PRC-STP-00241
Revision 4

Sludge Treatment Project-Engineered Container Retrieval and Transfer System - Thermal and Gas Analyses for Sludge Transport and Storage Container (STSC) Storage at T Plant

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

ch2m

P.O. Box 1600
Richland, Washington 99352

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(3) Revision	(4) Description of Change – Replace, Add, and Delete Pages ADD ROW	Authorized for Release (5) DA (TA) Date
1	Complete revision to document conducted. The composition of K Basin sludge types from HNF-SD-SNF-TI-015, volume 2, revision 19 and an updated version of the FATE model code were used to calculate the updated thermal and gas geenration rates for STSCs during transportation and storage at T Plant.	☒
2	Complete revision to document to incorporate analyses for layering of engineered container SCS-CON-230 (Settler) sludge beneath engineered container SCS CON 240, -250, or -260 (KE) sludge in an STSC; combining KW 220 engineered container with segregated settler material; analyses for STS cask venting and purging at T Plant; and analyses for STSC purging at T Plant.	☒
3	Included new cases in Section 6.2.1 and Appendix B for sludge stored in an STSC without a vent pipe added to nozzle F2. Included calculations in Section 6.1 and Appendix C to determine maximum duration before the hydrogen concentration reached 1% in the cask void space after venting / purging the cask at 5 cfm with nitrogen and then reducing the purge rate to 0.5, 0.75, 1.0, or 1.25 scfm. Add Appendix D to provide vendor datasheet for loss of fluid at disconnect of automatic quick-release coupling. Incorporated in Appendix B, Fauske and Associates review of FATE model changes made by CHPRC.	☒
4 RS	Expanded calculations in Section 6.1 and Appendix C. Calculations include new cases to determine maximum duration before the hydrogen concentration reached 1% in the cask void space after venting / purging the cask at 4.5 or 5 cfm with nitrogen and then reducing the purge rate to 0.5 to 2.0 scfm. per ECR-15-001542	12/7/2015 M.E. Johnson ☒
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1.0 Introduction

The Sludge Treatment Project (STP) is responsible for the disposition of sludge contained in the 105-K West (KW) Basin. The STP will retrieve and transfer sludge from the six engineered containers in the KW Basin directly into a Sludge Transport and Storage Containers (STSC) contained in a Sludge Transport System (STS) cask. The STSC / STS cask will be transported to T Plant for storage of the STSC. The STS cask will be loaded with an empty STSC and returned to the KW Basin to load additional sludge for transportation and storage at T Plant.

CH2MHILL Plateau Remediation Company (CHPRC) contracted with Fauske & Associates, LLC (FAI) to perform thermal and gas generation analyses for transport and storage of STP sludge in the STSCs at T Plant (PRC-STP-00893). FAI also previously prepared analyses for evaporative water loss from storage of an STSC at T Plant and the potential for sludge to freeze during storage at T Plant. The results of thermal and gas generation analyses for transporting STP sludge in the STSC / STS cask are discussed in PRC-STP-00688. This report discusses: 1) STS cask venting, STS cask purging and STSC purging at T Plant, 2) thermal and gas generation rate analyses for storage of STSCs containing K Basin sludge at T Plant, 3) evaporative water loss from the STSCs during storage at T Plant, and 4) the potential for K Basin sludge to freeze during storage at T Plant. The FAI reports documenting these analyses are issued as a multi-volume document as PRC-STP-00893, *Thermal and Gas Generation Analyses for Sludge Treatment Project - Engineered Container Retrieval and Transport System* and PRC-STP-00908, *Analysis of Cask Venting, Cask Purging, and STSC Purging at T Plant*.

The sludge types considered for storage at T Plant are engineered container SCS-CON-210 (i.e. KW 210) sludge, engineered container SCS-CON-220 (i.e. KW 220) sludge combined with segregated settler material (SSM), and engineered container SCS-CON-230 (KW 230 or Settler Tank) sludge layered with engineered container SCS-CON-240, -250, or -260 (KE) sludge. Sludge properties are discussed in Section 2.0. Major assumptions used by FAI to conduct these analyses are discussed in Section 3.0. Section 4.0 provides a brief overview of the Flow, Aerosol, Thermal, and Explosion (FATE™) computer program version 2.062a models developed by FAI to conduct the requested analyses. The cases specified by CHPRC for analysis are provided in Section 5.0 and results for each analysis are discussed in Section 6.0.

™ FATE is a registered trademark of Fauske & Associates, LLC, Chicago, Illinois.

2.0 Background

The STP is being conducted in two phases with the first phase known as the STP Engineered Container Retrieval and Transfer System (ECRTS) subproject (KBC-30811). The ECRTS subproject includes all activities necessary to remove the sludge from the Engineered Containers in the K West Basin and place the sludge into storage at T Plant, which is located on the 200 Area Central Plateau. The second phase of the STP, known as the K Basins Sludge Treatment and Packaging subproject, includes the future sludge retrieval from the STSCs temporarily stored in T Plant, treatment and packaging of the retrieved sludge, and conducting associated preparations required for placing packaged sludge into storage pending shipment to the Waste Isolation Pilot Plant.

The ECRTS subproject will retrieve and transfer sludge from the six engineered containers directly into STSCs contained within the STS cask. The STS Cask is designed to stay on the transport trailer. The transport trailer is positioned in the modified annex building at the 105-KW Basin. Clarifloc® N-300P flocculant is added to the sludge during the transfer to enhance settling of the suspended solids. A batch of retrieved sludge is allowed to settle within an STSC to concentrate the solids and clarify the supernatant. Additional flocculant may be added to the supernatant to enhance the settling rate of the suspended solids in the STSC. After achieving the desired supernatant clarity, the supernatant is decanted from the STSC and transferred through a sand filter to remove the remaining suspended sludge particles. The filtered supernatant is returned to the 105-KW Basin. Subsequent batches of sludge are added to the STSC, settled, and excess supernatant removed in the same manner as previously described until the prescribed quantities and types of sludge are collected in an STSC. The solids collected on the sand filter are fluidized and flushed directly into the STSC that is being loaded with sludge. The STSC and the STS cask are purged with nitrogen gas and configured for transportation to T Plant. At T Plant the STS cask is vented and purged with nitrogen to remove potentially flammable gases. The STS cask lid is removed and the STSC is purged with nitrogen to remove potentially flammable gases. After purging, the STSC is removed from the STS cask and placed into a T Plant canyon cell for storage. Further details on retrieval and transfer of sludge into an STSC and transport of the STSC/STS cask to T Plant are provided in HNF-41051, *Preliminary STP Container and Settler Sludge Process System Description and Material Balance.*

The types of sludge that will be placed into STSCs; 1) engineered container SCS-CON-210 (KW 210) sludge, 2) engineered container SCS-CON-220 (KW 220) sludge combined with segregated settler material (SSM), 3) engineered container SCS-CON-230 (KW 230 or Settler Tank) sludge layered with engineered container SCS-CON-240, -250, or -260 (KE) sludge, 4) KW Basin Garnet Filters media, 5) ECRTS Sand Filter media, and 6) 105-KW Basin Sand Filter media. The sludge types are described further below.

- KW 210 and KW 220 sludges originated from vacuuming sludge from the floor and pits of the 105-KW Basin into two engineered containers SCS-CON-210 and -220 within the 105-KW Basin. KW 210 and KW 220 sludges also contain some sludge that originated from the KE and KW fuel canisters that were stored in the KW Basin.

- KW 230 sludge is the less than 600-μm fraction of sludge that originated from the Integrated Water Treatment System used for cleaning uranium metal fuel in the 105-KW Basin. The less than 600-μm fraction of sludge from fuel cleaning was collected into Settler Tanks, with fine sludge particles transferred to the KW Basin garnet filters. The sludge was retrieved in 2010 from the Settler Tanks and collected in engineered container SCS-CON-230.

- KE sludge originated from vacuuming sludge from the floor and pits of the 105-KE Basin and some fuel canister sludge. KE sludge was collected into engineered containers within the 105-KE Basin. This sludge was then transferred into three engineered containers (SCS-CON-240, -250, -260) within the 105-KW Basin.

- Segregated settler material was generated from pretreatment and processing of the KOP material conducted in FY 2012. A fraction of the less than 600 μm particulate material (containing uranium metal, uranium oxides, and non-uranium compounds) was captured in strainers equipped with 600 μm screens. Normally, this less than 600 μm particulate material would have been collected in the Settler Tanks. However sludge was retrieved from the Settler Tanks in FY 2010. Therefore, these strainers were used to minimize collecting additional sludge in the Settler Tanks, to avoid the need for a second sludge retrieval campaign.

- The KW Basin Garnet Filters collected fine sludge particles that did not settle in the Settler Tanks. The KW Basin Garnet Filters media and collected fine sludge particles currently reside within the three filter vessels. The disposition of the KW Basin Garnet Filters media and sludge is not included in the scope of the ECRTS subproject (KBC-30811) but is discussed here for completeness.

- The ECRTS subproject will install a sand filter in the modified 105-KW Annex Building. The ECRTS Sand Filter will separate entrained solids from supernatant decanted from an STSC. The ECRTS Sand Filter is backwashed to the STSC that is being loaded to remove solids. The volume and radionuclide inventory of the sludge solids collected on the ECRTS Sand Filter media are less than the sludges being loaded into the STSCs.

- The 105-KW Sand Filter is currently being used to remove suspended solids from the water in the 105-KW Basin. Solids collected on the 105-KW Sand Filter media are backwashed into the north load-out pit. Sampling and characterization of the 105-KW Sand Filter media is planned before loading of this material into STSCs. The disposition of the 105-KW Sand Filter media and sludge is not included in the scope of the ECRTS subproject (KBC-30811) but is discussed here for completeness.

Previous analyses evaluated storage of Settler Tank sludge in an STSC that includes a water-filled insert (PRC-STP-00893 Volume 4). However, the STP now plans to not store Settler Tank sludge in an STSC with a water-filled insert. Sludge from the engineered containers and segregated settler material are now evaluated for storage in an STSC without the water-filled insert. The 105-KW Basin Sand Filter media, ECRTS Sand Filter media and KW Basin Garnet Filters media and sludge contained in these media are also planned to be stored in T Plant in STSCs without the water-filled insert.

