Evaluation of the Safety of the Situation (ESS): Vulnerabilities Associated with Gas Release Mode Evaluations and Application of Trapped Gas Release Information for Sludge (PISA PI-2014-0007)

APPROVALS

S.K. Guardiano, Author — Date: 5/10/15

W.M. Matthews, Technical Reviewer — Date: 5/10/2016

N/A, Appendix 1 not revised; Signature on file Rev. 1 — Date: _____
D.K. Allison, Appendix 1 Originator

N/A, Appendix 1 not revised; Signature on file Rev. 1 — Date: _____
E.R. Henley, Appendix 1 Reviewer

C. Ridgeway, Flammability Subject Matter Expert — Date: 5/10/16

T.H. Huff, LW Safety Basis Regulatory Authority — Date: 5-10-16

D.C. Bumgardner, Facility Manager, Tank Farm — Date: 5/11/16

1.0 PISA Description/Summary

The primary purpose of this revision to the ESS is to update the ESS expiration date.

The primary purpose of Revision 1 of the ESS (Ref. 14) was to update Section 3.4 with respect to resolution of Potential Inadequacy in the Safety Analysis (PISA) PI-2014-0007 and to provide an expiration date for the ESS. PISA PI-2014-0007 and associated Compensatory Measures were replaced by the ESS Compensatory Measures of Reference 13. Reference 13 was DOE approved and fully implemented by the facility. Information in this ESS revision pertaining to PISA PI-2014-0007 and its Compensatory Measures are retained for historical purposes.

PISA PI-2014-0007 pertains to the Concentration, Storage, and Transfer Facilities (CSTF) Documented Safety Analysis (DSA), WSRC-SA-2002-00007, and is described in the PISA Database as follows:

"The Safety Basis provides information (safety analysis inputs/assumptions) concerning trapped gas (hydrogen) release from sludge in waste tanks (e.g., trapped gas fractions, retention rates, release rates, and sludge disturbance regions). This information is correlated in the Safety Basis based on whether the waste tank is in (or not in) the Quiescent Time (Q-Time) Program. Waste tanks enter the Q-Time Program after they are fully slurried (all sludge in the tank completely mixed). A condition exists for a waste tank to be partially slurried (either from partially slurrying the tank contents or receiving slurried sludge from a different tank) but have not yet entered the Q-Time Program. Sludge that has been recently slurried behaves differently from long term settled sludge in trapped gas release phenomena and has different inputs/assumptions. In the condition where the waste tank contains both slurried and settled sludge, utilization of the settled sludge trapped gas release inputs/assumptions for evaluating the trapped gas release from the sludge may not be conservative."

Additional information pertaining to PISA PI-2014-0007 includes:

- Date of Discovery: 7/22/2014
- ORPS Report Number: EM-SR—SRR-HTANK-2014-0012

References pertaining to PISA PI-2014-0007 include:

[Note: Two revisions are listed as references for WSRC-SA-2002-00007. Reference 1 was the "approved and implemented" DSA revision at the discovery time of the PISA and creation of the ESS. Reference 2 is the current "approved and implemented" DSA revision. Both DSA revisions were evaluated in this ESS (Reference 1, and related information, was retained for historical purposes). Additionally, WSRC-SA-2002-00007 Revision 18 has been approved by DOE but not yet implemented by the facility. This DSA revision is not referenced or evaluated below, as WSRC-SA-2002-00007 Revision 18 is the permanent change to the Safety Basis to resolve PISA PI-2014-0007.]

1. Concentration, Storage, and Transfer Facilities Documented Safety Analysis, WSRC-SA-2002-00007, Rev. 16, June 2014.
2. Concentration, Storage, and Transfer Facilities Documented Safety Analysis, WSRC-SA-2002-00007, Rev. 17, July 2015.
3. CSTF Flammability Control Program – Program Description Document, WSRC-TR-2003-00087, Rev. 24, April 2015.
4. Bounding Hydrogen Release Rates During Liquid Removal From Salt and Aged Sludge Tanks, U-CLC-G-00019, Rev. 1, October 2003.
5. Required Purge Flow Rates for CST Waste Tanks during Free Supernate Removal (U), S-CLC-G-00303, Rev. 0, November 2003.
6. Insoluble Solids Settling in Tank 51 During Baseline Runs, WSRC-RP-96-87, Rev. 0, May 1996.
7. Maximum Waste Tank Insoluble Sludge Solids Settling Time, U-CLC-G-00033, Rev. 0, September 2014.
8. Type I and Type II Waste Tanks Purge Flow Parametric Analysis for Chemical Cleaning (U), S-CLC-G-00329, Rev. 2, June 2012.
9. Input Data and Assumptions for the Concentration, Storage, and Transfer Facilities (U), S-CLC-G-00235, Rev. 7, July 2011.
10. Flammable Stratified Gas Layer Formation in High Level Waste Tanks During Slurry Pump Operations, WSRC-TR-2004-00052, Rev. 2, April 2004.
11. Waste Tank Explosion (CST SAR DBA Analysis) (U), S-CLC-G-00258, Rev. 1, June 21, 2004.
12. CST Waste Tank Explosion Accident Analysis for Offsite Consequences Following a Seismic Event (U), S-CLC-G-00359, Rev. 0, July 2011.
13. Evaluation of the Safety of the Situation (ESS): Vulnerabilities Associated with Gas Release Mode Evaluations and Application of Trapped Gas Release Information for Sludge (PISA PI-2014-0007), U-ESS-G-00002, Rev. 0, September 2014.
14. Evaluation of the Safety of the Situation (ESS): Vulnerabilities Associated with Gas Release Mode Evaluations and Application of Trapped Gas Release Information for Sludge (PISA PI-2014-0007), U-ESS-G-00002, Rev. 1, July 2015.

2.0 Compensatory Measures / Operational Restrictions

2.1 PISA Compensatory Measures / Operational Restrictions

PISA PI-2014-0007 and associated Compensatory Measures were replaced by the ESS Compensatory Measures of Reference 13. However, the following Compensatory Measures were in place at the time the PISA was approved, as documented in PISA PI-2014-0007:

2.1.1 All Gas Release Mode Evaluations for tanks containing sludge must assume 100% of the sludge in tanks release 100% of its trapped gas regardless of pump zone of influence.

2.1.2 Evaluate all Waste Tanks (containing sludge) for Trapped Gas Evaluations utilizing slurried (Q-Time) parameters (e.g., 20% bubble gas volume vs 10%), except Tank 32.

