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Alternate Approach to Hazard Categorization for Saltstone Facility @ SRS

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Abstract

The Saltstone Facility at Savannah River Site (SRS) was originally segmented into two segments: the Saltstone Production Facility (SPF) and the Saltstone Disposal Facility (SDF). Based on the inventory of radionuclides available for release the SPF and SDF were categorized as Nonreactor Hazard Category (HC) -3. The hazard categorization recognized the SDF will contain contributions of radionuclides which would exceed the HC-2 Threshold Quantity (TQ) in the form of grout. However it was determined not to impact the facility hazard categorization based on the grout being in a solid, monolithic form which was not easily dispersible. But, the impact of a quantity of unset grout expected to be present at the vault following operation of the process was not addressed. A Potential Inadequacy in Safety Analysis (PISA) was later issued based on the hazard categorization determination for the facility not addressing unset grout. This initiated a re-evaluation of the accident scenarios within the hazards analysis.

During this re-evaluation, the segmentation of the facility was challenged based on the potential interaction between facility segments; specifically, the leachate return line and the grout transfer line, which were considered separate segments, are located in close proximity at one point. such that for certain events (NPH as well as External Vehicle Impact) both could be damaged simultaneously and spill contents on the ground that could commingle. This would violate the guideline for segmentation. Therefore, the Hazard Categorization (HC) was reevaluated based on the facility being a single segment and including the additional unset grout as part of total inventory. This total inventory far exceeded the limit for HC-2 TQ and made the facility's initial categorization as HC-2.

However, alternative analysis methodology based on credible release fractions allowed in DOE-STD-1027-92 (Ref.1) showed that the Saltstone facility could still be categorized as Hazard Category 3 Nuclear Facility with no segmentation. Since it was the first time any facility at SRS tried this alternate approach safety analyst had to face substantial resistance and reservations from both the facility and local DOE customers which were eventually overcome with approval and acceptance from DOE-HQ.

Background

For hazard categorization purposes, the Saltstone Facility was originally separated into two segments: the Saltstone Production Facility (SPF) and the Saltstone Disposal Facility (SDF), with the grout transfer line considered part of the SPF.

The original hazard categorization recognized the SDF will contain contributions of radionuclides which would exceed the HC-2 TQs in the form of grout but determined it would not impact the facility hazard categorization based on the grout being in a solid, monolithic form which was not easily dispersible. However, the impact of a quantity of unset grout expected to be present at the vault following operation of the process was not addressed.

A PISA was issued for Saltstone facility based on the hazard categorization determination for the Saltstone facility not addressing unset grout that may be present in the vault cells. This initiated a re-evaluation of the accident scenarios within the hazards analysis. During this re-evaluation, the segmentation of the facility was challenged based on the potential interaction between facility segments; specifically, the leachate return line and the grout transfer line, which were considered separate segments, are located in close proximity at one point. Therefore, the Hazard Categorization (HC) was re-evaluated without segmentation. An initial HC was performed based on the facility being a single segment and evaluated the facility as HC-2. The subsequent final hazard categorization performed determined the facility to be HC-3 based on the bounding event identified by the CHAP team.

Methodology

This alternative hazards assessment is performed based on the provisions of DOE-STD-1027 (Ref. 1). This standard requires the initial hazard categorization to be performed based on the total inventory of radionuclides in the facility. This inventory is compared against the TQs identified in Ref.1 for both HC-2 and HC-3. The initial HC is determined if the sum of fractions based on this comparison is greater than 1.

The TQs stated in Ref. 1 are based on a release fraction of 1.0E-03 or greater. If the release fraction for the bounding event identified by the Consolidated Hazard Analysis Process (CHAP) team differs from that assumed in the standard, Ref. 1 allows the TQs to be adjusted based on the ratio of the release fractions: "Hazard Categorization threshold values…….may be revised …..if the credible release fractions are shown to be significantly different…….and the revisions are based on the physical or chemical form of the release material."

