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RECENT IMPROVEMENTS IN THE K-AREA CRITICALITY SAFETY PROGRAM

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ABSTRACT

The K-Area facility at the Savannah River Site provides for the handling and interim storage of the United States' excess plutonium. Operations consist of plutonium storage in large arrays of shipping packages and surveillance capabilties that include various non-destructive analysis instruments and one glovebox. Through a philsophical shift and many technical improvements in the criticality safety documentation, the number of required controls has been significantly decreased.

Up through 2016, a suite of criticality safety evaluations was in place for all of K-Area's fissile material operations. These nine evaluations established requirements for 315 credited criticality safety controls. Among these evaluations, there was a high reliance on quantitative frequency analysis to demonstrate that the frequency of a criticality accident was less than 1E-6/year. These frequency analyses were used as justification that a criticality accident alarm system was not needed. The large number of controls was a result of using quantitative frequency analysis as well as performing very detailed computational analyses that implied many details were important to criticality safety and must be controlled.

Starting in 2014, a philosophical shift began to enable a change in approach for criticality safety in K-Area. The old approach determined how many controls were needed to quantitatively prove that the frequency of a certain upset event sequence would remain below 1E-6/year. The new approach determines which controls are needed to ensure that credible upset conditions will remain subcritical. During the same time, a new methodology was developed for assessing the need (or lack thereof) for a criticality accident alarm system (1). Instead of relying on quantitative frequency arguments, the new methodology asseses the aggregate risk of a criticality accident in the facility based on the nature of the fissile material processes and the complexity of operations, among other factors. This change in methodology enabled the abandonment of quantitative frequency analyses.

In the past five years, the nine criticality safety evaluations have been revised, consolidated, or replaced altogether with new evaluations. These new evaluations employ more reliance on American Nuclear Society standards, handbook values, and hand calculation methods. These new evaluations rely less on Monte Carlo calculations and do not rely at all on quantitative frequency calculations. The result is five evaluations that contain a total of 100 controls, which is a reduction of 68%. At the same time, operational capability, throughput, and efficiency have been increased.

In this paper, the philosophical change and technical improvements will be presented, and the resulting elimination of controls will be discussed.

INTRODUCTION

K-Area operations primarily consist of storage and warehouse operations for the United States' excess plutonium. To demonstrate the safety of long-term storage of plutonium, K-Area also has non-destructive and destructive examination capabilities. K-Area operations are housed in a Cold War era reactor facility that has been modified for the current missions.

In the early 2000s, K-Area began accepting shipments of plutonium in Type B shipping packages, primarily 9975s. K-Area stores nuclear material in shipping packages until a final disposition path is determined. The main storage area is the Material Storage Area (MSA), where shipping packages are stored in large, 3-high arrays. Removing product containers from their shipping package is prohibited.

Figure 1 K-Area Material Storage Area

In the mid-2000s, K-Area began surveillance activities on the stored plutonium using non-destructive and destructive examination in the K-Area Interim Surveillance (KIS) Vault. The KIS Vault has contained active and passive non-destructive analysis (NDA) instruments and one dry glovebox for destructive analysis. The KIS Vault has a gaseous fire suppression system and firefighting with water is prohibited.

In 2014, an effort was begun to make large-scale improvements in the K-Area criticality safety program. The goal of this effort was to make the quantity and quality of criticality controls commensurate with the complexity of operations in K-Area. The number of controls was excessive, and the heavy reliance on controls driven by quantitative frequency analyses was not appropriate for K-Area operations.

CUTTING THE TIE BETWEEN CAAS AND FREQUENCY ANALYSES

The first step in making large-scale improvements to the K-Area criticality safety program was to eliminate the reliance on quantitative frequency analysis to determine the need for a criticality accident alarm system (CAAS) [also referred to as a nuclear incident monitor (NIM)]. If it could be demonstrated that a CAAS was not needed based on an assessment of aggregate risk, then the quantitative frequency analyses, and the resulting controls, that had been utilized could be eliminated.

DOE-STD-3007-2007 (2) specifies that a CAAS needs analysis be performed for facilities where the inventory of fissionable materials exceeds the threshold levels provided in ANSI/ANS-8.3-1997 (3). DOE-STD-3007-2007 states, "The purpose of an alarm system is to reduce risk to personnel. Evaluation of the overall risk should recognize that hazards may result from false alarms and subsequent sudden interruption of operations and relocation of personnel." A holistic CAAS needs analysis was performed for K-Area for the first time in 2014, and a summary of the method was presented at a meeting of the American Nuclear Society (1). The CAAS needs analysis primarily focused on the fissile form and complexity of operations in K-Area. Only fissile oxides and metals are stored, handled, or processed in K-Area. There are no fissile solutions, which eliminates the largest risk factor for a criticality accident. Operations are very simple in K-Area, mostly consisting of storage, internal transfers, and accountability measurements with fissile material in Type B shipping packages, which provides significant safety margin. Product containers are handled in the KIS Vault with strict mass limits. Dry fissile oxide is processed in a single glovebox, where there are no plumbed liquids. All of these considerations factor into the conclusion that a CAAS would not decrease the overall risk to the workers, and, therefore, a CAAS is not recommended. Once this document was issued, it was no longer necessary to perform quantitative fault trees to prove a frequency of criticality of less than 1E-6, and the analyses that relied on these fault trees could be revised to include more appropriate qualitative arguments.