2.1.3 Sludge Slurry receipts prohibited in Tank 32. Waste tank mixing device operation is prohibited in Tank 32.

2.1.4 Free supernate removal is prohibited for Very Slow Generation tanks containing sludge that exceed 40” of settled sludge.

2.2 ESS Compensatory Measures / Operational Restrictions

Based on the evaluation provided in Section 3.1, the Compensatory Measures in Section 2.2 are adequate to prevent/mitigate Waste Tank Explosions, and will be implemented by this ESS. These Compensatory Measures are identical to those in Reference 14.

For the purposes of the Compensatory Measures and evaluations stated below, sludge meeting the following shall be considered settled sludge (see Section 3.1 for discussion on sludge type determination and documentation):

- Sludge that has not been mixed for greater than or equal to 15 years.
- Sludge receipts into a waste tank received greater than or equal to 15 years ago.

For the purposes of the Compensatory Measures and evaluations stated below, sludge meeting the following shall be considered slurried sludge (see Section 3.1 for discussion on sludge type determination and documentation):

- Sludge that has been mixed less than 15 years ago.
- Sludge receipts into a waste tank received less than 15 years ago.

For the purposes of Compensatory Measures 2.2.4, 2.2.5, and 2.2.6 (and associated evaluations), the following Free Supernate Removal Hydrogen Release Rate Limits in Table 1 shall apply.

Table 1
Free Supernate Removal Hydrogen Release Rate Limits
by Tank Flammability Classification
(HR_{FSR} is total gallons of hydrogen released
per inch of liquid removed during free supernate removal)

Tank Type	Flammability Classification		
	Rapid Generation Tank	Slow Generation Tank	Very Slow Generation Tank
Type I	$HR_{FSR} \leq 104$	$HR_{FSR} \leq 104$	$HR_{FSR} \leq 69$
Type II	$HR_{FSR} \leq 149$	$HR_{FSR} \leq 149$	$HR_{FSR} \leq 89$
Type III/IIIA	$HR_{FSR} \leq 181$	$HR_{FSR} \leq 167$	$HR_{FSR} \leq 89$
Type IV	$HR_{FSR} \leq 190$	$HR_{FSR} \leq 185$	$HR_{FSR} \leq 90$

For the purposes of Compensatory Measures 2.2.4, 2.2.5, and 2.2.6 (and associated evaluations), the following Hydrogen Release Rates During Free Supernate Removal from Table 2 shall be used with the Equation 1 for the Total Hydrogen Release During Free Supernate Removal.

Equation 1: $HR_{FSR} = (L_{salt} \text{ x } HR_{salt}) + (L_{settled} \text{ x } HR_{settled}) + (L_{slurried} \text{ x } HR_{slurried})$

Where:

HR_{FSR} = Total gallons of hydrogen released per inch of liquid removed during free supernate removal
L_{salt} = Total height of saltcake in waste tank (inches)
HR_{salt} = Gallons of hydrogen released per inch of saltcake (from Table 2)
$L_{settled}$ = Total height of settled sludge in waste tank (inches)
$HR_{settled}$ = Gallons of hydrogen released per inch of settled sludge (from Table 2)
$L_{slurried}$ = Total height of slurried sludge in waste tank (inches)
$HR_{slurried}$ = Gallons of hydrogen released per inch of slurried sludge (from Table 2)

Table 2			
Tank Type	Gallons of Hydrogen Released per Inch of Liquid Removed per Inch of Waste Material (based on a vapor space at 0°C and 1 atmosphere)		
	Saltcake (gal H2/inch)	Settled Sludge (gal H2/inch)	Slurried Sludge (gal H2/inch)
Type I	0.39	0.50	1.50
Type II	0.50	0.65	1.95
Type III/IIIA	0.50	0.65	1.95
Type IV	0.51	0.99	1.98

2.2.1 For trapped gas release evaluations for sludge agitation (seismic and non-seismic) on a waste tank that contains <u>any</u> slurried sludge, the evaluation shall assume the trapped hydrogen release percentage is 100% of the entire tank sludge inventory (regardless of the agitation source zone of influence). For trapped gas release evaluations for sludge agitation (seismic and non-seismic) on a waste tank that contains <u>all</u> settled sludge, the evaluation may use trapped hydrogen release percentage inputs/assumptions stated in DSA Section 3.4.1.5.3 for waste tanks that are not under the Waste Tank Quiescent Time Program.

2.2.2 For trapped gas release evaluations for sludge agitation (seismic and non-seismic), the evaluation shall assume the hydrogen percent in trapped gas is 75%. In waste tanks with known chemistry and heat loads, the equation stated in DSA Section 3.4.1.5.3 (Hydrogen Percent in Trapped Gas Subsection) for H_{Mix} can be used in lieu of the above value.

2.2.3 For trapped gas release evaluations for sludge agitation (seismic and non-seismic) on a waste tank that contains <u>any</u> slurried sludge, the evaluation shall assume the trapped gas bubble gas volume is a maximum of 20%. For trapped gas release evaluations for sludge agitation (seismic and non-seismic) on a waste tank that contains <u>all</u> settled sludge, the evaluation may use trapped gas bubble gas volume inputs/assumptions stated in DSA Section 3.4.1.5.3 for waste tanks that are not under the Waste Tank Quiescent Time Program.

2.2.4 Prior to free supernate removal from a Rapid Generation Tank or Slow Generation Tank (excluding waste tanks under the Waste Tank Quiescent Time Program), an engineering evaluation shall be completed to demonstrate that the resultant free supernate hydrogen release rate is less than or equal to the values in Table 1.

Flammability classification of a waste tank may be reclassified, based on the engineering evaluation, to meet the above criteria. The evaluation shall consider the combined contents of the waste tank (saltcake, settled sludge, and slurried sludge). For this engineering evaluation, the Hydrogen Release Rates During Free Supernate Removal (from Table 2) shall be used with Equation 1 for the Total Hydrogen Release During Free Supernate Removal.

2.2.5 Prior to free supernate removal from a Very Slow Generation Tank (excluding waste tanks under the Waste Tank Quiescent Time Program) that contains both saltcake and sludge (settled sludge or slurried sludge), an engineering evaluation shall be completed to demonstrate that the resultant free supernate hydrogen release rate is less than or equal to the values in Table 1.

Flammability classification of a waste tank may be reclassified, based on the engineering evaluation, to meet the above criteria. The evaluation shall consider the combined contents of the waste tank (saltcake, settled sludge, and slurried sludge). For this engineering evaluation, the Hydrogen Release Rates During Free Supernate Removal (from Table 2) shall be used with Equation 1 for the Total Hydrogen Release During Free Supernate Removal.

