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Summary: This document contains a quantitative and qualitative Event Tree (and associated write-up) that evaluates the likelihood of a criticality from a solution spill in which a vacuum cleaner is used. This was generated as a result of a recent vacuum cleaner solution spill while being transferred outside of Recovery.

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From Ron Green, Nuclear Criticality Safety Engineer	or Ref. - NCS-2007-224
Subj. Safety Concern Analysis for the Risk Analysis of the Criticality Potential from Solution Spills in Uranium Processing Operations	Date September 25, 2007

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1.0 Introduction

This Safety Concern Analysis documents a study of the likelihood of a criticality event as a result of a spill in a uranium processing facility. This study is limited, however, to the use of vacuum cleaners in association with such spills. An unanalyzed event occurred on 7-26-07 in which solution containing possible uranium bearing material was spilled out of a vacuum cleaner and collected in a potentially unfavorable geometry configuration. As a result, an event sequence was established to evaluate the risk of such a condition resulting in a criticality. Most or all of the events for this scenario are essentially random (either loosely controlled or not controlled at all), but it is valuable to learn if such an occurrence is credible, and if so, how likely it is. An Event Tree was utilized to identify a pathway to a criticality for the sequence of events that could occur as a result of a solution spill in one of the uranium processing areas. The Event Tree was modeled both quantitatively and qualitatively. One Event Tree assigns probabilities to event sequences in order to quantify the likelihood of a criticality. The other Event Tree assigns estimates of likelihood to event sequences in order to look at the scenario from a more traditional double contingency perspective. Both Event Trees model the same sequence of events.

2.0 Process Description

Raschig ring vacuum cleaners are used daily within the facilities that process uranium. The use of vacuum cleaners is normally for cleanup of low concentrated uranium solutions or uranium contaminated solutions. Most of the liquid collected is from floor washing, rain water, condensates, or wash solution following cleanup of small spills. More than 95% of solutions come from floor washing. Although vacuum cleaners are not procedurally restricted from collecting highly concentrated fissile solutions, in practice it is rarely done. Fissile solutions must be returned to the process system, typically to primary extraction. Collecting such solutions introduce soaps and other contaminants that adversely affect the extraction process. Therefore, other methods are used to collect fissile spills.

When a spill occurs, A and B samples are taken to determine the uranium content. If it is determined to be a fissile spill, the solution is collected manually (usually via sponges) and placed into favorable geometry bottles. After this collection is complete the area where the spill occurred is washed down. The wash solution is subsequently collected in a Raschig ring filled vacuum cleaner. Such solution typically contains less than gram quantities of uranium. When the vacuum is full, or in need to be emptied for other various reasons, the solution is measured for uranium content and either dumped into a waste drain, diluted and dumped into a waste drain, or returned to the process system, depending on measured uranium content.

In the rare instance when a vacuum cleaner is used for cleanup of fissile spills, the solution is measured for uranium content and returned to the process system as soon as possible. Such vacuum cleaners are never stored or transferred outside of the processing area.

3.0 Event Tree Analysis

An Event Tree was chosen for this Safety Concern Analysis since the sequence of events for this scenario is well defined and limited. As mentioned previously, the Event Tree was evaluated both quantitatively and qualitatively and is presented as Appendix A and B, respectively. For the quantitative Event Tree, simple probabilities are readily established for each event sequence using process history data and estimations based on expert opinion. Once the event sequences were defined and frequencies were input into the tree, the overall probability of a criticality event was determined. The qualitative Event Tree uses the same basic data, but the estimate of likelihood for each event sequence was determined based on a sliding, qualitative scale.

3.1 Accident Analysis

Small fissile spills do not represent a credible pathway to a criticality since multiple spills would need to occur to collect enough fissile solution within a single vacuum cleaner such that a criticality could occur. Fissile spills are not normally collected in vacuum cleaners and are rare compared to everyday use of vacuum cleaners. It is highly unlikely that multiple spills would occur and be collected within a single vacuum, regardless of procedures for collecting such. Hence, the scenario evaluated in this analysis is based on the occurrence of a single, large volume spill. Additionally, general spills within the uranium processing area will not credibly result in a criticality since the solution will form a safe slab. Only those vacuum cleaners transferred outside of the processing facilities have a credible potential to collect in an unfavorable geometry configuration.