The STSC used to store these sludge types is designed as an ASME Section VIII pressure vessel constructed of stainless steel. The STSC has 2:1 radius elliptical top and bottom heads. The bottom head is ½ inch thick and the top head is ¾ inch thick. The inner diameter of the STSC is ~1.5 m (58 ±0.5-inches). The height of the STSC is ~2.6 m (102.75-inches) from the bottom to the top of the elliptical heads. The STSC is nominally filled to 3.8-cm (1.5-inches) below the tangent line for the top elliptical head. This fill limitation is to provide an air space (~0.4 m^3) above the slurry for dilution of hydrogen gas generated during STSC transportation. Therefore, the design capacity of the STSC is ~3.5 m^3.

The storage of sludge in the STSC over an extended period of time may lead to the formation of a stable sludge plug. The stable sludge plug is caused when substantial shear strength causes a stable sludge layer that hinders the release of evolved gases (e.g. hydrogen). The retention of gases leads to the formation of a vessel spanning bubble and the sludge plug above the bubble remains stable until obstructed. Obstruction of the sludge plug leads to sludge plug failure and the release of trapped gases. The design of each STSC includes a 5 degree sloped fin extending from slightly above the tangent line of the top elliptical head into the bottom elliptical head to obstruct the potential formation of a vessel spanning bubble and release gases potentially trapped beneath the sludge plug.

2.1 Sludge Properties

Core samples were obtained between 2009 through 2010 from the six engineered containers in the KW Basin that contain sludge. Detailed physical, chemical, and radio-isotopic characterization of these sludge samples was conducted. The STP has analyzed these sludge characterization results to determine nominal (or mean) values and credible extreme values for sludge physical properties, analytes, radionuclides, total uranium, and uranium metal concentrations.

The ECRTS subproject uses the mean values for sludge physical properties, analytes, radionuclides, total uranium, and uranium metal concentrations as the nominal values for designing systems, structures, and components to retrieve and transfer K Basin sludge into STSCs. The mean values for sludge physical properties, analytes, radionuclides, total uranium, and uranium metal concentrations are known as design basis values.

The ECRTS subproject also uses the *credible extreme values* for sludge physical properties, analytes, radionuclides, total uranium, and uranium metal concentrations in safety analyses and these values are known as safety basis values. Safety basis values are derived from statistical analysis of the data and incorporate random and systematic variability associated with the sludge data. The sources of systematic variability include: sludge layer systematic uncertainty, container sampling equipment systematic uncertainty, analytical methodology systematic uncertainty, and undissolved solids / residues (related to laboratory chemical analyses) systematic uncertainty. Safety basis values for the compositions (analytes, radionuclides, total uranium, and uranium metal concentrations) and physical properties of the sludge apply to a relatively small population of the sludge owing to the statistical methods used to derive these values. The design basis values for the compositions and physical properties of sludge represent the bulk of the sludge.

The STP ECRTS subproject uses the highest measured ^{137}Cs concentration for each sludge type and the corresponding radionuclide analyses for radiation shielding calculations and As Low As Reasonable Achievable (ALARA) evaluations. The STP ECRTS subproject defines the highest measured ^{137}Cs concentration for each sludge type and the corresponding radionuclide analyses as the shielding basis radionuclide concentrations. In some ALARA evaluations, the STP ECRTS subproject has used design basis radionuclide concentrations when large volumes of sludge are present.

The design basis, safety basis, and shielding basis sludge properties are reported in HNF-SD-SNF-TI-015, *Spent Nuclear Fuel Project Technical Databook, Volume 2, Sludge*). The design basis and safety basis sludge properties are shown in Table 1 and the sludge radionuclide concentrations are shown in Table 2. The analyses conducted by FAI use the sludge properties shown in Table 1 and Table 2; using 0.163 g/cm^3 for the uranium metal concentration in all of the engineered container SCS-CON-230 sludge.

Table 1. Properties for Sludge and Segregated Settler Material

Property	SCS-CON-240,250,260		SCS-CON-210		SCS-CON-220		SCS-CON-230		Segregated Settler Material[2]		Units
	Design Basis	Safety Basis	Design Basis	Safety Basis	Design Basis	Safety Basis	Design Basis	Safety Basis	Design Basis	Safety Basis	
Settled Volume	18.4		4.2		1.0		3.5		0.0254		m^3
As Settled Density	1.5	1.6	1.25	1.66	1.47	1.72	2.0	2.8	3.7	3.7	g/cm^3
Percent Water in Sludge	75%	75%	71%	71%	77%	77%	73%	55%	40%	40%	Vol. %
Total Uranium	0.038	0.062	0.044	0.17	0.188	0.409	0.61	0.84	2.56	2.56	$g\ U/cm^3$
Uranium Metal Concentration in Settled Sludge	0.00027	0.00457	0.0042	0.0593	0.0121	0.0341	0.022	0.163 North Half[1] 0.022 South Half	2.51	2.51	g/cm^3
Decay Heat, decay corrected to 7/12/2009	1.28	2.45	2.24	10.1	5.91	12.8	20.5	49.4	175	263	W/m^3
Fissile Grams Equivalent, decay corrected to 7/12/2009	2.44E+02	3.93E+02	2.84E+02	1.05E+03	1.16E+03	2.67E+03	4.07E+03	5.64E+03	1.70E+4	1.68E+04	FGE/m^3
Dose Equivalent Curies, decay corrected to 7/12/2009	1.50E+01	2.39E+01	1.83E+01	5.70E+01	6.39E+01	1.61E+02	2.75E+02	4.10E+02	1.11E+03	2.93E+03	$DE\text{-}Ci/m^3$
Expansion Factors											
Uranium Metal Corrosion	1.0	1.0	1.0	1.05	1.01	1.03	1.02	1.12	7.56	7.56	unitless
Gas Retention	1.41	1.54	1.41	1.54	1.41	1.54	1.41	1.63	1.41	1.72	unitless
Combined	1.41	1.54	1.41	1.62	1.42	1.59	1.44	1.83	10.7	13.0	unitless

Notes:

1. Uranium metal concentration assumes special provisions (i.e. divider plate assembly) for preventing selective retrieval of the higher uranium metal content sludge from the mound in the north half of engineered container SCS-CON-230.
2. Sludge expansion factors for segregated settler material are assumed to the same as fuel piece sludge as reported in HNF-SD-SNF-TI-015 Vol. 2.

Table 2. Radionuclide Concentrations - Settled Sludge Basis

Sludge Radionuclide Inventories - Settled Sludge Basis; Decay Corrected to October 1, 2013										
Isotope	**SCS-CON-240, 250, 260**		**SCS-CON-210**		**SCS-CON-220**		**SCS-CON-230**		**Segregated Settler Material**	
	Design Basis	**Safety Basis**	**Design Basis**	**Safety Basis[2]**	**Design Basis**	**Safety Basis**	**Design Basis**	**Safety Basis**	**Design Basis**	**Safety Basis**
	Ci/m^3	**Ci/m^3**	**Ci/m3**	**Ci/m3**	**Ci/m^3**	**Ci/m^3**	**Ci/m^3**	**Ci/m^3**	**Ci/m^3**	**Ci/m^3**
Am-241	7.58E+00	1.19E+01	9.05E+00	2.69E+01	3.21E+01	7.77E+01	1.34E+02	2.05E+02	5.93E+02	1.38E+03
Np-237	4.75E-04	9.32E-04	7.68E-04	2.95E-03	2.03E-03	5.66E-03	1.26E-02	2.12E-02	7.26E-02	1.19E-01
Pu-238	9.46E-01	1.51E+00	1.14E+00	3.72E+00	3.95E+00	1.01E+01	1.76E+01	2.70E+01	1.21E+02	3.00E+02
Pu-239	4.45E+00	7.12E+00	5.54E+00	1.76E+01	1.94E+01	5.10E+01	8.08E+01	1.13E+02	2.71E+02	4.43E+02
Pu-240	2.55E+00	4.11E+00	3.07E+00	9.89E+00	1.07E+01	2.78E+01	4.73E+01	6.74E+01	1.48E+02	3.50E+02
Pu-241	4.11E+01	6.51E+01	5.20E+01	1.80E+02	1.69E+02	4.36E+02	1.02E+03	1.84E+03	4.19E+03	8.32E+03
Pu-242	8.74E-04	1.44E-03	9.79E-04	3.42E-03	3.43E-03	8.72E-03	2.14E-02	3.82E-02	6.50E-02	2.23E-01
Co-60	6.03E-02	1.21E-01	4.31E-02	2.17E-01	1.17E-01	2.23E-01	3.84E-01	6.60E-01	7.48E-01	7.07E-01
Cs-134	NR[1]	NR	NR	NR	NR	NR	NR	NR	1.40E-01	9.62E-02
Cs-137	6.13E+01	1.37E+02	1.33E+02	7.41E+02	2.14E+02	4.44E+02	6.36E+02	4.06E+03	1.25E+04	1.73E+04
Ba-137m	5.78E+01	1.29E+02	1.26E+02	7.00E+02	2.02E+02	4.19E+02	6.01E+02	3.83E+03	1.18E+04	1.64E+04
Eu-154	2.18E-01	3.09E-01	2.45E-01	7.75E-01	9.46E-01	2.08E+00	4.08E+00	5.98E+00	4.24E+01	8.35E+01
Eu-155	NR	NR	3.28E-02	1.17E-01	1.87E-01	3.68E-01	5.31E-01	8.86E-01	3.24E+00	3.02E+00
Sr-90	6.10E+01	1.25E+02	1.25E+02	5.79E+02	3.55E+02	6.87E+02	1.09E+03	1.99E+03	9.60E+03	1.22E+04
Y-90	6.10E+01	1.25E+02	1.25E+02	5.79E+02	3.55E+02	6.87E+02	1.09E+03	1.99E+03	9.60E+03	1.22E+04
Tc-99	4.86E-02	7.89E-02	NR	NR	NR	NR	NR	NR	3.83E+00	5.60E+00
U-234	1.60E-02	8.66E-02	2.00E-02	7.34E-02	7.61E-02	1.60E-01	2.16E-01	3.89E-01	1.10E+00	9.81E-01
U-235	5.76E-04	9.34E-04	6.61E-04	2.60E-03	2.88E-03	6.27E-03	9.39E-03	1.29E-02	4.29E-02	3.23E-02
U-236	1.84E-03	4.93E-03	2.07E-03	8.24E-03	8.90E-03	1.94E-02	2.95E-02	4.43E-02	1.64E-01	1.83E-01
U-238	1.28E-02	2.07E-02	1.46E-02	5.75E-02	6.26E-02	1.36E-01	2.03E-01	2.81E-01	8.48E-01	8.45E-01

Notes:

1. NR – Not Reported
2. The SCS-CON-210 sludge safety basis concentrations for radionuclides, total uranium, and uranium metal represent credible extreme values. The organic ion exchange resin (OIER) concentration in SCS-CON-210 sludge core samples decreases the closer the core sample was obtained to a sludge distributor head. Therefore, a credible extreme is no OIER resin present in a portion of the SCS-CON-210 sludge. The OIER acts as a diluent for the radionuclides and other analytes present in the SCS-CON-210 sludge subsamples and therefore the mass or volume contribution of the OIER in each SCS-CON-210 core subsample was removed to calculate the safety basis concentrations for the radionuclides, total uranium, and uranium metal.