2.2.6 Prior to free supernate removal from a Very Slow Generation Tank (excluding waste tanks under the Waste Tank Quiescent Time Program) that contains only sludge (settled sludge or slurried sludge), an engineering evaluation shall be completed to demonstrate that the resultant free supernate hydrogen release rate is less than or equal to the values in Table 1.

Flammability classification of a waste tank may be reclassified, based on the engineering evaluation, to meet the above criteria. The evaluation shall consider the combined contents of the waste tank (settled sludge and slurried sludge). For this engineering evaluation, the Hydrogen Release Rates During Free Supernate Removal (from Table 2) shall be used with Equation 1 for the Total Hydrogen Release During Free Supernate Removal.

2.2.7 Interstitial liquid removal from saltcake on a waste tank that contains sludge below the saltcake layer is prohibited.

Transfers out of a tank that expose saltcake peaks/mounds and saltcake on coils results in insignificant interstitial removal and these activities are judged to result in an insignificant hydrogen release and are not considered interstitial liquid removal.

3.0 Safety Assessment Results

3.1 Immediate Safety Assessment

The main purpose of an ESS is to evaluate the PISA and its associated Compensatory Measures with respect to the Safety Basis and the facility. This was performed in Reference 13. Reference 13 was DOE approved and fully implemented by the facility. Reference 14 removed evaluation of the PISA Compensatory Measures and retained information related to evaluation of ESS Compensatory Measures identified in Section 2.2. Additionally, Reference 2 modified controls within the Pump Run Program and Salt Dissolution/Interstitial Liquid Removal Program. These program control changes in Reference 2 do not alter the technical conclusions derived below, but are annotated for completeness.

The DSA (Ref. 1, 2 - Section 3.4.1.5.3) discusses the flammable vapor release methodology for hydrogen as it relates to hydrogen retention and trapped gas release. The hydrogen can be released directly to an adjacent vapor space or can be retained in the waste. The retained hydrogen is captured in the tank saltcake/sludge (i.e., trapped hydrogen). Trapped hydrogen is assumed to be released from saltcake when the saltcake is dissolved, agitated (e.g., seismic event, waste tank mixing device operation), during interstitial liquid removal, or from the reduction in static pressure (e.g., free supernate removal). Trapped hydrogen is assumed to be released from sludge when the sludge is agitated (e.g., seismic event, waste tank mixing device operation), from the reduction in static pressure (e.g., free supernate removal), or the spontaneous liberation of gas bubbles from the sludge layer. The trapped hydrogen release rates are dependent on the characteristics of the saltcake/sludge and the initiator of the release.

The sludge retains hydrogen based on the rheological properties and geometry of the sludge material. The saltcake layer retains hydrogen based on the size of the voids and the associated equilibrium with the liquid also in the void spaces. Typically, release rates are stable until the waste is disturbed, with the exception of the periodic spontaneous liberation of trapped hydrogen within the sludge layer. The release rate can be increased if the waste becomes disturbed (e.g., sludge agitation, saltcake dissolution, seismic induced, free supernate removal).

The Waste Tank Explosion Design Basis Accident (DSA Section 3.4.2.11) provides the prevention/mitigation strategy and related controls to address flammable gas retention and release. The related controls vary depending upon waste tank conditions and activities. Additionally, the evaluations for the activities (e.g., trapped gas release evaluations) or DSA support documents for derived control values (e.g., free supernate removal limitations) utilize the inputs and assumptions from DSA Section 3.4.1.5.3. For each of these categories, further discussion is provided below to assess potential impacts associated with PISA PI-2014-0007 trapped gas release vulnerabilities to the reported methods and evaluate related controls/Compensatory Measures. Subsections of DSA Section 3.4.2.11 which pertain to trapped gas release involved with bulk salt

dissolution are not discussed below as these activities and related controls are not affected by PISA PI-2014-0007. Additionally, control strategies associated with Closure Waste Tanks are not affected by PISA PI-2014-0007 as these tanks are shown (using conservative inputs) not to reach 100% of the Lower Flammability Limit (LFL), given only atmospheric breathing and a hydrogen generation rate less than or equal to 0.5 ft^3/hr.

Based on the nature of PISA PI-2014-0007, the assessment below evaluates application of DSA Section 3.4.1.5.3 methodology and DSA Section 3.4.2.11 control strategies for waste tank conditions where the tank contents have been partially slurried (contains both settled sludge and slurried sludge). Additionally, this evaluation assesses application of methodology/control strategies for waste tank conditions where the tank contents have a combination of saltcake and sludge (settled sludge or slurried sludge).

For purposes of the discussion below and application of the appropriate Compensatory Measure aspect (or Table 2 value), determination of the waste type (saltcake, settled sludge, or slurried sludge) and amount must be made for each waste tank. In applying Compensatory Measures (or associated evaluations), determination of the waste type/amount within a waste tank shall be documented in an engineering evaluation and should consider the following:

- Waste Characterization System information
- Sludge/saltcake sounding information (or historical height indications)
- Transfer or waste tank mixing device operational history
- Waste tank sample results
- Process knowledge or operational conditions

For the waste type/amount determination for application in Compensatory Measures (or associated evaluations), a conservative approach may be used in lieu of developing a basis for the waste tank contents (e.g., assume the entire sludge inventory is slurried sludge versus settled sludge).

Additionally, Section 2.2 also provides the guidance for determination of settled sludge and slurried sludge for application of the appropriate Compensatory Measure/value (15-year criteria). Sludge settling studies have been performed in support of sludge batch preparation. One study (Ref. 6) describes the mechanisms for sludge particle settling, and provides equations for calculating settling time. Sludge particles settling in a fluid pass through three distinct settling regimes. The first regime is constant rate settling. This regime is characterized by particles falling in a fluid such that other particles do not hinder their fall. These particles increase in velocity until the accelerating force of gravity is equal to the resisting drag and buoyancy forces. At this point, the particles settle at a constant velocity. This occurs within a few minutes of initiating settling. As the particles settle, the distance between adjacent particles

decreases. The particles are settling through a suspension of solids, rather than through the original fluid. The properties of the suspension are not the same as the original liquid. The suspension has a higher viscosity and density than the original fluid, which increases the drag force, and settling velocity decreases. This regime is called "hindered" or "transition" settling. Eventually, another mechanism predominates settling. This regime is called "compression" settling. During compression settling, a blanket of particles exerts pressure on the sludge below, and force liquid upward through the solids. Compression settling is very slow.