Facility Segmentation

It was decided to re-evaluate the facility Hazard Categorization based on the identification of the potential interaction between facility process areas. Given the close relative proximity of the grout line and leachate return line, for certain events (NPH as well as External Vehicle Impact) it is postulated they could be damaged simultaneously and the contents brought together. Therefore, segmentation of the facility was not considered.

Nuclear Facility Classification

The initial Hazard Categorization evaluated a conservative full facility inventory of 135,000 gallons against the threshold quantities identified in Table -2 and was determined to far exceed the limit for HC-2.

Hazards Assessment

The hazard analysis comprehensively evaluated the possible energetic events that would affect a full facility inventory release and identified the following events to be evaluated for final hazard categorization: the SFT explosion, the loss of confinement due to a full facility spill, and a full facility fire.

The SFT explosion event was determined to be the bounding explosion event. There were no events postulated to occur simultaneously with the SFT explosion event due to its long time to LFL (Ref.2). The SFT explosion event conservatively assumed volume of 7513 gallons. The source term calculated for this event is 7.164 gallons of salt solution. This was determined to bound the potential explosion in the leachate collection and return system due to the minimal volume of the system which can be isolated and contain flammable vapors. This section consists of the system piping and pumps for a total of 466 gallons of dilute salt solution. The remainder of the system is able to diffuse to the cells or the SFT.

The full facility spill event was determined to result in the spill of the SFT (6504 gallons), associated process piping (19 gallons), the LCS (15,000 gallons), unset grout from the Vault or grout transfer line, as well as a release of vapor space aerosol and settled dust accumulation in the vault, in addition to the maximum missing waste (15,000 gallons) from the sending facility.

The full facility fire was assumed to impact the SFT, the LCS, and the HEPA filters within the process area as well as the SDF. Also included is the unset grout in the SDF, the maximum missing waste from the sending facility, and the vapor/dust in the SDF. The hazards analysis also determined the vault would maintain its integrity during the fire event and would not release unset grout. It was determined the wildland fire would be bound by the full facility fire.

The release fractions for the SFT explosion, the full facility spill, and the full facility fire were evaluated against the release fraction assumed in Ref.1. The TQs used to evaluate Hazard Categorization were ratioed based on these release fractions. The HC was then re-evaluated based on the revised TQs.

Inputs & Assumptions (Ref.3)**:**

Lowest ambient temperature during a spill event is assumed to be 0 deg C- per Generic SRS SAR average daily minimum temperature observed in the coldest month is 36 deg F. A minimum temperature of 32 deg F (0 deg C) is assumed [note- low ambient night time pouring of grout in vault is very unlikely] in the assessment of ARF/RF in Table -1.

Table 1 – Freefall ARF x RF

Spill >3 m, ARF/ RF for saltstone solutions
[Per Ref. 4, Para 3.2.3.1, Eqn. 3-13]

Material	Density-air (0 C), g/cc	Spill Ht cm	Soln Viscosity Poise	ARF *	RF Table 3-7 of Ref. 4	ARFxRF	**Final**
Grout Lqd	1.29E-03	750	2.00E-01	8.52E-06	0.4	3.41E-06	**3.00E-06**
Grout Unset	1.29E-03	700	2.00E-01	7.60E-06	0.4	3.04E-06	**3.00E-06**
Leachate	1.29E-03	700	0.0125	1.60E-04	0.2	3.21E-05	**1.00E-04****

* ARF = 8.9E-10 Arch $^{0.55}$,

where Arch = Archimedes Number

$$= (\text{density}_{air})^2 \times (\text{Spill Height})^3 \times g/\text{Soln Viscosity})^2$$

Density$_{air}$ is in g/cc, spill height is in cm, solution viscosity is in poise, and g is a gravitational constant, 981 cm/s^2 (Ref.3)