The KW Basin Garnet Filters collected the less than 15μm sludge particles that did not settle in the Settler Tanks. Retrieval of the KW Basin Garnet Filter media and sludge is not included in the scope of the ECRTS subproject (KBC-30811 Section 6); however information for this material is provided for completeness. Laboratory-scale settling tests were conducted with subsamples of the Settler Tank sludge samples collected from engineered container SCS-CON-230 to determine the composition and particle size distribution of sludge particles that remained suspended (PNNL-20884). The median (i.e. diameter at which 50vol% of the particles is smaller than) particle size was ~2 μm and 95vol% of all particles were less than 10 μm for the suspended solids from settling tests with Settler Tank sludge. The density of uranium metal is 19 g/cm^3 and would not be carried into the KW Basin Garnet Filters but, instead collect in the Settler Tanks. Table 3 provides the radionuclide concentrations in the suspended solids from settling tests with Settler Tank sludge (PRC-STP-CN-CH-00556). An estimated 0.069 m^3 to 0.092 m^3 of sludge particles are present in each of the three KW Basin Garnet Filters (PRC-STP-CN-CH-00556).

Table 3. Suspended Solids from Settling Test with Settler Tank Sludge, Settled Mass Basis

Sample ID >	**SSKW230- 05S-S**	**SSKW230- 05D-S**	**SSKW230- 10S-S**
Analyte	**(μCi/cm^3)**	**(μCi/cm^3)**	**(μCi/cm^3)**
Alpha Energy Analysis Screen			
^{238}Pu + ^{241}Am	2.33E+02	2.33E+02	2.33E+02
$^{239+240}$Pu	2.08E+02	2.03E+02	2.20E+02
Gamma Energy Analysis			
^{60}Co	7.98E-01	8.33E-01	7.88E-01
^{137}Cs	6.22E+02	5.68E+02	4.23E+02
^{154}Eu	7.48E+00	7.75E+00	7.45E+00
^{155}Eu	1.37E+00	1.07E+00	1.21E+00
^{241}Am	2.05E+02	2.08E+02	2.08E+02
^{90}Sr (β-Liquid Scintillation Counter)			
^{90}Sr	1.87E+03	1.76E+03	1.06E+03
GEA reference date is January 11, 2011. AEA analyte reference date is July 29 through August 9, 2011. ^{90}Sr reference date is July 12, 2011			

The radionuclide concentrations in the sludge in the KW Basin Garnet Filters are similar to the concentrations for Settler Tank sludge. However, each KW Basin Garnet Filter contains ~2.26 m^3 (80 ft^3) of media and only 0.069 m^3 to 0.092 m^3 of sludge particles (PRC-STP-CN-CH-00556). The ECRTS subproject plans to load 0.4 m^3 of the Settler Tank sludge along with 1.6 m^3 of KE sludge into one STSC. A maximum of 2.26 m^3 of KW Basin Garnet Media and 0.092 m^3 of sludge is anticipated to be loaded into an STSC. An STSC containing 0.4 m^3 of Settler Tank sludge (layered with 1.6 m^3 of KE sludge in an STSC) would contain greater than 4 times the sludge volume as an STSC containing 2.26 m^3 of KW Basin Garnet Filter media and 0.092 m^3 of sludge. Therefore, using 0.4 m^3 of Settler Tank sludge (layered with 1.6 m^3 of KE sludge in an STSC) in the thermal and gas generation analyses results in a conservative (i.e. higher) estimate of heat generation and the hydrogen concentrations in the STSCs and in T Plant than analyses of 2.26 m^3 of KW Basin Garnet Media and 0.092 m^3 sludge loaded into an STSC.

Presently, there is no estimate of the sludge volume or composition that may be present in the ECRTS Sand Filter media or the KW Basin Sand Filter media at the end of their service life. Additionally, retrieval of the KW Basin Sand Filter media and sludge is not included in the scope of the ECRTS subproject (KBC-30811 Section 6). The KW Basin Sand Filter media is comprised of approximately 0.59 m^3 of support sand and 2.5 m^3 of media sand. The KW Basin Sand Filter is periodically backwashed to remove sludge to the KW Basin north load-out pit. The KW Basin Sand Filter media is estimated to retain 0.30 to 0.35 m^3 of sludge when it is ready for backwashing (PRC-STP-CN-CH-00906). The ECRTS Sand Filter will contain approximately 0.3 m^3 of sand and garnet (HNF-41051 Section 3.6). The ECRTS Sand Filter will be backwashed into the STSC that is being loaded with sludge as part of normal operations. Therefore, it is anticipated that the ECRTS Sand Filter media and KW Basin Sand Filter media will contain a small volume of sludge that has composition similar to the sludge in the engineered containers.

2.2 Sludge Settling During STSC Filling

The STSC is initially filled with water as part of establishing the buoyant weight of the STSC. The water is removed to the maximum extent possible; leaving approximately 0.47 m^3 of water in the STSC (HNF-41051). A batch of sludge slurry is retrieved from an engineered container and transferred into an STSC where the sludge is settled by gravity. After the sludge has sufficiently settled, excess water is removed from above the settled sludge by decanting and filtered to remove entrained solids. Subsequent batches of sludge are added to the STSC, settled and excess water decanted until the target volume of settled sludge in the STSC is obtained.

Settling each batch of sludge added to an STSC results in the sludge batch segregating into uranium metal-rich and uranium metal free sludge layers. FAI calculated the volumes, densities, compositions, and other properties of the uranium metal-rich and uranium metal-free sludge layers in an STSC as part of the thermal and gas generation analyses. PRC-STP-00893 Volume 2 provides further discussion of the uranium metal-rich and uranium metal-free sludge layers and properties from batch loading each sludge type in an STSC.

3.0 Major Assumptions

A complete list of assumptions used in the FATE^{TM} model is given in PRC-STP-00893 Volume 1 and includes the following key assumptions.

3.1 STS Cask Model Assumptions

1. Full insolation is used to model normal shipping. A solar insolation absorptivity multiplier of 0.52 is assumed for the STSC cask consistent with the value for weathered 304 stainless steel in *Thermal Analyses Methods for Safety Analysis Reports for Packaging* (WHC-SD-TP-RPT-005, rev. 1 Table A-51).

2. Diurnal temperature variations are considered.

3. The STSC and STS cask are assumed to be sealed and inerted with nitrogen gas for transportation after all batches of sludge are added.

3.2 STSC and Sludge Model Assumptions

1. The FATE^{TM} sludge model considers pertinent phenomena at an appropriate level of detail. Notable model features include the correlation for the rate of uranium metal oxidation (includes reaction rate enhancement factor), the "shrinking-core" model for metal oxidation, local water evaporation into evolved hydrogen gas bubbles (vapor stripping), representation of sludge properties consistent with HNF-SD-SNF-TI-015 Volume 2, radiolysis, and mass and energy balances. The oxygen poisoning model is not employed here, which is a conservative approach in terms of maximizing hydrogen production.

2. The STSC and its contents are azimuthally symmetric, so that two-dimensional discretization in the axial and radial dimensions provides a sufficient description for the evolution of composition and temperature within the sludge and STSC structure.

3. While the temperature distribution in the sludge and STSC structure is distributed, the overlying water pool and gas spaces are assumed to be well-mixed with each having a uniform temperature.

4. The uranium metal reaction with water rate enhancement factor is set to the safety basis value of 3 when safety basis composition sludge is present and a value of 1 when design basis composition sludge is present in an STSC.

5. Holes in the support skirt are sufficiently large and numerous to permit effective natural circulation heat transfer from the elliptical bottom head to gas inside the skirt and eventual convective exchange of gases inside and outside the skirt. Calculations in PRC-STP-00893 Volume 4 Appendix B validated this assumption.

6. The STSC has two open, unfiltered vents open to the T Plant cell configured to provide a stack height to induce natural circulation. The nozzle S2 inlet vent diameter is 2 inches (0.0508 m), and the nozzle F2 outlet vent diameter is 2 inches (0.0508 m), with stack heights and orientation as shown on drawing H-2-836175, *STP Interim Storage STSC Vent Configuration*.

3.3 Sludge Property Assumptions

1. Sludge is loaded in batches as described in the case descriptions. Within each batch, the sludge material is assumed to separate (or segregate) into a lower layer containing all the metallic uranium of the batch, and an upper layer that is metal-free. The composition of each layer is given by a model described in PRC-STP-00893 Volume 2 which uses the particle size distribution for sludge components and a settling model to predict properties of each sludge layer. Loading with more batches / sludge layers for the same net volume is non-conservative because it would have the effect of distributing the uranium metal more uniformly and result in lower temperatures, as demonstrated in previous analyses. Therefore, the cases specified by the STP assume a minimum number of sludge batches transferred into an STSC to achieve the desired sludge volumes. This maximizes the rate of increase of the sludge temperature and gas generation to provide conservative results.

2. In most analyses, safety basis properties define the batch properties. Cases that use design basis sludge properties are clearly identified. The safety basis sludge properties represent a small population of the sludge owing to the statistical methods used to derive these values. Applying safety basis sludge properties to the sludge loaded into an STSC is conservative since an accumulation of all batches at the safety basis (high) concentrations is unlikely in any one STSC and physically impossible for all STSCs.