Reference 6 provides a method for calculating the time required for sludge slurry to settle. For any given unslurried sludge height, the settling time to reach some percentage of its original, unslurried height, can be calculated. The unslurried height is the height to which sludge would settle, given an infinite settling time. Using these equations, and assuming an unslurried sludge height of 90 inches, it can be shown that a slurry would settle back to its original height in about 13.5 years (Ref. 7). To account for uncertainty between different sludge types and add conservatism, the total sludge settling time is increased by 10%. This provides a reasonably conservative sludge settling time of 15 years (Ref. 7). Use of 90 inches for unslurried height is considered conservative, since it exceeds the sludge inventory in any waste tank currently. Lower sludge levels would settle more quickly. Settling back to the original, unslurried height is considered conservative for declaring sludge as "settled". Very little actual settling (as measured by sludge height change) would occur beyond the 15-year point. Treating sludge as "slurried" up until the 15-year point is conservative, since slurried sludge requires higher assumed trapped gas content than settled sludge does.

Some sludge agitation activities have the potential to disturb only a localized region of sludge, and these activities (unto themselves) do not require changing the sludge type determination from settled sludge to slurried sludge. Examples of these activities include the following:

- Rotation of waste tank mixing device turntables
- Sludge sampling
- Inserting/removing tank components below the sludge layer
- Normal air blowing of transfer jets that have a suction below the sludge layer
- Operating transfer pumps or jets that have a suction below the sludge layer
- Transfers into the waste tank (regardless of downcomer location)
- Flushing of transfer pumps, jets, or other equipment
- Riser mining in a settled sludge tank

Activities such as rotation of waste tank mixing device turntables, sludge sampling, inserting/removing tank components below the sludge layer, and normal air blowing of transfer jets (nominal range of 5 to 30 minutes) do not significantly change the

rheological properties and geometry of the sludge material. Operation of transfer pumps or jets that have a suction below the sludge layer is not typically performed on a settled sludge tank (since the sludge needs to be slurried in order to have transfer pump/jet suction capabilities); however, even if this operation were attempted on settled sludge, the resulting effect is judged to have an insignificant impact on the remaining sludge material. A transfer into the waste tank and flushing of transfer pumps/jets or equipment also has an insignificant impact to the overall waste tank sludge material. Although these transfers/flushes may cause some small localized disturbance of sludge, the flowrates/velocities of the transfers/flushes are not sufficient to have significant impact on overall waste tank sludge material. Note that transfer receipts of actual sludge slurry would be considered slurried sludge; thus, causing this waste tank material to be considered slurried sludge. Operations involved with riser mining in a settled sludge tank are typically for a very limited sludge volume (since mining is not normally done to the very bottom of the waste tank). However, even if sludge mining were performed to insert four waste tank mixing devices to the bottom of a waste tank (assuming 90 inches of settled sludge) and it were assumed that a three foot diameter area were affected by the mining (devices normally installed in 24-inch diameter risers), the overall effect of potentially slurried sludge would be less than one inch in the waste tank (regardless of waste tank type). Based on this minimal impact to the overall sludge material, other conservatisms within the trapped gas release analysis, and that typical sludge mining normally affects a localized/limited amount, this operation is judged to have insignificant impact on the sludge material. Additionally, all other activities above are judged to be bounded by the discussion pertaining to operations involved with riser mining with respect to the overall effect of potentially slurried sludge (would be less than one inch in the waste tank).

In general, if activities in waste tanks are physically limited by design to disturb a localized region of sludge, then these activities are judged as insignificant sludge agitation and do not require changing the sludge type determination from settled sludge to slurried sludge.

Routine Flammability Controls (excluding Free Supernate Removal)

Discussion pertaining to Tank 50 is excluded from the Routine Flammability Controls discussion as this tank is currently under the Waste Tank Quiescent Time Program. Any sludge present in this tank would be considered slurried sludge and would have appropriate application of the inputs and assumptions from DSA Section 3.4.1.5.3. Aspects potentially impacted for other waste tanks in the Routine Flammability Controls subsection of DSA Section 3.4.2.11.1 are discussed below.

The Flammability Control Program calculates and tracks the time to LFL of each waste tank and provides the flammability classification. Waste tanks are classified into types according to the time it takes to go from the safety analysis value to 100% of the LFL following a loss of ventilation. Since this flammability classification does not include

the effects of trapped gas release, this aspect is not affected by PISA PI-2014-0007 and no Compensatory Measures are required.

Waste tanks, prior to performing Mechanical Cleaning activities, shall meet the definition of a Very Slow Generation Tank, accounting for an additional 100,000 gallons (permitted liquid additions and rainwater in-leakage) and seismic hydrogen release potential. Compensatory Measures 2.2.1, 2.2.2, and 2.2.3 ensure conservatism in the seismic hydrogen release evaluation to account for vulnerabilities associated with DSA Section 3.4.1.5.3 methodology. Reference 2 removes Mechanical Cleaning waste tanks from the DSA/TSR; however, this has no impact on the facility or the ESS related aspects.

Ventilation is required on all Rapid and Slow Generation Tanks to ensure that the minimum time to LFL associated with the tank flammability classification is protected. To satisfy the flammability safety function of the ventilation system, a minimum ventilation flow rate is required. Since this minimum ventilation flow rate requirement does not include the effects of trapped gas release, this aspect is not affected by PISA PI-2014-0007 and no Compensatory Measures are required.

For activities not exceeding the gas release criteria, the hydrogen concentration limits shall be established by the Flammability Control Program and shall ensure the minimum time to LFL, defined by the tank flammability classification, is maintained. The hydrogen concentration limits shall be on an individual tank basis and shall consider any proposed activities having the potential to release trapped gas (e.g., sludge agitation, bulk salt dissolution, interstitial liquid removal). Compensatory Measures 2.2.1, 2.2.2, and 2.2.3 ensure conservatism in the trapped gas release evaluation to account for vulnerabilities associated with DSA Section 3.4.1.5.3 methodology. Additionally, Compensatory Measure 2.2.7 is adequate to prevent interstitial liquid removal from saltcake in waste tanks with sludge below the saltcake layer (see subsection below for Controls for Waste Tanks Undergoing Interstitial Liquid Removal).

