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Material Limits Adjusted by a Modified Airborne Release Fraction

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This paper will discuss the methods used at a depleted uranium facility to develop a hazard categorization and a limiting condition for operation (LCO) for the inventory based on increased Category 2 threshold quantity values (TV) from DOE Standard 1027-92. A revision to the safety analysis report (SAR) for a Category 3 depleted uranium facility was required to meet current methodologies and isotope content. The previous SAR first approved in 1992, allowed an inventory of depleted uranium that exceeded the Category 2 threshold quantity values in the material storage warehouses using an accident analysis methodology for final hazard categorization. New information regarding the isotopic content of the depleted uranium required an updated hazard categorization evaluation. The DOE Standard 1027-92 requires the evaluation to be based on inventory (Reference 1, 3.1, page 5), therefore, the previous method of performing a hazard consequence and probability analysis could not be used. The standard (1027) requires a facility to be designated as a Category 3 Nuclear facility when the inventory levels in the facility, or facility segments, are greater than Category 3 thresholds and below Category 2 thresholds. A Category 2 Nuclear Facility requires a more in depth hazard and accident analysis. Our categorization was based on an inventory, adjusted by a form and containerization analysis.

The process we used started with an evaluation of the current operational requirements. This included a review of the current depleted uranium inventory, both in storage and in the manufacturing process. The existing hazard analysis was also reviewed. The hazard analysis also required modification due to the elimination of chemical processes. Although changes were required, the existing hazard analysis could be used in the new hazard categorization. The standard states that the final categorization is based on an "unmitigated release" of available hazardous material. For the purposes of hazard categorization, "unmitigated" is meant to consider material quantity, form, location, dispersibility and interaction with available energy sources, but not to consider safety features (e.g., ventilation system, fire suppression, etc.) which are designed to prevent or mitigate a release. (Ref. 1, 3.1.2, pg. 5) Our inventory was compared against the threshold quantity values identified in Attachment 1 of DOE Standard 1027. A sum-of-the-fractions method was used to define the Category 2 threshold quantity value. Uranium is best measured by its mass. This is because of its very low specific activity. A curie of depleted uranium weighs about three tons. So we evaluate the sum of the fractions using mass instead of activity as follows.

$$\Sigma M_n/TV_n < 1 \qquad \text{(Ref. 1, A-2)}$$

The isotopes contained in our depleted uranium include uranium (U)-238, U-235, U-234, U-236, and traces of transuranics and technicium-99. The mass fraction of each of the isotopic constituents of depleted uranium are reasonably constant, therefore, they may be expressed as a fraction of the whole mass. The expression would be modified to the following.

$$\Sigma M_{du}f_n/TV_n < 1$$

This equation is then set to equal to one and solved for the mass of depleted uranium. The basic threshold quantity value was determined to be 1.39 million pounds of depleted uranium. This can be compared to the threshold quantity value for U-238 of 1.56 million pounds. Three facility segments were determined to have operational needs greater than that value. One segment, a warehouse, had a current inventory of nearly twice that value.

The standard specifies the airborne release fraction (ARF) that is the basis of the threshold quantity values. The ARF is the fraction of the material that will be respirable (not greater than 10 μm in diameter). The threshold quantity value is derived using the following equation. (Ref. 1, A-6.)

$$TV = (1\ rem)/(ARF*SA*X/Q*(CEDE*RR + CSDE))$$

The threshold quantity value may be modified if the credible ARF can be shown to be significantly different. The new threshold quantity value (TV_{new}) is determined by dividing the "default" threshold quantity value (TV_{1027}) (Ref. 1, Table A.1) by the ratio of the maximum potential ARF (ARF_{HC}) to the default ARF (ARF_{1027}) (pg. A-9). (Ref. 1, pg. 5)

$$TV_{new} = TV_{1027}/ (ARF_{HC}/ARF_{1027}) \qquad \text{(Ref. 3, pg. II-1)}$$
$$TV_{new} = (TV_{1027} \times ARF_{1027})/ ARF_{HC} \qquad \text{Simplified}$$