3. Design basis sludge expansion factors (HNF-SD-SNF-TI-015 Vol. 2 Table 4-9) were used to determine the maximum volume of water allowed above the settled sludge in an STSC. Furthermore, it was assumed that the fully expanded sludge and water could occupy the entire volume of the STSC including the upper head. This assumption precludes the discharge of water and sludge from an STSC resulting from sludge expansion during storage at T Plant.

4. The fractions of decay power from alpha, beta, and gamma radiation are based upon isotopic compositions and are documented in the Sludge Databook (HNF-SD-SNF-TI-015 Vol. 2 Table 4-39).

5. The radiolysis model of SNF-22059 applies. SNF-22059 provides a calculation of the fraction of alpha, beta, and gamma power that is absorbed by interstitial water, and therefore leads to radiolysis of water. This calculation was performed for several sludge types of interest at the time. A best match to those sludge types is found for sludge compositions used for this work, so that the power fraction absorbed by water for those reference compositions is used for the sludge compositions in this work.

3.4 T Plant Model Assumptions

1. One STSC with safety-basis sludge inside an overpack is modeled in detail for transient behavior, while five other STSCs in the "analyzed cell" are represented by constant design basis heat and hydrogen generation rates.

2. Other standard process cells (generally containing five STSCs each) are considered, and average heat sources are used for these "hot" cells. Aside from the analyzed cell there are effectively 24 other STSCs in five hot cells.

3. Worst case cover block gaps (giving reduced flow area) are assumed for the ventilated cases for the process cell with the analyzed STSC.

4. For natural circulation, when facility ventilation is secured, the air flow through the STSC storage cells is minimized when an alternate, less restrictive flow path is provided in the canyon that is not part of the process cells containing STSCs. In cases without ventilation, rather than assume worst case (larger area) cover block gaps for the process cells not containing STSCs, the cells are simply assumed to be open (bounding) and nominally worst case cover block gaps are assumed for the pipe trench, in order to minimize natural circulation flows through the process cells containing STSCs. With ventilation, the choice of resistances is moot because the cell purge rate is sufficiently high as borne out by results.

5. Standard cells can have a natural circulation flow pattern involving the pipe trench, ventilation duct, and canyon, which is independent of the natural circulation flow pattern involving the long cells (i.e. 1L, 1R, 2L, and 2R) connected by the 24" external ventilation pipe. This is true because the 24" pipe connects to the ventilation system downstream of the ventilation duct serving sections 3 through 20 in T Plant.

6. Heat sinks have idealized external boundary conditions. In most cases, the "inside" boundary condition is convection to the cell or other region atmosphere, while the "outside" boundary condition is insulated. This is valid for concrete for a time scale of about a day but not for several weeks, but the effect of a variation in external temperature is considered to be minor with regard to its impact on cell temperature.

7. For cases with ventilation, the minimum ventilation flow of 17,500 cfm from HNF-SD-SNF-TI-015 Vol. 2 Table 4-37 is used, and the minimum canyon pressure of -0.15 inches water gage from HNF-12563 is used to calculate an effective resistance to air infiltration into the canyon. The infiltration is assumed to be equally divided between inlet to cell 2L (via the roll-up door) and paths direct to the canyon (such as the rear stairwell doors).

8. The effect of the T Plant stack is specifically considered for cases without ventilation.

9. Diurnal temperature variations in the ambient are considered.

4.0 FATE™ Description and Validity

The FATE™ computer program is used for this work (SNF-23281 and PRC-STP-00299); the ™ symbol will be dropped for simplicity. The FATE sludge model was developed by FAI for the Hanford Spent Nuclear Fuel Program and the K Basins Closure Project under the FAI QA program. FATE has been used for K Basins sludge applications including scoping calculations, normal and off-normal behavior, and accidents including pump station spills and spray leaks at CVD.

Briefly, FATE can model heat transfer, fluid flow, and chemical reactions in sludge, its containers, a cask if present, a building or facility containing them, and the environment. Decay power, oxidation power, and conversion of metal to oxide with decrease of reactive surface area are included. Heat conduction in sludge and its container is allowed in one or more dimensions, according to the problem; natural convection occurs in overlying water or air. Pressure, temperature, gas composition, and exchange flows are considered in control volumes that typically consist of the container headspace and surrounding compartments.

The scope of calculations considered here is within the scope of model testing and previous applications, and does not involve untested model capabilities.

Figure 4-1 and Figure 4-2 show the FATE model for sludge storage in two types of the STSCs. Figure 4-1 depicts an STSC with a water-filled insert that reduces the conduction length and the peak sludge temperature. The STSC design with the insert was previously evaluated in PRC-STP-00893 Volume 4 for transporting and storing 0.5 m^3 of Settler Tank sludge. However, the STSC with the insert is no longer being considered for storing Settler Tank sludge. The STSC with the insert (Figure 4-1) is shown to aid in comparison of thermal and gas generation results for the older FAI model and the current FAI model, as discussed in Section 6.1. The STP plans to use the STSC without the insert as shown in Figure 4-2 to load, transport and temporarily store the different sludge types at T Plant.

FAI uses the FATE model to develop the conditions for the receipt at T Plant of an STSC loaded with each sludge type(s) contained in the STS cask. The conditions of the received STSC / STS cask include temperature, internal pressure, and compositions of the STS cask and STSC. Figure 4-3 shows the FATE model for an STSC in an STS Cask. Thermal radiation occurs from the bottom head of the STSC to the bottom of the STS cask and to the short "skirt" that supports the STSC. The STS cask cover gas is modeled as a separate region connected to the STSC inner cylinder head space through two filtered openings. The outer surface of the STS cask is exposed to insolation, with separate solar fluxes for the top and sides. The outer surface of the STS cask is also exposed to ambient air with diurnal temperature variation. The bottom surface of the STS cask is insulated. Two-dimensional axisymmetric heat conduction is modeled in the side wall, and one-dimensional planar conduction is considered in the lids for the STS cask.