CUTTING THE TIE BETWEEN FREQUENCY ANALYSES AND OVERMASS

Previous criticality safety evaluations had invoked a control that required the performance of quantitative fault tree analyses to prove that the total frequency of overmassing a shipping package by more than 1 kg was less than 1E-6/year. A total frequency of less than 1E-6/year meant that each shipping package had to have a frequency of overmass on the order of 1E-10 to 1E-14. Each shipping facility had to determine their frequency of overmass based on their process for packaging and implementing enough controls to ensure such low frequencies. Even for foreign shippers, K-Area would send personnel to the shipping facility to audit their processes and paperwork to verify compliance with the fault tree controls. This was a very expensive and resource-heavy task.

Since K-Area is primarily a storage facility, overmass events are driven by the production, handling, storage and packaging processes at the facilities where the material is generated and prepared for shipment. In most cases, these facilities are not at SRS. However, a realistic likelihood and extent of an overmass had never been determined. To evaluate the likelihood and extent of a potential overmass event, the records of over 5,000 shipments of Type B shipping packages were reviewed by a team consisting of material control and accountability, engineering, and criticality safety personnel. This includes every shipping package received in K-Area, where NDA measurements with a passive neutron multiplicity counter are performed as part of the receipt process. Approximately 4% of measurements are outside the acceptable measurement uncertainty, and these items receive further, more accurate measurements, including calorimetry, gamma isotopic measurements, or active neutron multiplicity measurements. In the 15 years and over 5,000 shipping packages received in K-Area, an overmass beyond instrument uncertainty has never been discovered. In addition to these nondestructive receipt measurements, destructive analysis has also been performed on many items. These items include Pu oxide that is examined in the KIS glovebox and fissile items that have been dissolved in H-Canyon. Although an overmass has never been discovered with these items, there have been some discrepancies between shipper values and actual mass values. All the items with mass discrepancies were Pu oxide originating from Rocky Flats and have been attributed to errors in convenience can tare weights. This data, along with engineering judgement, factored into the conclusion that credible overmass events are bounded by 10% of the mass limit.

In order to eliminate the control that required quantitative overmass frequencies be determined for each shipping facility, the hazards analysis had to be completely redone. The first step was to assemble a hazards analysis team with the appropriate disciplines – engineering, operations, nuclear safety, and criticality safety. Prior to starting the hazards analysis, education was provided on how to perform a proper hazards analysis for criticality safety. Concepts such as unmitigated, normal, and credible were discussed. It was also emphasized that the end goal was to determine credible upsets that could result in a criticality accident, not just upsets that could affect a parameter related to criticality. If an upset could not credibly result in a critical configuration, then it does not require criticality safety controls. This concept should be obvious, but it was not obvious for some members of the hazards analysis team that had been involved in the prior criticality safety evaluations. This education was crucial to ensure that the team was starting with the same understanding of terminology and concepts.

Redoing the hazards analysis resulted in many changes to the criticality safety controls, some of which will be discussed in the next section. For the overmass event, establishing a mass limit (without specifying the particular implementation of the mass limit, e.g., weighing multiple times or maintaining inventory records in a specific manner) was deemed sufficient to prevent a criticality accident due to overmass. Moreover, new analyses showed that certain controls primarily serve to define the process, rather than to provide safety margin. For example, it is not a practical concern to overload a shipping package with dry Pu oxide to the extent that a criticality accident will occur. Other upsets would have to occur concurrently. Nevertheless, it is appropriate to implement a mass control to make the necessary analyses tractable and consistent.

METRICS AND OTHER IMPROVEMENTS

Along with eliminating the control that directed a fault tree be performed for overmass events, the hazards analysis team also eliminated many more controls. One such control that was eliminated was the stacking limit. Normal storage conditions are three tiers because other safety disciplines impose that limit. In previous analyses, stacking shipping packages was limited to three tiers high for criticality safety purposes as well. However, the shipping packages provide sufficient spacing between fissile units such that the fissile units are nearly isolated. There is very little interaction between fissile units inside shipping packages, especially in the vertical direction. Monte Carlo simulations were run that show that up to 10 tiers high was still subcritical. The hazards analysis team determined that only 4 tiers high was the credible upset condition, and since this had been shown to be subcritical, no criticality safety controls were needed. In addition, a pallet of shipping packages falling from the credible 4^{th} tier was considered, due to potential damage and increased interaction between units. However, the hazards analysis team (with help from engineering evaluations) concluded that damage from a fall from the 4^{th} tier is bounded by damage from a forklift crash, which has also been shown to be subcritical. Therefore, no stacking limits are needed for criticality safety purposes.