** Final ARF multiplied by factor of 3 for low density liquid per HDBK-3010 (Ref. 4, page 3-35)

Full Facility Spill Evaluation

a) Leachate: 15,000 gal [Eqv. salt solution] –
Applicable ARF x RF = 1E-04 (Ref. 4)
DOE-STD-1027 ARF x RF = 1E-03
Multiplication factor for Haz Cat-2 TQ = 1E-03/1E-04 = **10** **[a]**

b) Unset Grout: [release through grout line break or failure of vault cell containment]
=115 gpm x 60 m/h x12 h ~ 83,000 gal [Eqv. salt solution]
Average Fall height 7.0 m Viscosity ~ 20 cp
Applicable ARF x RF = 7.60E-06 x 0.4 = 3.04E-06 ~ 3.0E-06 [Table-1]
DOE-STD-1027(Ref. 1) ARF x RF = 1E-03
Multiplication factor for Haz Cat-2 TQ = 1E-03/3E-06 = **333** **[b]**

c) Vault cell Vapor concentration [assume full accumulation of aerosol from total cell volume pouring of grout with no settling or passive vent loss] = 0.50 [salt solution fraction in grout] x 1.8 [nominal grout density] x 30 x 30 x 8.23 x 1E+06 [cell vol in cc] x 3E-06 [ARFxRF for ~7.5 m free fall, see Table-1] = 20,000 g ~ 20 Liters of salt solution ~ 5.5 gal of salt solution
Assume ARF x RF =1 for vapor release (conservative)
DOE-STD-1027 ARF x RF = 1E-02 [for semi volatiles]
Multiplication factor for Haz Cat-2 TQ = 1E-02/1 = **0.01** **[c]**

d) Dust from settled grout (settled Powder):
1500 pounds /cell (Ref. 3) x 12 cells = 18000 pounds = 18000/2.2 Kg= 818 Kg
This amount of grout in eqv. salt solution = (818 Kg x 0.50[fraction of salt solution in grout]) / (1.8 [density of grout Kg/L] x 3.785 L/gal) = 60 gal

Applicable ARF x RF =2E-03 [pressurized release of powder < 25 psig] (Table F-1 of Ref. 4)
DOE-STD-1027 ARF x RF = 1E-03
Multiplication factor for Haz Cat-2 TQ = 1E-03/2E-03 =**0.5** **[d]**

e) Salt solution: [spillage from SFT tank] =6504 gal
Applicable ARF x RF =1E-04 (Ref. 4)
Multiplication factor for Haz Cat-2 TQ = 1E-03/1E-04 = **10** **[e]**

f) Maximum Missing Waste: 15,000 gal [Eqv. salt solution] –
Applicable ARF x RF = 1E-04 (Ref. 4)
DOE-STD-1027 ARF x RF = 1E-03
Multiplication factor for Haz Cat-2 TQ = 1E-03/1E-04 = **10** **[f]**

g) Process Piping: 19 gal [salt solution, remainder considered unset grout] –
Applicable ARF x RF = 1E-04 (Ref. 4)
DOE-STD-1027 ARF x RF = 1E-03
Multiplication factor for Haz Cat-2 TQ = 1E-03/1E-04 = **10** **[g]**

Full Facility Fire Evaluation

a) Leachate: 15,000 gal [Eqv. salt solution] –
Boiling Liquid. ~ 860 gal, ARF x RF = 2E-03 (Ref. 4)
Heated Liquid = 20000 gal, ARF x RF = 3E-05 (Ref. 4)
Multiplication factor for Haz Cat-2 TQ,
Boiling =1E-03/2E-03 =**0.5**; Heated= 1 E-03/3E-05 = **33** **[a]**

b) Other: HEPA Filters: MAR = 650 gal each x 16 = 10,400 gal
Applicable ARF x RF = 1E-04 (Ref. 4)
Multiplication factor for Haz Cat-2 TQ = 1E-03/1E-04 = **10** **[b]**

c) Process Piping: MAR = 19 gal salt solution, remainder considered unset grout
Boiling to Dryness = 19 gal, ARF x RF = 5.6E-03 (Ref. 4)
Multiplication factor for Haz Cat-2 TQ,
Boiling to Dryness =1E-03/5.6E-03 =**0.18** **[c]**