The available volume of solution collected within a vacuum is approximately 30 liters. The critical concentration [see NCS-2006-265] for bare 30 liter sphere containing fully enriched $UO_2(NO_3)_2$ solution is 45 g U^{235} per liter (see Figure 1). This corresponds to a mass of 1350 grams U^{235}. This is approximately the minimum critical mass for this type of system. The minimum critical volume for fully enriched $UO_2(NO_3)_2$ solution is 14 ¾ liters at a concentration of 300 g U^{235} per liter. Thus, the initiating event for this scenario is a spill that is greater than 14 ¾ liters with a concentration exceeding 45 g U^{235}/l.

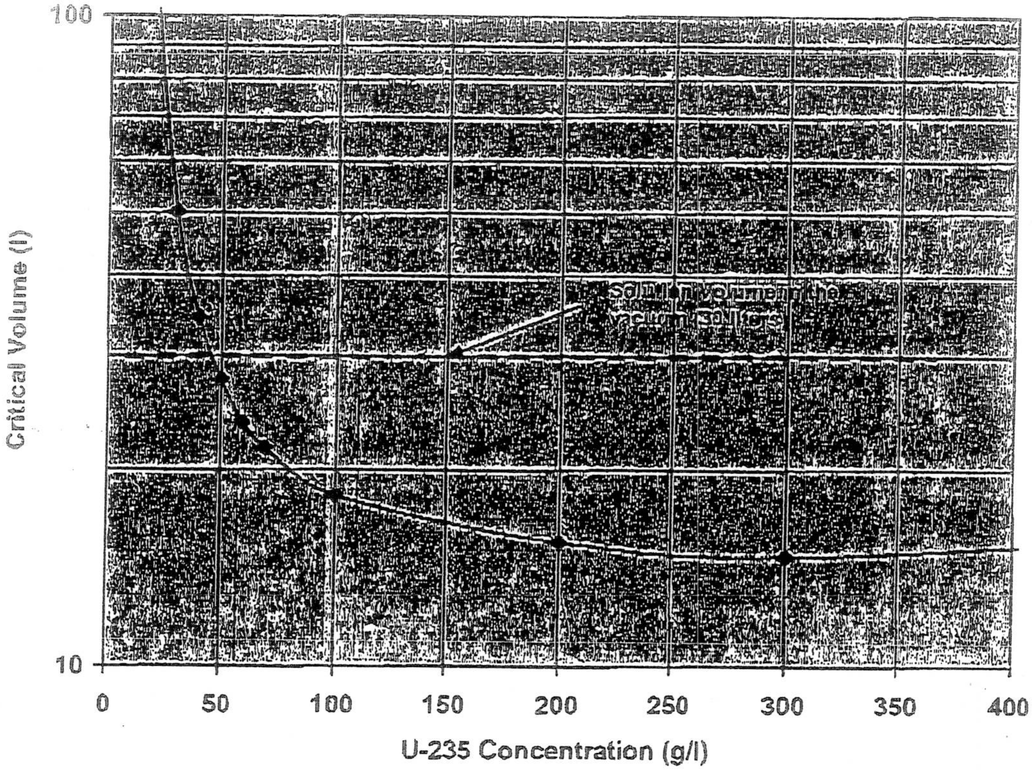


Figure 1: Critical Volume for Full Enriched $UO_2(NO_3)_2$ Solution in a Bare Sphere

As mentioned before, vacuums are not normally used for cleanup of fissile spills, so either personnel would have to violate normal practice to cleanup the solution with the vacuum, or a special need would arise in which using a vacuum would be the preferred method of cleanup, such as a very large fissile spill. Once collected, such a solution would be required to be returned to the process system. The solution would not be stored inside the vacuum cleaner and the vacuum cleaner cannot be transferred outside of the facility. In the unlikely event the solution remained within the vacuum cleaner, it would subsequently have to spill out of the vacuum and collect into an unfavorable geometry configuration before a criticality could occur. As mentioned previously, such a condition is not credible unless the vacuum cleaner is being transferred outside the facility.

3.2 Data Analysis

The Event Tree utilizes two types of data for event sequences, quantitative and qualitative. Both sets of data are based on likelihood of occurrence, but one set uses hard numbers to establish risk while the other approaches risk from a standpoint of double contingency by looking at a series of unlikely and concurrent changes in process conditions.