Free Supernate Removal

Free supernate removal involves removing liquid from a tank containing solids (saltcake or sludge) that can retain trapped gas. Removing the supernate reduces the hydrostatic head over the gas trapped within the solids, causing the gas to expand and be released. At the same time, the tank vapor space volume is increasing due to the liquid removal that caused the reduction in hydrostatic pressure. The DSA (with support from References 4 and 5) developed prohibited operations associated with free supernate removal from saltcake or settled sludge tanks. These prohibitions ensured waste tank ventilation flowrate requirements were sufficient to maintain the minimum time to LFL (based on the tank flammability classification) given the hydrogen release associated with free supernate removal. However, several factors are not considered for development of these limitations with respect to waste tanks that may contain

combinations of different types of waste. Additional controls are required to protect Rapid/Slow/Very Slow Generation Tanks or waste tanks containing different types of waste.

Compensatory Measures 2.2.4, 2.2.5, and 2.2.6 provide a conservative method for demonstrating that the resultant free supernate hydrogen release rate is within acceptable values. These Compensatory Measures are adequate to protect wastes tanks that contain only one type of waste material or any combination of waste materials. The Free Supernate Removal Hydrogen Release Rate Limits in Table 1 (based on tank flammability classification) are provided by Reference 5 and are not affected by PISA PI-2014-0007. The values for Table 2 (Gallons of Hydrogen Released per Inch of Liquid Removed per Inch of Waste Material) for each waste tank type are based on Reference 4 (Appendix C for saltcake and Appendix D for settled sludge) with the following adjustments to account for potential non-conservatisms or other factors:

- All values are increased by approximately 3% to account for varying saltcake/sludge levels and measurement uncertainty.
- Type I, II, and III/IIIA slurried sludge values are based on settled sludge values increased by a factor of 3:
    - Factor of 2 to adjust trapped gas bubble gas volume (from 10% for settled sludge to 20% for slurried sludge)
    - Factor of 1.5 to adjust hydrogen percent in trapped gas (from 50% for settled sludge to 75% for slurried sludge)
- Type IV slurried sludge values are based on settled sludge values increased by a factor of 2 to adjust trapped gas bubble gas volume (from 10% for settled sludge to 20% for slurried sludge) [Note: Type IV settled sludge values had already used 75% for hydrogen percent in trapped gas].

The trapped hydrogen release rate calculated in Reference 4 used a 25°C basis to determine the molar volume, and then adjusted the volume to a 0°C basis. The purge flow analysis in Reference 5 used 100°C as the basis for both molar volume and the LFL. This is conservative to actual conditions in the waste tanks as gas is trapped in the solids layers, which are typically at a higher temperature than either the supernate or the vapor space in the waste tank. Therefore, thermal expansion does not occur as trapped gas is released. Thus, no temperature correction is needed for the values in Tables 1 and 2.

<u>Controls for Type I/II Acidic Chemical Cleaning Waste Tanks</u>

Ventilation is required on Chemical Cleaning Tanks to prevent flammable vapor accumulation and protect the initial hydrogen concentration within the tank vapor space. To satisfy the flammability safety function of the ventilation system, a minimum ventilation flow rate is required. The minimum ventilation flow rate must account for

trapped gas release from 10,000 gallons of sludge; however, this calculation (Ref. 8) used conservative application of the inputs and assumptions from DSA Section 3.4.1.5.3 for trapped gas release (i.e., entire inventory, 20% trapped gas bubble gas volume, 75% hydrogen percent in trapped gas). Therefore, no Compensatory Measures are required.

Type I/II Non-Acidic Chemical Cleaning Waste Tank Trapped Gas Release Activities and Controls

Per the DSA, no additional controls other than Routine Flammability Controls (also Pump Run Program per Reference 2) are required for Type I/II Non-Acidic Chemical Cleaning Waste Tanks when undergoing sludge agitation activities provided an engineering evaluation (using the methodology of DSA Section 3.4.1.5.3) shows that the release of hydrogen due to the activity will not cause the vapor space to exceed the gas release criteria. Compensatory Measures 2.2.1, 2.2.2, and 2.2.3 ensure conservatism in the trapped gas release evaluation to account for vulnerabilities associated with DSA Section 3.4.1.5.3 methodology.

Tank 50 Trapped Gas Release Activities and Controls

Per the DSA, no additional controls other than Routine Flammability Controls (also Pump Run Program and Salt Dissolution/Interstitial Liquid Removal Program per Reference 2) are required for Tank 50 when undergoing sludge agitation, saltcake removal, bulk salt dissolution, and interstitial liquid removal activities provided an engineering evaluation (using the methodology of DSA Section 3.4.1.5.3) shows that the release of hydrogen due to the activity will not cause the vapor space to exceed the gas release criteria. Sludge agitation, saltcake removal, bulk salt dissolution, and interstitial liquid removal activities in Tank 50 that could violate the gas release criteria are not permitted. Tank 50 is currently under the Waste Tank Quiescent Time Program. Any sludge present in this tank would be considered slurried sludge and would have appropriate application of the inputs and assumptions from DSA Section 3.4.1.5.3. Although the methodology application is correct, Compensatory Measures 2.2.1, 2.2.2, and 2.2.3 ensure conservatism in the trapped gas release evaluation to account for vulnerabilities associated with DSA Section 3.4.1.5.3 methodology.

Controls for Waste Tanks Undergoing Planned Sludge Agitation

Per the DSA, no additional controls other than Routine Flammability Controls (also Pump Run Program per Reference 2) are required for tanks undergoing sludge agitation activities provided an engineering evaluation (using the methodology of DSA Section 3.4.1.5.3) shows that the release of hydrogen due to the activity will not cause the vapor space to exceed the gas release criteria. Compensatory Measures 2.2.1, 2.2.2, and 2.2.3 ensure conservatism in the trapped gas release evaluation to account for vulnerabilities associated with DSA Section 3.4.1.5.3 methodology.

The DSA also requires that for tanks exceeding the gas release criteria specified above, additional controls are required to ensure that the waste tanks do not exceed 60% of the LFL and that the minimum time to the LFL requirements are protected. The Pump Run Program is one of the additional controls and is credited with controlling operation of waste tank mixing devices to limit the planned release of trapped gas such that the tank vapor space does not exceed the established hydrogen concentration limit (determined by engineering evaluation). The methodology used for this program to determine the necessary controls (e.g., number of pumps, indexing) is based on the methodology of DSA Section 3.4.1.5.3. Compensatory Measures 2.2.1, 2.2.2, and 2.2.3 ensure conservatism in the trapped gas release evaluation to account for vulnerabilities associated with DSA Section 3.4.1.5.3 methodology.

