing the item name which is not easily translated into a consistent variable form like IDC. If these methods failed, then leveraging subject matter expert (SME) knowledge was imperative, providing information such as the process history for process procedures active at the time of item creation, shipping records, or simply knowing the item personally from actually working and/or generating it.

The population was down selected into an initial list of 65 items, grouped into the six categories listed in Table 3. Containers placed on this list were determined to be of the greatest risk to facility workers and programmatic deliverables in the next five years. The number is arbitrary, but it was agreed that this would be a reasonable number to target for disposition and/or repackaging over the five year timeframe. The identification process involved searching and sorting the inventory by various criteria using the augmented RRR and aforementioned identification techniques to include the graduation date from "Medium" to "High" RRR (>377); containers with known (and tracked) external issues (e.g., corrosion or powder near filter); containers with MSE residues with high Pu-240, Pu-242, and/or Am content (known to cause significant corrosion); the likelihood of bag out bag failure determined by multiplying RRR by BDF; other high Am content containers suspected to have calcium metal (potentially pyrophoric and packaged outside current content limitations); and high does per gram curium items. Search criteria also included non-standard containers greater than 30 years old, containers with similar characteristics to items known to have plutonium metal in contact with plastic, and containers with high Pu-238 content.

Table 3. 65 Elevated Risk Item Categories and Quantities

Category	Description	# of Containers
High RRR	Containers graduating from "Medium" to "High" RRR within the next 5 years	22

Category	Description	# of Containers
Known External Defects	Containers with known (and tracked) external defects	11
High Heat Load MSE Salts	Containers with high Pu-240 and/or Pu-242 content in molten salt extraction (MSE) salts	25
High Bag Degradation Factor	Containers with high bag degradation factor (RRR * power (wattage) * age / container radius ^ 2)	3
High Americium	Containers with high Am content and calcium metal (procedural rules of use violation)	3
Curium	Container with curium (high dose per gram)	1

The committee of experts prioritized the initial list of 65 containers to identify containers for remediation in the next year and those for following years, and to allow for the possibility of swapping containers in and out of the high priority list. The prioritization process consisted of asking the entire committee to rate containers using scores shown in Table 4. Sixteen SMEs provided their ratings for all 65 containers. Respondents were provided an opportunity to explain their ratings and/or add additional comments. The survey ratings from the 16 respondents, along with their detailed comments, were collated for analysis into an Excel spreadsheet.

Table 4. Elevated Risk Items Ranking Description

Rating Value	Rating Description
5	**Highest priority** for repack (i.e., repack within a year)
4	**Medium priority** for repack (i.e, repack within five years)
3	**Lowest priority** for repack (i.e., when 3 and 2 are repacked revisit these)
2	**Not enough information** to categorize for repacking - investigate further – (e.g., radiograph, gather information, etc.)
1	This **item should not be on the list** (i.e., does not need repacking) (Please provide a reason for this choice)

To rank the containers based on the ratings, the scores for each container were grouped by the mode of the scores (the most frequent score). In case of a tie, the higher mode was used (for example, if 8 scores were 4 and 8 scores were 5, the mode of 5 was used). In each mode grouping the containers were then ordered (smallest to largest) by a measure of diversity or unalikability. This measure is described in [16]. The measure, denoted *u2* in the paper, basically sums up the number of disagreements between all possible pairs of respondent scores and normalizes the sum so *u2* varies from 0 to 1. A value of zero means all respondents agreed and a score of one means there was no agreement between respondents. The highest ranked containers are those containers with a mode of 5 and a *u2* of zero (complete agreement). It should be noted that there were no zeros in this exercise. The lowest *u2* score was 0.32, with 13 respondents agreeing on 5, two agreeing on 2, and one score of 4. In the case of tied *u2* scores for a mode group, ranks were assigned randomly within the mode group. Containers with mode 5 were put in the highest priority category. Within that category, containers were ranked based on *u2* (lowest-most agreement to highest-least agreement). Raters generally had higher agreement on non-standard containers and Pu-238 items being higher priority.

There was some additional expert judgment used to determine the final list. Based on the rating scores, there was high agreement that the six Hagans with weld NCRs should be done after all the others, so six non-standard containers were swapped with these for the final list. These non-standards had been reviewed by the CoE and were of concern, but they were not on the list of 65 that was rated. It was believed by the authors that if they had been on the list of 65, they would have had higher scores than the six Hagans.