3.2.1 Quantitative Analysis

The event probability data developed for the quantitative Event Tree was established such that the sequence probability was based on an annual frequency. Hence, the initiating event is given as a probability of occurrence in any given year. Subsequent events are given as unitless probabilities based on occurrence of the initiating event. Process history/operational experience along with expert judgment were used to determine event probabilities. Several process engineers were consulted during the process of establishing the probability data, one of which has worked at the plant for 40 years. NCS engineers and other cognizant plant personnel were also consulted as part of this analysis. The following basis is applied to determine each event probability.

Initiating event – Large, highly concentrated fissile solution spill occurs

As described previously, large solutions spills are defined as those that are greater than 14 ¾ liters in volume with a U^{235} concentration in excess of 45 g/l. Based on process history it is conservatively estimated that these events occur once every 5 or 6 years, with the last one occurring approximately 4 years ago. The conservative value of 1 every 5 years was chosen for the initiating event resulting in probability of occurrence of 0.2 per year.

Vacuum cleaner used to collect highly concentrated fissile solution spill

Even though a large spill is assumed to occur, it is not likely that a vacuum cleaner would be used for cleanup. Contaminants present within vacuum cleaners, such as soap, cause severe problems when introduced into the uranium extraction process. Even fairly large spills of 20-30 liters would preferentially be collected without the use of vacuums. Operations personnel know of only one occasion of using vacuum cleaners to collect large fissile spills, though one engineer believed it may have happened one other time. Using the more conservative number of occurring twice, and based on the initiating event of 10 such spills during the life of the plant (once every 5 years), the probability used for this event is 0.2.

Highly concentrated fissile solution spill left in the vacuum cleaner

MC&A requirements are such that fissile solution collected within a vacuum cleaner must be constantly monitored. Such solutions are returned to the process as soon as possible and are not stored or transferred outside the area. Based on discussions with engineering and operations personnel, it is conservatively estimated that the probability of leaving such material unattended and subsequently transferring it outside the facility is one chance in a thousand. Hence, the probability for occurrence of this event is 0.001. (Note: transfer of vacuum cleaners outside of the uranium processing areas typically occurs during inventory (once every six months) and only involves a few vacuums. The chance that fissile solutions were collected and stored, and then subsequently transferred out of the facility is remote. Normally the transfer from process areas that have fissile solutions involves return of empty vacuum cleaners, which were previously sent to Recovery to process low-level uranium contaminated solutions.)

Highly concentrated fissile solution spill during vacuum cleaner transit

Vacuum cleaner transit is defined here as an unusual movement of a vacuum using a forklift, cart, truck, or some other miscellaneous device. This does not include normal movement (sliding, pushing, etc.) that occurs during use. Such movement is not applicable to the type of transit that occurs when a vacuum is moved outside the processing facilities. Solution spills from normal use will result in material spreading into a safe slab configuration within the processing area, thus they are ignored. (Note: Engineering/Operations personnel could not recall any vacuum cleaner spills during normal movement. Not including these movements in the event probability actually raises the probability of occurrence. Therefore, ignoring ordinary movement spills is conservative.) Per plant history, it is estimated that 25 vacuum cleaners are transferred per the criteria defined above. This results in 1,000 vacuum cleaners being transferred over the past 40 years. Since it is believed that only one vacuum cleaner has ever spilled during transit during this time period, the probability of occurrence of this event is 0.001.

Highly concentrated fissile solution collects in an unfavorable geometry configuration

As mentioned earlier, fissile solution spills within the process facilities cannot credibly result in a criticality. Spills outside the area could end up in an unfavorable geometry if they are bagged, and collect in such a bag, or they collect in a low spot or drainage ditch. Most vacuum cleaner transfers are single bagged, not double bagged. It is expected that the Raschig rings would remain with the solution when vacuums are single bagged, but less likely for cases where double bagging is used. But even during cases where the solution is separated from the raschig rings it would require a significant amount of solution to exceed the ~ 3-in slab required to support a criticality. Similarly with non-bagged vacuum cleaners, it is expected that most spills will spread out and remain below a 3-in slab height. Solution that spills into sewer drains will be immediately diluted from the flowing water within. Taking this into account, it is conservatively estimated that given a fissile solution transfer spill from a vacuum cleaner, an unfavorable geometry configuration capable of supporting a criticality event would occur one time out of ten. Therefore, a probability of 0.1 is used for this event.