Controls for Waste Tanks Undergoing Interstitial Liquid Removal

Per the DSA, no additional controls other than Routine Flammability Controls (also Salt Dissolution/Interstitial Liquid Removal Program per Reference 2) are required for tanks undergoing interstitial liquid removal activities provided an engineering evaluation (using the methodology of DSA Section 3.4.1.5.3) shows that the release of hydrogen due to the activity will not cause the vapor space to exceed the gas release criteria. The evaluation assumes that all interstitial liquid in the tank above the pump suction is removed. Although DSA Section 3.4.1.5.3 does not provide specific methodology (or related inputs/assumptions) associated with interstitial liquid removal, Reference 4 developed the applicable hydrogen release rates for interstitial liquid removal from saltcake based on waste tank type. These hydrogen release rates were then incorporated into Input IPR0168a of Reference 9. These rates were based on the hydrogen release associated with hydrostatic head reduction over saltcake and the hydrogen release due to liquid removal within the saltcake. These values may not be conservative for interstitial liquid removal from saltcake in waste tanks with sludge below the saltcake layer. However, Compensatory Measure 2.2.7 is adequate to prevent this activity.

The DSA also requires that for tanks exceeding the gas release criteria specified above, additional controls are required to ensure that the waste tanks do not exceed 60% of the LFL and that the minimum time to the LFL requirements are protected. The Salt Dissolution/Interstitial Liquid Removal Program is one of the additional controls and is credited with controlling interstitial liquid removal activities to limit planned release of trapped gas such that the tank vapor space does not exceed the hydrogen concentration limit (determined by engineering evaluation). The methodology used for this program to determine the necessary controls (e.g., liquid removal rate) is based on the methodology of DSA Section 3.4.1.5.3. As discussed above, the hydrogen release rate values may not be conservative for interstitial liquid removal from saltcake in waste tanks with sludge below the saltcake layer. However, Compensatory Measure 2.2.7 is adequate to prevent this activity.

Flammable Transient due to Trapped Gas Release

The DSA establishes High Liquid Level Conductivity Probe (HLLCP) setpoints for waste tanks such that flammable transients are not considered a safety hazard. The setpoints in DSA Section 3.4.2.11.1 are established based on whether a tank is in (or not in) the Waste Tank Quiescent Time Program, the bubble gas hydrogen concentration (H_{Mix}), and the position of the mixer discharge. HLLCP setpoints for tanks in the Waste Tank Quiescent Time Program are higher than for other tanks.

The analysis for flammable transients (Ref. 10) examines local releases and global releases of hydrogen. Global releases, which would occur in a fully slurried tank, cannot form a flammable stratified layer; the tank is protected as long as the total release does not exceed 60% in the entire vapor space. However, for settled sludges with a high yield stress, a local release has the potential to form a plume such that a flammable layer of hydrogen may form in the waste tank. In addition, the release from hardened sludge will not occur evenly and proportionately with pump flow; it is possible for gases to coalesce under the sludge surface and then suddenly break through, causing a larger or more concentrated plume than indicated by the model.

The potential for formation of a flammable stratified layer from slurried sludge is bounded by the potential for settled sludge. The current division established in the DSA between Quiescent Time tanks and non-Quiescent Time tanks is correct, and no Compensatory Measures are required for flammable transients.

Controls Addressing Release of Trapped Gas During a Seismic Event

Per the DSA, sludge agitation, saltcake removal, bulk salt dissolution, and interstitial liquid removal activities in Tank 50 that could violate the gas release criteria are not permitted. Tank 50 is currently under the Waste Tank Quiescent Time Program. Any sludge present in this tank would be considered slurried sludge and would have appropriate application of the inputs and assumptions from DSA Section 3.4.1.5.3. Although the methodology application is correct, Compensatory Measures 2.2.1, 2.2.2, and 2.2.3 ensure conservatism in the trapped gas release evaluation to account for vulnerabilities associated with DSA Section 3.4.1.5.3 methodology.

For the remaining waste tanks, the Waste Tank Quiescent Time Program is credited as part of the first level of control in preventing a Waste Tank Explosion following a seismic event for the waste tanks under the program that could exceed the gas release criteria. Waste tanks that are under the Waste Tank Quiescent Time Program would contain slurried sludge and would have appropriate application of the inputs and assumptions from DSA Section 3.4.1.5.3. Although the methodology application is correct, Compensatory Measures 2.2.1, 2.2.2, and 2.2.3 ensure conservatism in the trapped gas release evaluation to account for vulnerabilities associated with DSA Section 3.4.1.5.3 methodology.

The DSA also requires that for tanks exceeding the gas release criteria specified above, additional controls are required to ensure that the waste tanks do not exceed 60% of the LFL and that the minimum time to the LFL requirements are protected. The Pump Run Program and Salt Dissolution/Interstitial Liquid Removal Program are part of the additional controls and are credited with controlling the activity to limit the planned release of trapped gas such that the tank vapor space does not exceed the established hydrogen concentration limit (determined by engineering evaluation). The methodology used for these programs to determine the necessary controls (e.g., number of pumps, indexing, liquid removal rate) is based on the methodology of DSA Section 3.4.1.5.3. Compensatory Measures 2.2.1, 2.2.2, and 2.2.3 ensure conservatism in the trapped gas release evaluation to account for vulnerabilities associated with DSA Section 3.4.1.5.3 methodology. Additionally, Compensatory Measure 2.2.7 is adequate to prevent interstitial liquid removal from saltcake in waste tanks with sludge below the saltcake layer.

The DSA also credits the Flammability Control Program for all tanks with tracking the time to reach LFL and limiting the number of waste tanks that can reach LFL in less than 24 hours or seven days (including the effects of post seismic trapped gas release). Compensatory Measures 2.2.1, 2.2.2, and 2.2.3 ensure conservatism in the trapped gas release evaluation to account for vulnerabilities associated with DSA Section 3.4.1.5.3 methodology.