5 – RESULTING NOVEL LIMITATIONS TO THE RRR

The process of down selecting and ranking the 65 elevated risk items resulted in additional insights into further limitations of the RRR. These limitations included: using IDC to fully understand the material characteristics; using the nuclear material control and accountability system data "at face value" to understand the packaging configuration; weighting age linearly instead of following a more practical lifetime representation such as the bathtub curve; not weighting certain materials high enough due to high worker safety concerns; and needing to reassess Hagan weighting due to known design issues.

Non-descriptive and/or incorrect IDC was a common issue during this process and necessitated the use of the in-depth material identification techniques. Unfortunately, no immediate techniques are available for improving this limitation as item name and the remarks field are not easily codified into consistent, trackable metrics.

Following closely to the IDC issue, the nuclear material control and accountability system has no input parameter for the inner packaging configuration of a given outer container. More recent procedures require this information to be input into the remarks field, but it still rarely is and is virtually absent for all legacy containers.

An interesting observation during this process was noting that age is weighted as a linear factor in the overall RRR score. This type of relationship is actually very unlikely given the failure rate tendencies by which most engineered products experience, that being a high initial "mortality" rate due to glaring unresolved design issues, followed by decreasing failure rate to a constant, normal "useful" life failure rate, and finally a rising end of life failure rate. This concept is known as the bathtub curve and is being seriously considered to better account for the ever-increasing importance of age on legacy container failure probability [17].

A few materials stored at LANL have what would be considered an unusually high worker health consequence compared to other materials. Examples include primarily Pu-238, as well as Am depending on the material(s) in which it is mixed. Compared to their RelativeDose value, the team believes that these materials present a much higher worker safety consequence given the extremely small amount that would have to be inhaled to cause a dose past the Manual threshold value for a single event [18]. This is compared to other materials as well, such as Pu-239, which requires an inhaled amount orders of magnitude larger than Pu-238, for example.

Finally, from historical and recent testing, surveillance, and design review of the Hagan container, the team has determined a need for the reassessment of Hagan weighting factors based on observed design flaws. These flaws are observed both during normal operating conditions (storage and handling) and accident condition testing (drop tests). During normal operation, the container design promotes closure errors such as crimping the O-ring while tightening, having no indication of a present O-ring, and under tightening of the lid due to a lack of positive closure or effective closure indication mechanism. This is combined with a non-standard groove size which leads to insufficient O-ring compression even if closed correctly. Corrosion is also an issue, with general corrosion and pitting both observed during surveillance, and stress corrosion cracking observed during accelerated aging studies. During accident scenarios, the Hagan has been drop tested with results showing that the lid can slip threads or come off completely [12]. This results in a theoretically large release, or an even larger release if combined and exacerbated by one of the common normal operating condition failures. This however is dependent on storage height, weight, container diameter, orientation, and manufacture date (two thread lids vs. four thread lids).

6 – CURRENT 65 ELEVATED RISK ITEM DISPOSITION PROGRESS, TRACKING, AND FUTURE WORK

Monthly status reports are currently provided by the nuclear materials management team for tracking the status of and pushing priority for the remediation of the 65 elevated risk items. As of April of 2023, four items have been dispositioned (or worked) with many more planned for this fiscal year.

In addition to monthly tracking updates, the team intends to perform an annual priority review of the 65 items. This review would determine if items need prioritization for a particular or different year. Additionally, these reviews would allow the team to understand how any new information from elevated risk item surveillance validates or invalidates assumptions and decisions made when originally selecting the items. The surveillance aspect is key to the methodology's validation, and the collection of the data will help to improve the overall risk-based prioritization and selection technique, as well as allow for better tracking and disposition of items.

Finally, the team plans to perform a complete and thorough evaluation of the 65 elevated risk item selection process and results. This would include documentation from multiple aforementioned annual reviews and the compilation of surveillance data from the 65 items. Additionally, the team would plan to collect other direct and/or incidental data on the 65 items such as new NDA reports. This, all in an effort to continuously improve the risk-based prioritization and selection methodology to ensure worker safety and Manual compliance to deliver LANL's national security mission now and in the future.

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