3.2.2 Estimated Frequency of Occurrence

The estimated frequency of occurrence of a criticality as a result of a vacuum spill is 4.0E-9 per year of operation, which is incredible. Even assuming that every vacuum cleaner spill would result in an unfavorable geometry configuration, the probability of occurrence is still 4.0E-8 per year of operation, which is also incredible.

3.2.3 Qualitative Analysis

The qualitative Event Tree relies on the same data as above but bases risk on how likely the events are and whether they are anticipated to occur during the life of the plant. Each possible scenario outcome can be judged to be likely, unlikely, highly unlikely, or not credible. Based on the criteria described in Section 3.2.1, the following qualitative estimates are assigned:

Initiating event – Large, highly concentrated fissile solution spill occurs

This initiating event is unlikely, but anticipated to occur more than once during the life of the plant.

Vacuum cleaner used to collect highly concentrated fissile solution spill

This event is unlikely, but anticipated to occur more than once during the life of the plant.

Highly concentrated fissile solution spill left in the vacuum cleaner

This event is unlikely and not expected to occur during the life of the plant.

Highly concentrated fissile solution spill during vacuum cleaner transit

This event is unlikely and not expected to occur during the life of the plant.

Highly concentrated fissile solution collects in an unfavorable geometry configuration

This event is unlikely, but may occur given a vacuum cleaner spill.

4.0 Double Contingency

The Double Contingency Principle is defined in SNM-42 as the following: "Process designs shall incorporate sufficient factors of safety to require at least two unlikely, independent, and concurrent changes in process conditions before a criticality accident is possible." Typically this is met by evaluating credible process upsets and establishing limits and controls on operations such that two separate barriers exist to prevent a criticality. This approach can also be extended to unlikely and highly unlikely events, providing such events are independent, even in the case where limits and controls were not strictly established.

The qualitative Event Tree shows that five unlikely events, including the initiating event, must occur before a criticality is possible. However, three of the events are expected to occur during the life of the plant. Additionally, Events 1 and 2 are not independent from each other, as is the case with Events 4 and 5. But clearly Events 3 and 4 are both unlikely (and not expected to occur during the life of the plant) and independent from one another. From the perspective of barriers, the first barrier against a criticality is that it is unlikely that high concentrated fissile solution will be collected and left within a vacuum cleaner. The second barrier is that it is unlikely for a vacuum cleaner to spill solution during transit such that a critical configuration could result. The first barrier combines the first three events in the Event Tree, and the second barrier combines the last two. Both barriers are unlikely to highly unlikely and are independent from one another. Barrier one relates to concentration/mass parameters, and barrier two relates to geometry. Hence, this scenario meets the requirements for double contingency.

5.0 Results/Conclusions

The result of this Event Tree Analysis shows that a criticality as a consequence of a vacuum cleaner spill is not a credible scenario. The primary reason for this is that only under unusual circumstance are vacuums used to collect fissile solutions that could potentially lead to a criticality event. Most vacuum cleaner solutions contain less than gram quantity concentrations of uranium and are simply discarded to the waste system. It is very unlikely that any significant quantities of fissile material would ever be transferred outside of a uranium processing facility in such a vacuum. Combine this with the fact that dropping and spilling any individual vacuum cleaner is an unlikely event results in such a scenario being an incredible event.

Criticality safety evaluations of process systems are typically limited in scope to only evaluate credible upset conditions that can lead to a criticality. Once identified, limits and controls are established to ensure that two independent and unlikely concurrent changes in process conditions occur before a criticality is possible (i.e., double contingency). Scenarios deemed incredible are usually not identified nor controlled in an NCS evaluation. (The fact that a vacuum cleaner spill similar to the one that occurred recently is not documented in an NCS evaluation is neither surprising nor deficient. Many similar scenarios, such as meteor strikes, are simply dismissed during the evaluation process.) Per recollection of long term employees, this is the first time they recall a vacuum cleaner being dropped and spilled. This alone is an unlikely event. But even with this event occurring and assuming the spill collected in a geometry that could support a criticality (which is doubtful in this case), we are still left with a 4.5E-5 probability of a criticality event, which is barely credible at that point. Hence, since the accident sequence as defined by the Event Trees was determined to be incredible, no additional IROFS are required for vacuum cleaner use.