Further analysis on form, interaction with available energy sources and dispersibility was performed to obtain the project specific data needed to justify a modified ARF. This analysis was substantially contained in the existing SAR. The use of a technically justified decreased ARF provides for a technically valid method of maintaining a Category 3 designation even though the facility inventory exceeds the unmodified Category 2 threshold. The default ARF for the constituents of depleted uranium is 0.001 (1 E-3) for solids, powders and liquids regardless of form or containerization. That ARF, if used without regard for material form and containerization, would significantly overstate the postulated releases. The basis for the ARF is from NUREG-1140 (Reference 2). This reference noted that worst case analysis and experiments were used. The report contains an analysis of three uranium metal accidents. One relevant case was a fire involving uranium metal turnings. The analysis assumed all of the material was oxidized. The ARF was estimated to be 0.001 A fire is the most likely release scenario for our project.

The DOE ID Notice 420.A1, "Safety Basis Review and Approval Process," (Reference 3) provides guidance on how the ARF may be modified based on factors such as form in arriving at a facility's final hazard category. The primary relevant factors are how combustible or dispersible the material is. Depleted uranium metal is considered a combustible metal, especially in the form of unoxidized turnings and fines. However, research has shown that in bulk form the material is essentially non-combustible. If the larger pieces do not burn, or do not burn completely, then the ARF is significantly reduced. The key variable is the specific surface area (S_A), which relates material dimension to bulk weight in square-centimeters per gram. Depleted uranium metal with low specific surface area does not tend to burn and release small particles as readily as do turnings and fines. (Reference 4) The following table shows that characteristic.

Time (minutes) to Completely Oxidize DU Material

Temperature	805 °C	995 °C	1200 °C	1440 °C
Specific Area	(minutes)	(minutes)	(minutes)	(minutes)
S_a = 0.015	4690	4657	2007	996
S_a = 0.3	194	161	69	34
S_a = 0.4	135	101	43	21
S_a = 0.5	99	66	28	13
S_a = 0.6	75	42	18	8
S_a = 0.7	58	25	11	5

Wood and diesel oil is the combustible material likely to support fires at our facility. Wood and diesel fires develop temperatures of 1000 to 1100 °C. The available fuel source is not likely to burn significantly for more than an hour or two on its own. Therefore, it can be readily seen that these fires are not likely to consume the depleted uranium with a small specific area. Therefore, the amount of material that can be released as respirable particles is significantly decreased.

The following table contains currently accepted airborne release fractions developed by a DOE working group. It is contained in ID Notice 420.A1. The notice permits these ARFs to be employed without further approval by DOE-ID.

Alternate Airborne Release Fractions for Hazard Categorization

Material Form	ARF_{HC}
Contaminated combustible materials:	
In generic metal containers or drums	5 E-4
In WIPP-certified metal containers or drums (or fitted with a filter)	1 E-4
Non-metal or degraded/damaged metal containers	1 E-3
Contaminated non-combustible solids/powders/liquids in sound closed metal containers or drums.	5 E-5
Fixed matrix forms in sound and closed metal containers or drums (e.g. concrete, vitrified material, etc.)	1 E-6
Widely dispersed, low-level contamination attached to inert material (e.g. contaminated soil, surface contamination, etc.)	5 E-6

From this information it was determined that an alternate ARF of 5 E-4 could be used for materials with a S_A of < 0.3, (a factor of 2 decrease) and 1 E-4 for a S_A of 0.015 (a factor of 10 decrease). The DOE ID Notice also provided for an additional factor of 2 decrease in the ARF when packaging material in sound closed metal containers. We applied this reduction to depleted uranium with a S_A <0.7. These values were selected because they met operational needs and they are conservative. The decreased ARF for a particular material form and packaging results in an inversely proportional increase in the Category 2 threshold quantity value used for that component of the total inventory.

The facility has significant quantities of material in six combinations of S_A and packaging. Material limits were developed for each of these combinations for operational flexibility and to assure the facility operations were maintained within the authorization basis. The following table displays the various forms of depleted uranium, the packaging, ARFs and the associated thresholds.