Periodic Agitation for Trapped Gas Release (Waste Tank Quiescent Time Program)

Per the DSA, after successful initial sludge mixing (i.e., hydrogen depletion), tanks are placed under the Waste Tank Quiescent Time Program, which requires periodic waste tank mixing device operation to limit the amount of trapped gas that can be released during a seismic event. The Waste Tank Quiescent Time Program is a periodic waste tank mixing device run program required to safely manage the trapped hydrogen that may be retained within the sludge of some tanks. The quiescent time is the allowable time between tank agitation such that the hydrogen released during a seismic event does not cause the waste tank vapor space to reach LFL in less than seven days (radiolytic hydrogen generation and trapped hydrogen release). The percent of the hydrogen generated in the sludge during the quiescent period that is retained in the sludge is based on the methodology of DSA Section 3.4.1.5.3. Waste tanks that are under the Waste Tank Quiescent Time Program would contain slurried sludge and would have appropriate application of the inputs and assumptions from DSA Section 3.4.1.5.3. Although the methodology application is correct, Compensatory Measures 2.2.1, 2.2.2, and 2.2.3 ensure conservatism in the trapped gas release evaluation to account for vulnerabilities associated with DSA Section 3.4.1.5.3 methodology.

Waste Tank Explosion Consequences

The unmitigated and mitigated Offsite consequences for the Type IV Waste Tank Explosion (≤ 1.1 rem) reported by the DSA may not be conservative with respect to the

trapped gas contribution assumed in Reference 11. Reference 11 calculated the consequences and assumed 200 ft^3 of hydrogen was added to the vapor volume to account for trapped gas. The basis of this assumption pertaining to the application of trapped gas release inputs (e.g., hydrogen percent in trapped gas, trapped gas bubble gas volume) is indeterminate. Application of the most conservative trapped gas release inputs for this unmitigated analysis could increase the Offsite consequences; however, any increase is judged not to warrant a change in the control strategy or functional classification (i.e., change Safety Significant controls to Safety Class) for a Type IV Waste Tank Explosion. Using the methodology of Reference 11, an increase from 200 ft^3 to 5,000 ft^3 of hydrogen for trapped gas contribution would result in Offsite consequences of less than 1.5 rem (see Appendix 1). Note that 30 inches of sludge in a waste tank would release less than 2,500 ft^3 of hydrogen under conservative assumptions (30 inches * 3,540 gal/inch ÷ 7.481 gal/ft^3 * 75% H2 * 20% gas frac = 2,130 ft^3) and current sludge levels in Type IV waste tanks are less than 30 inches. Based on this discussion, no Compensatory Measures are required.

For the Seismic Waste Tank Explosion consequences (Ref. 12), inputs/assumptions were derived specifically for seismic consequence applications and are not affected by PISA PI-2014-0007. These consequences were determined at varying flammable conditions (based on sensitivity case) and are still valid for the amount of hydrogen that was analyzed. Therefore, there would be no impact to the DSA stated consequences and no Compensatory Measures are required.

Facility Calculations Involving Trapped Gas Release Evaluations

Calculations that were issued involving trapped gas release evaluations which used methodology of DSA Section 3.4.1.5.3 (prior to declaration of PISA PI-2014-0007) may have used non-conservative inputs/assumptions with consideration of the PISA or ESS Compensatory Measures. Compensatory Measures 2.2.1, 2.2.2, and 2.2.3 ensure conservatism in the trapped gas release evaluations for all CSTF activities conducted while under this ESS to account for vulnerabilities associated with DSA Section 3.4.1.5.3 methodology.

3.2 Final Safety Assessment

An Unreviewed Safety Question Evaluation (USQE), USQ-HTF-2014-00459, was performed for PISA PI-2014-0007 and resulted in a “positive” evaluation. The facility continues normal operation with the Compensatory Measures identified in the ESS (Ref. 14) in place.

The USQE was “positive” based on a “Yes” answer to the following Question (Note: Questions 2 through 7 were not answered based on Manual 11Q Procedure 1.05, Section 5.6.1.2.C):

- 1. Increase in probability of occurrence of an accident.

Trapped gas release assumptions associated with sludge influence scenarios in the Waste Tank Explosion, Tornado and High Winds Event, Seismic Event, Wildland Fire, and Loss of Offsite Power Design Basis Accidents in the DSA. Controls (and evaluations which determine the applicable controls) are based on the type of sludge present in the waste tank. A condition exists where tanks could contain both settled sludge and slurried sludge, but use trapped gas release inputs/assumptions that are not conservative. Thus, the USQE concluded a potential increase in probability of occurrence of an accident previously evaluated in the Safety Basis.

As discussed in Section 3.1, DSA controls and evaluations associated with this PISA are made conservative with the Compensatory Measures of this ESS. Each Compensatory Measure is further discussed below.

Compensatory Measure 2.2.1 requires trapped gas release evaluations for sludge agitation (both seismic and non-seismic applications) on a waste tank that contains <u>any</u> slurried sludge to assume the trapped hydrogen release percentage is 100% of the entire tank sludge inventory. This is the most conservative position and would cover waste tank conditions involving both settled sludge and slurried sludge (regardless of whether the waste tank was in or not in the Waste Tank Quiescent Time Program). This Compensatory Measure does allow hydrogen release percentage inputs/assumptions stated in DSA Section 3.4.1.5.3 to be used on a waste tank that contains <u>all</u> settled sludge; however, this application is adequate as these inputs/assumptions are valid for that type of waste material.

Compensatory Measure 2.2.2 requires trapped gas release evaluations for sludge agitation (both seismic and non-seismic applications) to assume the hydrogen percent in trapped gas is 75%. Use of this value (versus 50%) would be conservative with respect to waste tank conditions involving both settled sludge and slurried sludge (regardless of whether the waste tank was in or not in the Waste Tank Quiescent Time Program). This Compensatory Measure does allow use of the equation stated in DSA Section 3.4.1.5.3 (Hydrogen Percent in Trapped Gas Subsection) for H_{Mix} in waste tanks with known chemistry and heat loads; however, the derivation and use of this equation is not affected by PISA PI-2014-0007 and is considered adequate for continued use.

Compensatory Measure 2.2.3 requires trapped gas release evaluations for sludge agitation (both seismic and non-seismic applications) on a waste tank that contains <u>any</u> slurried sludge to assume the trapped gas bubble gas volume is a maximum of 20%. Use of this value (versus 10%) would be conservative with respect to waste tank conditions involving both settled sludge and slurried sludge (regardless of whether the waste tank was in or not in the Waste Tank Quiescent Time Program). This Compensatory Measure does allow trapped gas bubble gas volume inputs/assumptions stated in DSA Section 3.4.1.5.3 to be used on a waste tank that contains <u>all</u> settled sludge; however, this application is adequate as these inputs/assumptions are valid for that type of waste material.