Figure 4-1 FATE Model Representation for the STSC with Water Filled Insert

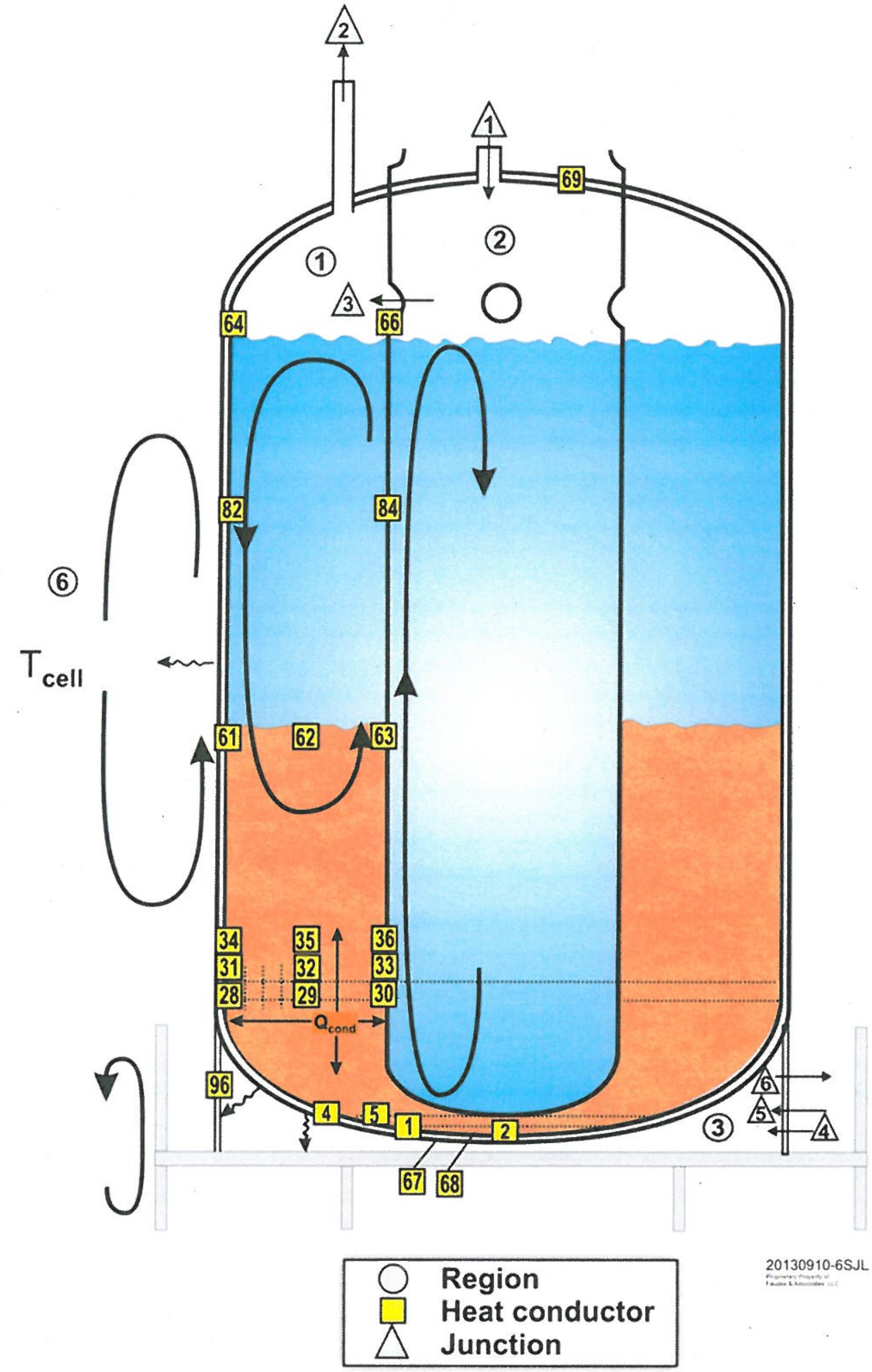


Figure 4-2 FATE Model Representation for the STSC without Water Filled Insert

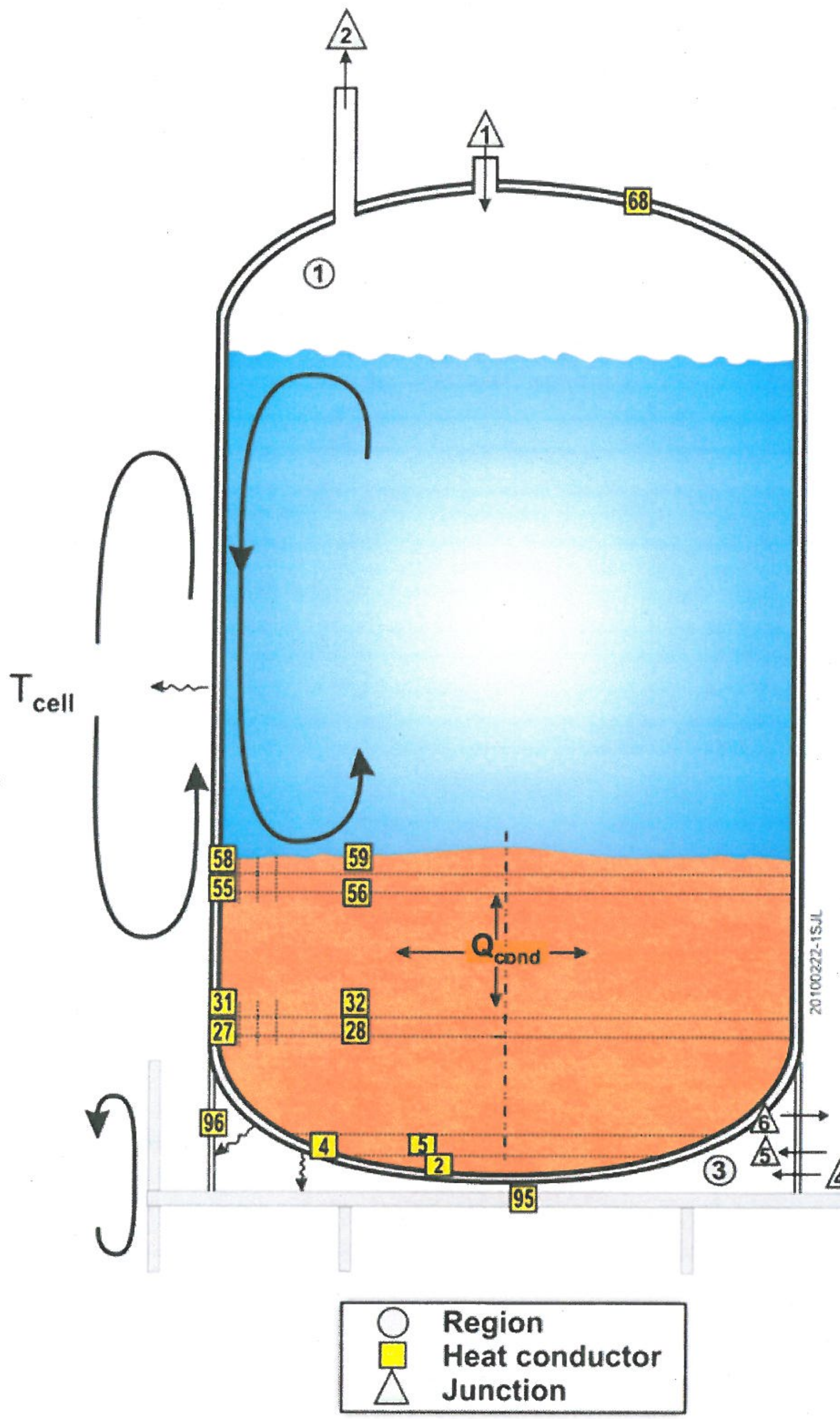
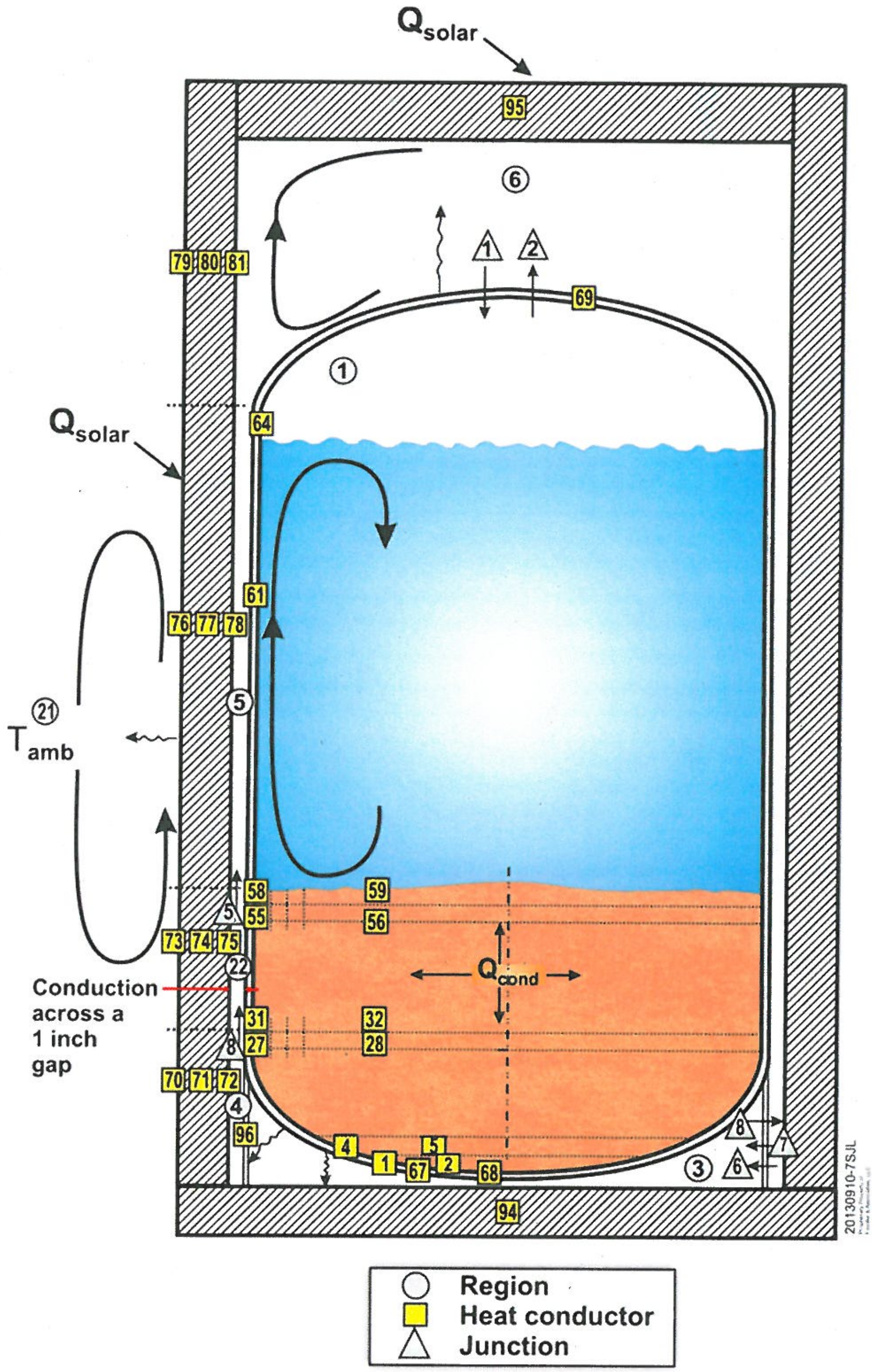


Figure 4-3 FATE Model Representation for the STSC and STS Cask



After venting and purging the STS cask and purging the STSC headspace, the STSC is equipped with two pipes to facilitate natural circulation of gases from the STSC headspace into the storage cell at T Plant. The STSC is then placed in a cell specifically equipped to store the K Basin sludge. FAI uses the FATE model to evaluate storage of STSCs in specific cells at T Plant. The T Plant model representation is shown in Figure 4-4 and is designed to allow cases with and without active ventilation, cases with the detailed STSC model residing in a standard cell, and cases with a variable number of cells containing STSCs. In particular, the model is designed to represent the potential for natural convection loops between cells, the canyon, and the ventilation duct in the absence of ventilation. The directions indicated by arrow heads in Figure 4-4 are nominal, and the FATE program mechanistically determines not only the actual direction of flow but whether or not countercurrent flow occurs along the path.

As mentioned above, one STSC with safety-basis sludge properties is modeled in detail. This STSC is placed in a standard cell, Region 6 in Figure 4-4. Sources of heat and hydrogen gas from other STSCs are approximated by constant, design-basis values. The STSC loses heat by convection and radiation to the cell gas, which in turn transfers heat to the cell walls and cell cover blocks modeled as one-dimensional heat conductors. Since the cell floor is cooler, it can be neglected.

Except for cell 2L, each cell region has a cover block flow path to the canyon and the pipe trench which also has a cover block flow path. Cell 2L has no cover blocks and a large rollup door to the outdoors. Standard cells and the pipe trench have 10-inch flow paths to the ventilation duct. Cells 1L, 1R, 2L, and 2R each have a 10-inch flow path to a 24-inch buried pipe that connects to the ventilation duct external to the plant. For cases with ventilation, the flows into cell regions and the pipe trench depend upon the cover block resistance input value. For cases without ventilation, the FATE model will automatically calculate flow direction and whether or not there can be countercurrent flow. The canyon ventilation exhaust model considers flow through the exhaust system HEPA filters and fans and out through the stack. Cell walls are modeled with external insulated boundary conditions as an approximation. The same applies to the ventilation duct and pipe trench. The wall between cells 2L and 2R is modeled with convection to both cells. The 24" pipe wall and surrounding ground are represented. For the stack, heat transfer is allowed both inside and outside the stack.

In the event that an STSC were to develop a leak during storage at T Plant, an overpack will be used to contain the leaking STSC. Each of the cells used at T Plant to store STSCs has a spare storage location for one STSC in an overpack. Figure 4-5 shows the FATE model for the STSC in an overpack. Each sludge type is considered for the overpack analysis. The STSC overpack is essentially an open-top cylindrical "bucket" in which a potentially leaky STSC is placed, thus adding some thermal resistance around the STSC. The gap between the STSC and overpack is modeled using two regions: one around the skirt and one around the cylindrical part of STSC. Heat generated in the STSC conducts across the 2.5 inch gap in the Overpack and is rejected into the atmosphere in the T Plant cell. Heat in the gap is also removed by counter-current flows in the gap.