Material At Risk Inventory Limits					
Material		**S_A**	**ARF_{HC}**	**Factor**	**Modified Threshold (ATV) (pounds)**
Turnings and Fines	(T)	>1	1 E-3	1.0	1.39E6
Processed Material in Wood	(P_w)	0.3 - 0.7	1E-3	1.0	1.39E6
Processed Material in Metal	(P_m)	0.3 - 0.7	5 E-4	2.0	2.78E6
Product in Wood	(A_w)	<0.3	5 E-4	2.0	2.78E6
Product in Metal	(A_m)	<0.3	2.5 E-4	4.0	5.56E6
Billets in Wood	(B_w)	0.015	1 E-4	10.0	13.9E6
Billets in Metal	(B_m)	0.015	5 E-5	20.0	27.8E6
Miscellaneous Sources	(S_m)	Default	Default	1.0	STD1027

Each facility segment could have a combination of material forms and packaging. The single material threshold could be used except for those segments that approached 1.39 million pounds. For those cases, the "sum-of-the-fractions" methodology was established to assure the facility would maintain an inventory in each facility segment less than the Category 2 threshold quantity value. This methodology involves dividing the weight (in pounds) of the material, accounting for form and container, by its threshold. This process is repeated for each material form and container type. The sum must be maintained less than 1.

$$1 > [(T/ATV_T) + (Pw/ATV_{Pw}) + (Pm/ATV_{Pm}) + (Aw/ATV_{Aw}) + (Am/ATV_{Am}) + (Bw/ATV_{Bw}) + (Bm/ATV_{Bm})] + [\Sigma\, Sm(i)/TVm(i)]$$

This formula was established as a LCO. The warehouses have developed a "checkbook" type transaction system for changes to the inventory. Transactions in and out of the facility are recorded accounting for mass, form and packaging. The warehouse workers are trained to perform "what-if" evaluations for the transactions. The level of rigor in the evaluations is graded based on the how much the current inventory and transaction challenges the limit. For example, if the facility segment is at 50% of the limit, then 695,000 pounds of depleted uranium in any form could be added. Assume the plan of the day calls for adding 150,000 pounds of billets to the inventory and shipping out of inventory 50,000 pounds of recycle scrap. This example does not require a detailed evaluation as the changes do not challenge the limits. However, if the facility is at 90% of the limit then only 139,000 pounds of depleted uranium in any form can be added. If the personnel desire to add the same 150,000 pounds of billets, then a calculation must be made. In this case, 1.39 million pounds of depleted uranium billets equal 10% of the limit (for billets), so the transaction can be authorized. However, because the facility segment is approaching the limit, each transaction must be tracked nearly real-time or before each action. For added assurance, procedures were established that required manager approval for transactions involving an inventory greater than 80% of the limit. In either case, a daily accounting is expected.

To summarize, the analysis and methodology described above was incorporated in a revision to the SAR. It replaced the previous hazard analysis method approved in the early 1990's. It clearly shows that unmitigated releases would not have an impact greater than those allowed for

Category 3 facilities. A material Limiting Condition for Operation was developed and implemented as described above. Administrative controls were established to assure compliance. Personnel were trained in the method of evaluating the current fraction of the limit and to perform "what-if" calculations for proposed additions. The resulting LCO did not impact the current operational needs of the facility.

Other Category 3 facilities, or proposed Category 3 facilities, could benefit from this methodology to appropriately categorize their facilities using the material inventory, form and containerization. This methodology is complementary to facility segmentation to determine material at risk.

References

1. DOE-STD-1027-92, "Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports"
2. NUREG-1140, "A Regulatory Analysis on Emergency Preparedness for Fuel Cycle and other Radioactive Material Licensees"
3. DOE ID Notice 420.A1, "Safety Basis Review and Approval Process"
4. R. K. Hilliard, *Oxidation of Uranium in Air at High Temperatures*, HW-58022, UC-4, December 1958.