Compensatory Measures 2.2.4, 2.2.5, and 2.2.6 perform an engineering evaluation to demonstrate that the resultant free supernate hydrogen release rate is within acceptable values (dependent upon the tank flammability classification and contents of the tank). Waste tanks under the Waste Tank Quiescent Time Program are excluded from these Compensatory Measures, as these tanks are under a trapped gas depletion regiment to assure flammability safety (periodic agitation such that the hydrogen released [including trapped hydrogen] during a seismic event does not cause the waste tank vapor space to reach LFL in less than seven days). As discussed in Section 3.1, the Free Supernate Removal Hydrogen Release Rate Limits in Table 1 (based on tank flammability classification) are provided by Reference 5 and are not affected by PISA PI-2014-0007. Additionally, the values for Table 2 (Gallons of Hydrogen Released per Inch of Liquid Removed per Inch of Waste Material) for each waste tank type are based on Reference 4 with adjustments to account for potential non-conservatisms or other factors. As discussed in Section 3.1, these Compensatory Measures also have conservative guidance for determination of settled sludge and slurried sludge for application of the appropriate values. These Compensatory Measures provide adequate protection to ensure waste tank ventilation flowrate requirements are sufficient to maintain the minimum time to LFL (based on the tank flammability classification) given the hydrogen release associated with free supernate removal.

Compensatory Measure 2.2.7 prohibits interstitial liquid removal from saltcake on a waste tank that contains sludge below the saltcake layer. As discussed in Section 3.1, the hydrogen release rate values may not be conservative for this application. This Compensatory Measure is adequate to prevent these activities.

The current operational status of the facility (as related to PISA PI-2014-0007) is not impacted by the PISA or this ESS, excluding the effect of prohibitions associated with Compensatory Measure 2.2.7. Compensatory Measures 2.2.1, 2.2.2, and 2.2.3 do require more conservative assumptions related to trapped gas release; however, application of these is not expected to have impact on near-term facility activities as these have already been implemented through the PISA PI-2014-0007. Compensatory Measures 2.2.4, 2.2.5, and 2.2.6 require an engineering evaluation prior to free supernate removal; however, a preliminary review indicates there will be no impact to facility operations involving free supernate removal. The prohibition associated with Compensatory Measure 2.2.7 is also not expected to impact facility operations, as interstitial liquid removal on a waste tank that contains sludge below the saltcake layer is not scheduled. Therefore, these Compensatory Measures should not impact operational aspects of the facility during resolution of the PISA.

3.3 Path Forward

1. Continue to implement the Compensatory Measures included in Reference 14 (ESS Compensatory Measures 2.2.1-2.2.7). Note: There are no changes to Compensatory Measures within this ESS revision from Reference 14.

2. Upon DOE approval of this ESS revision, this ESS revision supersedes Reference 14.

3. Develop and approve a Safety Input Review Committee package associated with trapped gas release information (inputs/assumptions) and application to associated control strategies for the affected DSA requirements.

4. Revise the associated analysis and Safety Basis related to Item 3.

3.4 Summary of Recommendations and Conclusions

Based on the results of USQ-HTF-2014-00459 and further evaluation of items associated with PISA PI-2014-0007, the ESS Compensatory Measures will remain in place until a permanent change is made to the Safety Basis and associated support documents.

This ESS expires on August 15, 2016. The Safety Basis change to resolve the Vulnerabilities Associated with Gas Release Mode Evaluations and Application of Trapped Gas Release Information for Sludge (PISA PI-2014-0007) has been submitted to and approved by DOE, but not yet implemented by the facility. Due to the extent of these changes, implementation by the facility will occur by August 15, 2016.

4.0 Appendices

Appendix 1 Explosion Consequences for Type IV Tank: Trapped Gas Parametric Analysis

4.1 Introduction and Methodology

This appendix describes calculations performed to show that the consequences of an explosion in a Type IV waste tank are relatively insensitive to the volume of trapped gas assumed to be released into the tank vapor space. The calculations performed here follow the methodology described in Reference 11.

The tank is assumed to be at the equilibrium hydrogen concentration established by atmospheric breathing and to have an additional 200 ft^3 of trapped hydrogen released into the vapor space after equilibrium has been established. The equilibrium concentration is calculated using Equation 6.7-2 of Reference 11. The potential presence of flammable organic vapors is taken into account by adding 0.96% to the equilibrium concentration. This appendix varies the amount of trapped hydrogen from 200 ft^3 to 20,000 ft^3 to determine the effect on the resulting radiological doses in rem to the Offsite receptor.

The consequences are maximized when a detonation is assumed. The source term from the detonation is calculated using the Trinitrotoluene (TNT) equivalent model in which the source term is assumed to equal the mass of TNT having the same energy as the vapor space explosion. The mass of TNT is calculated using Equation 6.5-1 of Reference 11. This mass is converted to volume by dividing by the waste density so that it can be multiplied by the Total Effective Dose Equivalent to determine the dose to the Offsite receptor. Only the Offsite receptor is used here because it is the relative change in dose that is of interest.

The TNT equivalent source term is proportional to the number of moles of flammable gas burned during the detonation. The maximum number of moles that can be burned occurs at the stoichiometric concentration (assumed here to be 30%); at higher concentrations, insufficient oxygen is present to burn all the hydrogen while at lower concentrations, insufficient hydrogen is present to take advantage of the available oxygen. The worst-case configuration for the waste tank is that which maximizes the vapor space volume existing at the stoichiometric concentration. This configuration is found by varying the liquid level (which determines the total radiolytic hydrogen generation rate and, therefore, the equilibrium concentration of hydrogen in the vapor space) until the level that just gives the stoichiometric concentration in the vapor space is determined. This maximization process includes the 0.96% hydrogen equivalency representing organics that might be present and the additional volume of trapped hydrogen. As mentioned above, the latter is varied here parametrically. Each trapped gas volume leads to a different optimum liquid level and a different Offsite dose. Key inputs are provided in Section 4.2 and the results are provided in Section 4.3.

4.2 Inputs

Parameter	Value
Empty Tank Volume	1,684,055 gal
Hydrogen Generation Rate	2.6E-06 ft^3/gal/hr @ 25°C
Minimum Tank Temperature	25°C
Tank Fill Factor	3,540 gal/inch

4.3 Results

Trapped Hydrogen (ft^3)	Liquid Level (in)	Dose (rem)	Ratio Dose to Dose at 200 ft^3
200	385	1.019	1.00
2,000	371	1.177	1.16
5,000	349	1.418	1.39
10,000	316	1.787	1.75
20,000	255	2.470	2.42