The corresponding list of regions, junctions, heat sinks, and modeling approach shown in these figures are discussed further in PRC-STP-00893 Volume 1.

Figure 4-4 FATE Model Representation for T Plant.

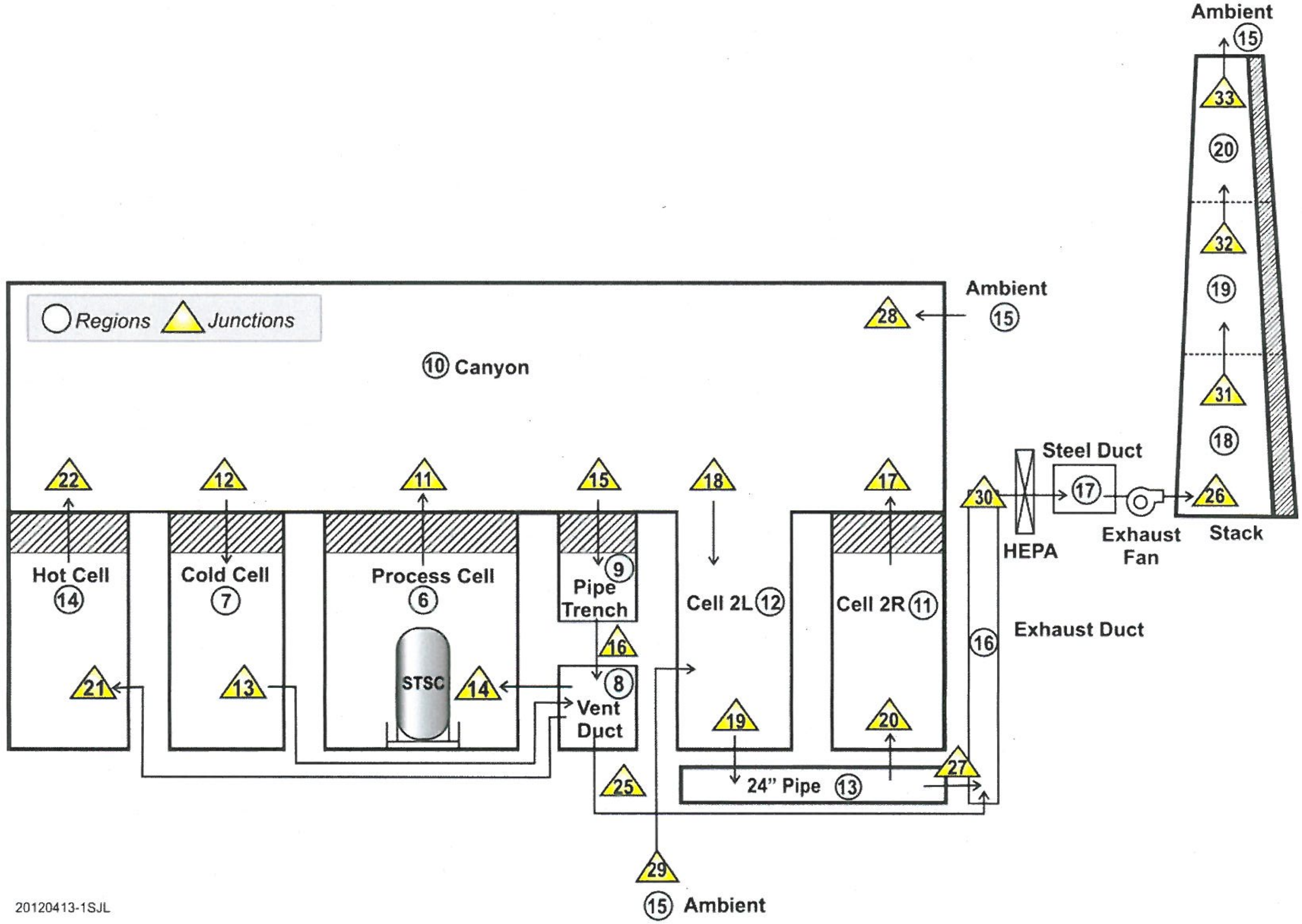
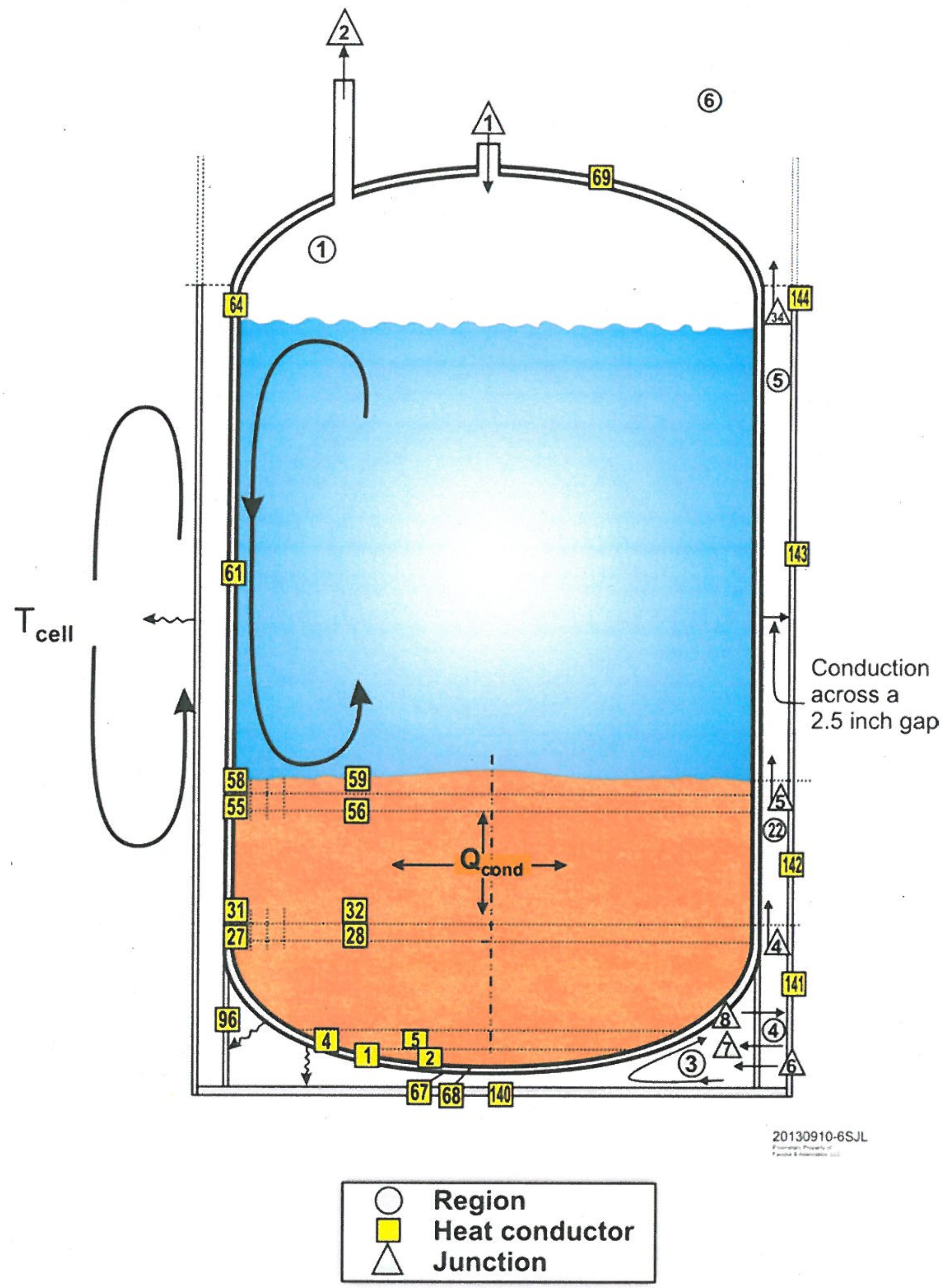


Figure 4-5 FATE Model Representation for the STSC and Overpack



5.0 Cases Analyzed

FAI previously analyzed two different methods for venting and purging the STS cask and purging the STSC headspace, ten cases for storing STSCs within T Plant cells with and without the T Plant exhaust ventilation fans operating, three cases to evaluate evaporative water loss from an STSC during storage at T Plant, and three cases to evaluate the potential for the sludge in an STSC to freeze. These previously analyzed cases are documented in PRC-STP-00241 revision 1 and PRC-STP-00893 Volume 4.