d) Unset Grout: [release through grout line break or failure of vault cell containment]
=115 gpm x 60 m/h x12 h ~ 83,000 gal [Eqv. salt solution
Boiling Liquid. ~ 569 gal, ARF x RF = 2E-03 (Ref. 4)
Heated Liquid. ~ 83000 gal, ARF x RF = 3E-05 (Ref. 4)
Multiplication factor for Haz Cat-2 TQ,
Boiling =1E-03/2E-03 =**0.5**; Heated= 1 E-03/3E-05 = **33** **[d]**

e) Vault cell Vapor concentration [assume full accumulation of aerosol from total cell volume pouring of grout with no settling or passive vent loss]
= 0.50 [conservative salt solution fraction in grout] x 1.8 [nominal grout density] x 30 x 30 x 8.23 x 1E+06 [cell vol in cc] x 3E-06 [ARFxRF for ~7.5 m free fall = 20,000 g ~ 20 Liters of salt solution ~5.5 gal of salt solution
Assume ARF x RF =1 for vapor release (conservative)
DOE-STD-1027 ARF x RF = 1E-02 [for semi volatiles]
Multiplication factor for Haz Cat-2 TQ = 1E-02/1 = **0.01** **[e]**

f) Dust from settled grout (settled Powder):
1500 pounds /cell (Ref. 3) x 12 cells = 18000 pounds = 18000/2.2 Kg= 818 Kg
This amount of grout in eqv. salt solution = (818 Kg x 0.50[fraction of salt solution in grout]) / (1.8 [density of grout Kg/L] x 3.785 L/gal) = 60 gal

Applicable ARF x RF = 6.0E-03 x 1.0E-02 = 6.0E-05 (Table F-1 of Ref. 4)
DOE-STD-1027 ARF x RF = 1E-03
Multiplication factor for Haz Cat-2 TQ = 1E-03/6E-05 =**17** **[f]**

g) Salt solution: 6504 gal (SFT contents)
Boiling Liquid =286 gal, ARF x RF = 2E-03 (Ref. 4)
Heated Liquid = 6504 gal, ARF x RF = 3E-05 (Ref. 4)
Multiplication factor for Haz Cat-2 TQ,
Boiling =1E-03/2E-03 =**0.5**; Heated= 1 E-03/3E-05 = **33** **[g]**

h) Maximum Missing Waste: 15,000 gal [Eqv. salt solution] –
Boiling Liquid. ~ 860 gal, ARF x RF = 2E-03 (Ref. 4)
Heated Liquid = 15000 gal, ARF x RF = 3E-05 (Ref. 4)
Multiplication factor for Haz Cat-2 TQ,
Boiling =1E-03/2E-03 =**0.5**; Heated= 1 E-03/3E-05 = **33** **[h]**

Note: the quantities of liquid heated, boiled and boiled to dryness were based on heat generated from combustible loadings specified for the various buildings and locations in Ref.2.

SFT Explosion Event Evaluation

Per Reference 5, the volume of material driven airborne by the SFT explosion is 7.164 gal for a MAR of 7513 gal. When conservatively assuming an RF, DR, and LPF = 1.0, this corresponds to an ARF x RF of 7.164/7513 ~ 1E-03. Because the release fraction for the explosion event is equal to the average release fraction used in DOE-STD-1027 (Ref.1), there is no reduction in the equivalent salt solution (i.e., the release fractions are not ratioed as they are for the following evaluations).

Final Facility Hazard Categorization:

From Table-2, the sum of fractions for HC-2 TQ equals 4.49 for 135,000 gal of salt solution equivalent. Therefore, a MAR of approximately 30,000 gallons (135,000/4.49) of salt solution equivalent would result in a sum of fractions of 1.00.