Prepared by: ______________________
Ron J. Green

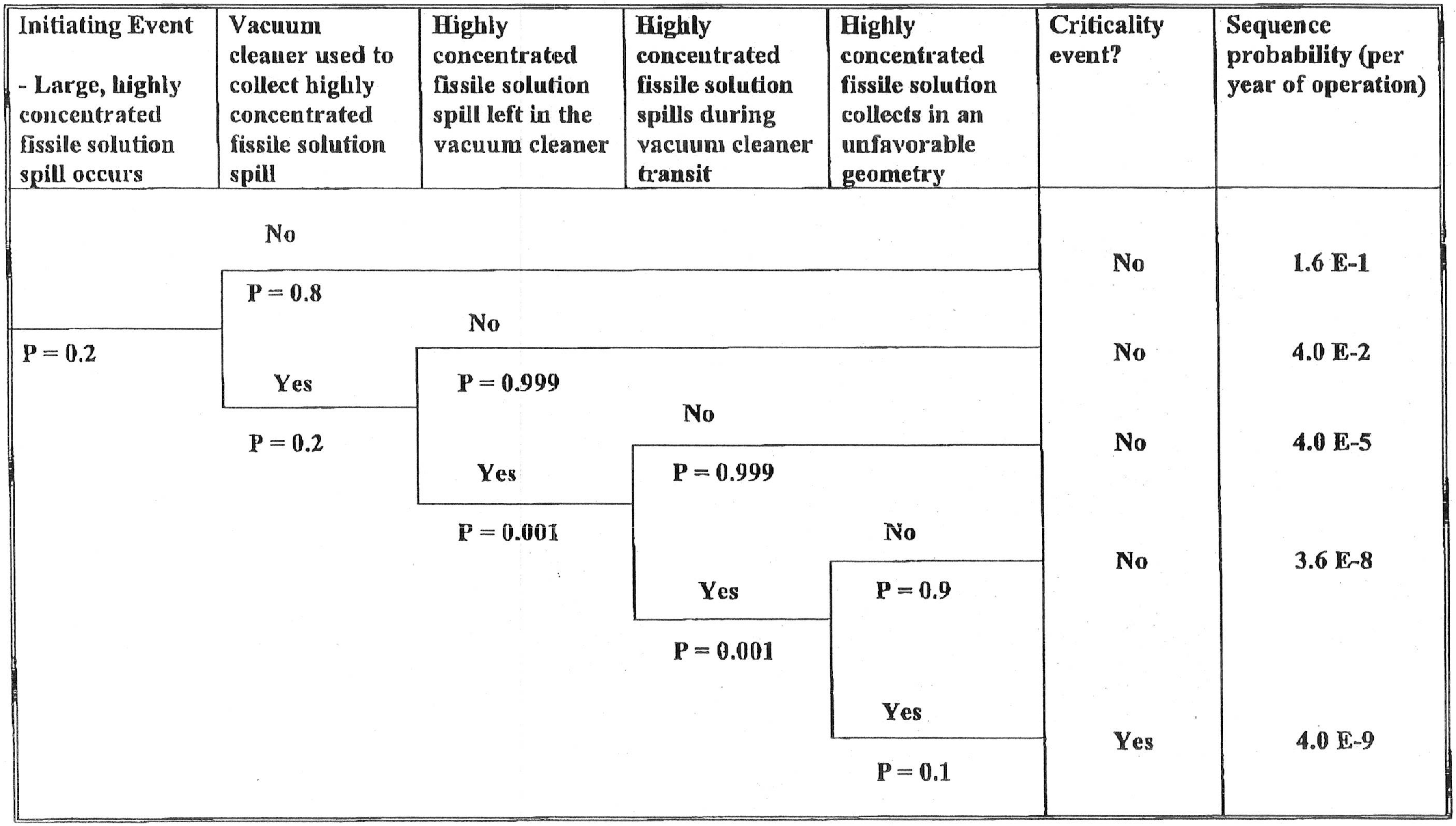
I have reviewed this Safety Concern analysis in accordance with NCSE-02 Rev. 33.

a. The analysis report meets the requirements of this procedure.
b. The methods used are acceptable and permitted by SNM-42.
c. Computer calculations, if performed, have been properly modeled and executed (N/A state the number of computer runs checked).
d. The basis for the judgment is valid.

The conclusions, recommendations, and requirements are valid and acceptable.

QA'ed by: ______________________
Larry L Wetzel

Appendix A: QUANTITATIVE EVENT TREE FOR VACUUM CLEANER SPILL



Appendix B: QUALITATIVE EVENT TREE FOR VACUUM CLEANER SPILL