The Sludge Treatment Project (STP) evaluated these previously analyzed sludge transportation and T Plant storage cases to identify opportunities to reduce the number of STSC required for transportation and storage of KW Basin sludge through combining sludge types in an STSC (PRC-STP-00867 and PRC-STP-00884). As a result of these evaluations, the STP identified an opportunity to layer KW 230 sludge with KE sludge in an STSC. The STP contracted with FAI to evaluate the venting and purging, thermal and gas generation rate, and evaporative water loss for an STSC / STS cask containing a combination of KW 230 and KE sludge. The evaluations by FAI are:

- A revised method for venting and purging the STS cask and purging the STSC upon receipt at T Plant when the STSC contains 0.4 m^3 of safety basis composition KW 230 sludge beneath a layer of 1.6 m^3 of safety basis composition KE sludge and 0.96 m^3 of water (case CV1)
- A revised method for venting and purging the STS cask and purging the STSC upon receipt at T Plant when the STSC contains 0.4 m^3 of design basis composition KW 230 sludge beneath a layer of 1.6 m^3 of design basis composition KE sludge and 0.96 m^3 of water (case CV2)
- Thermal and gas generation rate analyses for storing STSCs containing 0.4 m^3 of safety basis composition KW 230 sludge beneath a layer of 1.6 m^3 of safety basis composition KE sludge and 0.96 m^3 of water with and without the T Plant exhaust ventilation fans operating (cases S2-F and S2-NF)
- Thermal and gas generation rate analyses for storing STSCs containing 0.4 m^3 of design basis composition KW 230 sludge beneath a layer of 1.6 m^3 of design basis composition KE sludge and 0.96 m^3 of water with and without the T Plant exhaust ventilation fans operating (cases S3-F and S3-NF)
- Evaporative water loss analysis from an STSC containing for 0.4 m^3 of safety basis composition KW 230 sludge beneath a layer of 1.6 m^3 of safety basis composition KE sludge and initially 0.96 m^3 of water (case WL1)

Relative to the prior transport and storage modeling discussed in PRC-STP-00893 Volume 4, FAI made "Substantial changes to the STSC, overpack, and cask models which reflect more accurate geometry, especially with regard to loss coefficients from upper head penetrations, couplings, and fittings. Region nodalization in the gap between the STSC and the overpack or cask was changed to address a potentially non-conservative heat transfer path" (PRC-STP-00893 Volume 3 page 67). FAI used the revised models to re-analyze cases for transportation and storage of 1.6 m^3 of KW 210 sludge in the STSC without the water filled insert (storage cases[1] CONS21TRFO and CONS21TRNO re-analyzed as cases[2] S5F, S5FA, S5NF, and S5NFA) and 0.5 m^3 of KW 230 sludge in the STSC with the water filled insert (storage cases SETS1TRFO and SETS1TRNO re-analyzed as cases S4F, S4FA, S4NF, and S4NFA). A comparison of the older and revised model results, provided in Section 6.0, demonstrates the older analyses remain valid.

CHPRC used the revised FAI thermal and gas generation rate models to evaluate storing the 25.4 liters of segregated settler material with ~1.07 m^3 of safety basis composition KW 220 sludge in a single STSC. Appendix A discusses the modifications to the FAI thermal and gas generation rate models conducted by CHPRC to evaluate storing the 25.4 liters of segregated settler material with ~1.07 m^3 of safety basis composition KW 220 sludge in a single STSC. The cases evaluated by CHPRC are:

- Thermal and gas generation rate analyses for storing one STSC containing a uniform mixture of 0.0254 m^3 of safety basis composition segregated settler material combined with 1.07 m^3 of safety basis composition KW 220 sludge and 2.1 m^3 of water with and without the T Plant exhaust ventilation fans operating (cases S6FM and S6NFM)

- Thermal and gas generation rate analyses for storing one STSC containing the segregated settler material in a thin layer between two layers of KW 220 sludge and ~2.1 m^3 of water. The 0.0254 m^3 of safety basis composition segregated settler material is combined with 0.079 m^3 of safety basis composition KW 220 sludge to form the thin layer between two layers of KW 220 sludge. T Plant storage of the STSC containing this thin layer loading configuration is evaluated with and without the T Plant exhaust ventilation fans operating (cases S6FT and S6NFT)

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[1] The naming convention for the older model cases uses letter groupings as follows:
- CONS21 for two 0.8m^3 of batches of KW 210 container sludge,
- SETS1 for single-batch settler sludge
- T for T Plant;
- Cell type: R = regular, i.e. standard (cells 3 through 20)
- Ventilation type: F = T Plant fans running, N = no fans, R = restored after specified duration
- Overpack: O, <omitted> = no overpack
- Sensitivity case: 'S' = Sensitivity case, <omitted> = normal case

[2] The naming convention for the newer model cases uses letter groupings as follows:
- S1 for T Plant storage of 0.5m^3 of safety basis Settler sludge with 163 kg/m^3 uranium metal concentration in the STSC with the annular insert
- S2 for T Plant storage of 0.4m^3 of safety basis Settler sludge with 163 kg/m^3 uranium metal concentration with 1.6m^3 of safety basis KE Engineered Container sludge in the STSC without the annular insert
- S3 for T Plant storage of 0.4m^3 of design basis Settler sludge with 1.6m^3 of design basis KE Engineered Container sludge in the STSC without the annular insert
- S4 for T Plant storage of 0.5m^3 of safety basis Settler sludge with 144 kg/m^3 uranium metal concentration in the STSC with the annular insert
- S5 for T Plant storage of 1.6m^3 of safety basis KW 210 sludge in the STSC without the annular insert
- S6 for T Plant storage of 25.4 liters for segregated settler material with 1.0m^3 of safety basis composition KW 220 sludge; M is the mixture and t is the thin layer configuration
- Ventilation type: F = T Plant fans running, NF = no fans
- Initial T Plant cell temperature; <omitted> = 32°C; A = 35°C

CHPRC also used the revised FAI thermal and gas generation rate model to evaluate not installing the ~2-ft. tall vent pipe on STSC nozzle F2 with the STSC containing 0.4 m^3 of safety basis composition KW 230 sludge layered beneath 1.6 m^3 of safety basis composition KE sludge and 0.96 m^3 of water in a single STSC. Appendix B discusses the modifications to the FAI model conducted by CHPRC.

6.0 Discussion of Results

Section 6.1 provides the results for venting and purging the STS cask and purging the STSC at T Plant. Section 6.2 provides results for storing the STSCs in the T Plant canyon cells. The water loss rates during storage of an STSC for 1 year are presented in Section 6.3 which was previously documented PRC-STP-00241 revision 1 and PRC-STP-00893 Volume 4. The potential for the sludge in an STSC to reach the freezing point is discussed in Section 6.4, which was previously documented in PRC-STP-00241 revision 1 and PRC-STP-00893 Volume 4 and summarized in this document for convenience.

6.1 STS Venting and Purging and STSC Purging at T Plant

Upon receipt at T Plant, the STS cask needs to be vented to reduce internal pressure and purged using nitrogen to remove potentially flammable gas (i.e. hydrogen). The STS Cask is assumed to be at 80 psig and contain 96% hydrogen in the void space when received at T Plant (PRC-STP-00908 Section 5.1.2). The potentially flammable gases vented / purged from the STS cask will be discharged through a piping manifold that connects to a 20-inch long 2-inch diameter pipe (vent assembly) at an elevation of ~13-inches (0.33 m) above the canyon deck, as shown in Figure 6-1 (drawing H-2-830346 as modified by ECR-15-000336). FAI calculated the venting duration; plume diameter and height for lower flammability limit (LFL; i.e. 4 Vol. % hydrogen) and 25% of the LFL (i.e. 1 Vol. % hydrogen) when venting the STS cask at 5, 10, and 15 scfm for the two cases identified in Table 4 (PRC-STP-00908 Section 5.1.3). Results for venting the STS cask are shown in Table 5.

After venting the cask, a nitrogen source is used to purge the STS cask which was modelled as supplied at 2.7 psig and 26.7°C (80°F). The nitrogen flow to the STS cask enters the bottom of the cask through a connecting port and exits the cask through a port in the cask lid. These FAI calculations show the hydrogen concentration in the STS cask is ~76 Vol. % after venting and assume hydrogen continues to be generated at 490 liters/day for safety basis sludge while purging of the STS cask occurs (PRC-STP-00908 Table 5-5). These FAI calculations show the hydrogen concentration in the STS cask is ~0.4 Vol. % after venting and assume hydrogen continues to be generated at 10.6 liters/day for design basis sludge while purging of the STS cask occurs (PRC-STP-00908 Table 5-1).

FAI used the following equation to model the purging of the STS cask (PRC-STP-00908 Section 5.2), which is derived from Annex D of NFPA-69:

$$t = (-V/ (K * Q_{purge})) * LN [(x(t) - Q_{src} / (K * Q_{purge})) / (x(0) - Q_{src} / (K * Q_{purge}))]$$

Where:

V	is cask void volume
K	is mixing efficiency of purge with hydrogen in cask; K = 0.25 or 1
Q_{purge}	is purge flow rate, m^3/sec
Q_{src}	is hydrogen generation rate, m^3/sec
t	Time, seconds
x(t)	hydrogen mole fraction at time t
x(0)	hydrogen mole fraction at time zero

Purging the cask continues until the hydrogen concentration is reduced below 0.1 Vol. % or until a quasi-steady state condition is reached. FAI evaluated mixing efficiency values of 25%, as recommended by NFPA-69 Annex D for ventilation calculations, and 100%. FAI calculated the time and the required quantity of nitrogen for purging the STS cask at 5 scfm and venting at 5, 10, or 15 scfm for the two cases identified in Table 4 and mixing efficiencies of 25% and 100%. Results for purging the STS cask are shown in Table 6 and Table 7. FAI has stated a mixing efficiency of 100% (i.e. full mixing) is conservative:

> "The use of 25% mixing efficiency is considered overly conservative, in particular for safety basis Cask purging where nitrogen is introduced at the bottom of the Cask (within the skirt volume) and outflow exits from the top of the Cask. Even 100% mixing efficiency is considered conservative, since the purge system would tend to push the bulk of the lighter hydrogen-bearing gas out the Cask vent before the nitrogen purge flow reaches the purge exit."... "Consideration of 100% mixing efficiency artificially keeps hydrogen mixed throughout the Cask, extending the time to purge the Cask down to a target concentration. Full mixing in the Cask is thus conservative..." (PRC-STP-00908, Section 5.2.4).

Table 4. Cask Venting, Cask Purging and STSC Purging Cases

Case Name	Sludge Type	Sludge (m^3)	Cover Water (m^3)	T Plant Receipt Conditions
CV1(1)	KW 230	0.4	0.96	Bounding conditions for cask received at T Plant. Cask internal pressure is 80 psi after approximately 13.4 days shipping window; maximum possible hydrogen gas concentration of 96%
	KE	1.6		
CV2(2)	KW 230	0.3	1.25	Nominal conditions for cask received at T Plant. Cask received after 9 days shipping window, internal pressure is 3 psi and 5% hydrogen gas concentration
	KE	1.5		

(1) Safety basis sludge compositions; 0.163 g/cc U-metal for KW 230 and 0.00457 g/cc U-metal for KE. Uranium metal reaction rate with water is set at a multiplier of 3 to enhance hydrogen gas generation.
(2) Design basis sludge compositions; 0.022 g/cc U-metal for KW 230 and 0.00027 g/cc U-metal for KE. Uranium metal reaction rate with water is set at a multiplier of 1, which is nominal condition for hydrogen gas generation.