Table-2 – Saltstone Facility Hazard Categorization
(Illustration purpose only)

Isotope	Concen-tration (Ci/gal)	Inventory (1) (Ci)	Haz Cat 3 Threshold (Ci)	Haz Cat 3 Ratio (fraction)	Haz Cat 2 Threshold (Ci)	Haz Cat 2 Ratio (fraction)
Sr-90	9.46E-02	1.28E+04	1.60E+01	7.98E+02	2.20E+04	5.81E-01
Cs-137	5.00E-01	6.75E+04	6.00E+01	1.13E+03	8.90E+04	7.85E-01
I-129	4.73E-04	6.39E+01	6.00E-02	1.06E+03	3.17E+02	2.01E-01
Pu-239 (2)	1.01E-03	1.36E+01	5.20E-01	2.62E+01	5.60E+01	2.43E+00
Pu-241	3.52E-03	4.75E+02	3.20E+01	1.49E+01	2.90E+03	1.64E-01
Others				3.11E+02		3.29E-01
Total				**3.34E+03**		**4.49E+00**

(1) Value in this column equals value in previous column multiplied by 135,000 gal.
(2) Other TRU isotopes are bounded by Pu-239 because the concentration of Pu-239 in the bounding waste stream has been set such that grout made from this waste would have a Pu-239 concentration at the NRC Class C limit for total alpha. The sum of the isotopes denoted as bounded by Pu-239 and the Pu-239 itself cannot be any higher than the number given for Pu-239 without exceeding limits for classification as Low Level Waste. (Waste containing more than the total alpha Class C concentration limit is transuranic (TRU) waste, which cannot be disposed of at the Saltstone Disposal Facility.) Of the isotopes contributing to the total alpha limit, Pu-239 is selected as the bounding isotope because it has the highest dose conversion factor (DCF) of those isotopes expected to be present in significant quantities.

The amount of equivalent salt solution for hazard categorization purposes can be determined by multiplying the total inventory by the ratio of the maximum release fraction to that assumed in DOE-STD-1027:

A. Full Facility Spill Release:

   Equivalent Salt Solution = (15,000 gal/10)[a] + (83,000 gal/333) [b] + (5.5 gal/0.01)[c] + (60 gal/0.5) [d] + (6504 gal/10) [e] + (15,000 gal/10) [f] + (19 gal/10) [g]

   Equivalent Salt Solution = 1500 + 250 + 550 + 120 + 650 + 1500 + 2
   Equivalent Salt Solution = 4572 gallons

   Sum of Fractions = 4572 gallons / 30,000 gallons

   Sum of Fractions = **0.152**

B. Full Facility Fire Release:

   Equivalent Salt Solution = (860/0.5)[a] + (15000/33)[a] + (10400/10)[b] + (19/0.18)[c] + 569/0.5[d] + 83000/33 [d] + 5.5/0.01[e] + 60/17[f] + 286/0.5 [g] + 6504/33 [g] + 860/0.5[h] + 15000/33[h]

   Equivalent Salt Solution = 1720 + 455 + 1040 + 106 + 1138 + 2515 +550 + 4 + 572 + 197 + 1720 + 455

   Equivalent Salt Solution = 10472 gallons

   Sum of Fractions = 10472 gallons / 30,000 gallons

   Sum of Fractions = **0.349**

C. SFT Explosion Event

   Sum of Fractions = 7513 gallons /30,000 gallons
   Sum of Fractions = **0.25**

Conclusion

The initial hazard categorization based on the full facility inventory determined the facility to be HC-2. The hazards analysis determined the bounding events to be an SFT explosion event, a loss of confinement due to a full facility spill, or a full facility fire. The analysis performed above shows the bounding event to determine that hazard categorization is the Full Facility Fire. This results in a sum of fractions of 0.349 (<1.0) for the HC-2 TQ and thus the facility becomes HC-3.

References

1. Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports. DOE-STD-1027-92, Change Notice No. 1, U.S. Department of Energy, Washington, DC, September 1997.

2. Saltstone Facility Consolidated Hazards Analysis Process (CHAP) Basis (U). S-CLC-Z-00035, Rev. 2, Westinghouse Savannah River Company, Aiken, SC.

3. Input Data and Assumptions for the Saltstone Facility (U), S-CLC-Z-00044, Rev. 3, Westinghouse Savannah River Company, Aiken, SC.

4. Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities, Volume 1, DOE-HDBK-3010-94, U.S. Department of Energy, Washington D.C., December 1994.

5. Saltstone Facility Vault Explosion Analysis (U), S-CLC-Z-00036, Rev. 1, Washington Safety Management Solutions, Aiken, SC.