Many other controls have been eliminated by relying less on Monte Carlo simulations and relying more on American Nuclear Society standards, handbook values, and hand calculation methods. For example, since the new hazards analysis concluded that 10% was the maximum credible overmass in Type B shipping packages, hand calculations were used to demonstrate that the 10% overmass is subcritical (4). As another example, mass limits in the KIS Vault are now compared against the oxide mass limits from ANSI/ANS-8.1-2014 (5) to demonstrate subcriticality.

Previous analyses were segmented by location in the facility, although they usually had the same controls and limits. Even though the intent of the controls was the same, the wording was often slightly different and would sometimes drive slightly different implementation. This could cause problems with the interfaces between the documents, especially when shipping packages had to be transferred between areas. To eliminate these redundant or inconsistent controls, three criticality safety evaluations were consolidated into one evaluation (6), effectively combining multiple areas into a single process. Previously, when a change needed to be made to the process that affected a control, three documents had to be revised and approved. Now, only one document has to be revised. This has significantly reduced the administrative burden on the criticality safety staff to maintain these documents as well as engineering staff that must evaluate all changes against the current KAC safety basis documents.

One key to making such large-scale changes was to garner stakeholder support early and often. The primary stakeholders are operations management, criticality safety program management, and the regulator. Meetings were held routinely with each of the stakeholders to explain the changes, the technical justification supporting the changes, to elicit any questions or comments, and to get their buy-in. Obtaining the regulator's buy-in early in the project was especially important because the regulator had expertise in fault tree analysis and their proper use.

From 2014 to 2019, significant changes have been made to the K-Area criticality safety documents. A summary of the changes is provided below in Table 1.

Table 1 Changes Between 2014 and 2019

	2014	2019	Change
# of Evaluations	9	5	↓44%
Pages	729	363	↓50%
References	284	147	↓48%
Assumptions	60	3	↓95%
Design Features	85	25	↓71%
Programs	50	10	↓80%
Admin Controls	155	50	↓68%
Limits	25	12	↓52%
Total Controls	315	100	↓68%

Some of the metrics in Table 1 may seem superficial, such as number of pages or number of references. However, these metrics represent an administrative burden that should not be underestimated. When a document is revised, it invokes a cumbersome process of reviews and approvals. Also, the references must be maintained and reviewed to ensure their continued applicability. The more documents (and the longer the documents) there are, the more difficult it is for operators, supervisors, and engineers to know and understand the criticality safety controls, limits, and the undergirding technical justifications. Also, the more documents there are, the more difficult it is to ensure the interfaces between the documents are properly addressed. Therefore, there are many advantages to having fewer, simpler documents.

The simplified control sets for KAC activities, greatly reduce opportunities for infractions. This is a double benefit because it not only reduces efforts to respond, categorize and document the issue, but it eliminates the associated interruptions of normal activities in the affected area. Having excess and overly-conservative controls also potentially creates a “cry wolf” syndrome where the violation of a control appears to be a serious infraction when, in fact, that control contributed very little to the safety margin in the facility. Having the proper number of robust controls commensurate with the complexity of the operation solves this problem.

The overall reduction in controls from 2014 to 2019 is 68%. At the same time, operational capability and flexibility have been improved. Mass limits in the KIS Vault and several shipping packages have been increased, so that multiple batches or shipping packages are now allowed to be processed concurrently. Controls that existed only to specify implementation have been eliminated.

It is difficult to assign a monetary value to these control changes. Money saved is rarely easy to quantify because it is a cost avoidance in terms of increased efficiency and reduced overhead. However, a white paper was generated to estimate the monetary value of eliminating the most onerous control – the control that required a quantitative frequency be determined for an overmass event. The whole process of generating and implementing the overmass fault tree controls is estimated to cost USD $106k per shipping facility/process. If this value is applied to all 30 shipping facilities/process, the overmass control is estimated to have cost USD $3.18M.

CONCLUSION

Significant changes have been made to the K-Area criticality safety program over the last five years. These changes began with cutting the tie between frequency analyses and the need for a CAAS. This change enabled the elimination of frequency calculation for overmass events. The changes continued with a large-scale consolidation of criticality evaluations and eliminating 68% of the controls per a new hazards analysis.

The benefits of these changes are 1) a reduction in the need to perform supplemental analyses, 2) reduced costs in the forms of overhead and lost operational time due to infractions, 3) increased operational flexibility and capacity, and 4) improved understanding of the actual safety posture of the facility.

REFERENCES

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