Table 5. Results for STS Cask Venting at T Plant

Vent Case Name	Initial Pressure (psig)	Initial Temperature (°C)	STSC Hydrogen (Vol. %)	Venting Rate (scfm)	Venting Duration (minutes)	1% H_2 Plume Height (m)	1% H_2 Plume Diameter (m)	LFL H_2 Plume Height (m)	LFL H_2 Plume Diameter (m)
CV1L	80	53	96	5	96	3.76	1.25	1.61	0.57
CV1M	80	53	96	10	51	5.00	1.65	2.14	0.74
CV1H	80	53	96	15	36	5.88	1.94	2.52	0.86
CV2L	6	45	5	5	2	1.03	0.38	0.28	0.14
CV2M	6	45	5	10	1	1.12	0.41	0.29	0.14
CV2H	6	45	5	15	1	1.15	0.42	0.29	0.15

Table 6. Cask Purge Timing for 5 scfm Purge Rate and 25% Mixing Efficiency

Purge Case Name	Venting Rate (scfm)	Target Vol. % H_2 in Cask	Time to Target Vol. % H_2	Nitrogen Required
CV1LR	5	1.25	3.5 hours purge after 1.6 hours venting (5.1 hours total)	30 m^3 / 36 kg
		1.0	5.1 hours purge after 1.6 hours venting (6.7 hours total)	43 m^3 / 50 kg
CV1MR	10	1.25	3.7 hours purge after 0.8 hours venting (4.5 hours total)	31 m^3 / 38 kg
		1.0	5.9 hours purge after 0.8 hours venting (6.7 hours total)	50 m^3 / 58 kg
CV1HR	15	1.25	4.1 hours purge after 0.6 hours venting (4.7 hours total)	35 m^3 / 42 kg
		1.0	~8 hours purge after 0.6 hours venting (~8.6 hours total)	~68 m^3 / ~80 kg
CV2LR	5	<0.1	61 minutes	8.6 m^3 / 10 kg
CV2MR	10	<0.1	66 minutes	9.3 m^3 / 11 kg
CV2HR	15	<0.1	66 minutes	9.3 m^3 / 11 kg

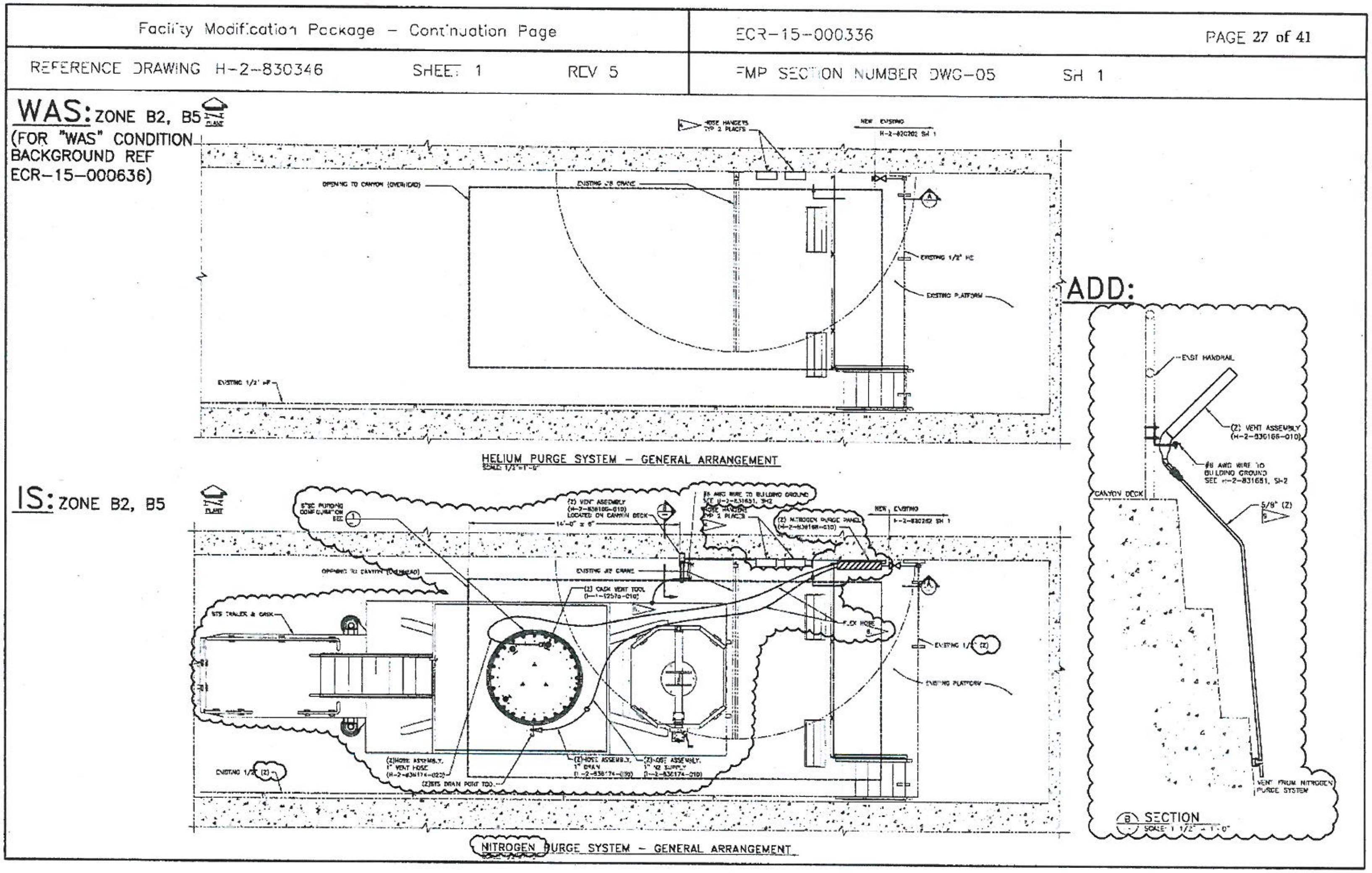

Figure 6-1 Future T Plant Arrangement for Cask Venting, Cask Purging and STSC Purging

Table 7. Cask Purge Timing for 5 scfm Purge Rate and 100% Mixing Efficiency

Purge Case Name	Venting Rate (scfm)	Target Vol. % H_2 in Cask	Time to Target Vol. % H_2	Nitrogen Required
CV1LRF	5	1.0	0.8 hour purge after 1.5 hours venting (2.3 hours total)	6.3 m^3 / 8 kg
CV1MRF	10	1.0	0.8 hours purge after 0.8 hours venting (1.6 hours total)	6.3 m^3 / 8 kg
CV1HRF	15	1.0	0.8 hours purge after 0.6 hours venting (1.4 hours total)	6.3 m^3 / 8 kg
CV2LRF	5	<0.1	17 minutes	2.5 m^3 / 3 kg
CV2MRF	10	<0.1	18 minutes	2.5 m^3 / 3 kg
CV2HRF	15	<0.1	18 minutes	2.5 m^3 / 3 kg

The FAI analyzed cases (CV1LRF, C V1MRF, and CV1HRF) for purging the STS Cask assumed the hydrogen concentration was reduced to 1 Vol. % in the cask headspace when the STSC contained 0.4 m^3 of safety basis KW 230 sludge layered beneath 1.6 m^3 of safety basis KE sludge (Table 7). CHPRC used the preceding purging equation to determine the duration required for nitrogen purging the STS Cask so that the minimum hydrogen concentration is achieved. These calculations were conducted at a purge rate of 4.5 scfm and 5 scfm and for varying hydrogen generation rates for the sludge in the STSC and are shown in Table 8 and Table 9, with the calculation details shown in Appendix C.

Table 8. Cask Purge Timing for 4.5 scfm Purge Rate and 100% Mixing Efficiency to Reach Minimum Hydrogen Concentration

x(0) Initial Vol. % H_2 in cask	x(t) theoretical minimum Vol. % H_2 in cask	Q_{src} H_2 generation Rate, Liters/day	Q_{src} H_2 generation rate, m^3/sec	Q_{purge} N_2 purge rate, rate, m^3/sec	t (sec)	t (minutes)
76.0%	0.22%	400	4.63E-06	2.12E-03	7.10E+03	118.3
76.0%	0.28%	500	5.79E-06	2.12E-03	6.95E+03	115.8
76.0%	0.33%	600	6.94E-06	2.12E-03	6.82E+03	113.7
76.0%	0.354	650	7.52E-06	2.12E-03	6.38E+03	106.4
76.0%	0.39%	700	8.10E-06	2.12E-03	6.12E+03	102.0
76.0%	0.41%	750	8.68E-06	2.12E-03	7.41E+03	123.4
76.0%	0.44%	800	9.26E-06	2.12E-03	6.63E+03	110.5
76.0%	0.50%	900	1.04E-05	2.12E-03	6.05E+03	100.8
76.0%	0.55%	1000	1.16E-05	2.12E-03	6.48E+03	107.9

Table 9. Cask Purge Timing for 5 scfm Purge Rate and 100% Mixing Efficiency to Reach Minimum Hydrogen Concentration

x(0) Initial Vol. % H_2 in cask	x(t) theoretical minimum Vol. % H_2 in cask	Q_{src} H_2 generation Rate, Liters/day	Q_{src} H_2 generation rate, m^3/sec	Q_{purge} N_2 purge rate, rate, m^3/sec	t (sec)	t (minutes)
76.0%	0.20%	400	4.63E-06	2.36E-03	6.00E+03	100.0
76.0%	0.25%	500	5.79E-06	2.36E-03	5.86E+03	97.7
76.0%	0.30%	600	6.94E-06	2.36E-03	5.75E+03	95.9
76.0%	0.32%	650	7.52E-06	2.36E-03	6.70E+03	111.7
76.0%	0.35%	700	8.10E-06	2.36E-03	5.66E+03	94.3
76.0%	0.37%	750	8.68E-06	2.36E-03	6.35E+03	105.8
76.0%	0.40%	800	9.26E-06	2.36E-03	5.58E+03	93.0
76.0%	0.45%	900	1.04E-05	2.36E-03	5.51E+03	91.8
76.0%	0.50%	1000	1.16E-05	2.36E-03	5.44E+03	90.7

After purging the STS Cask, the nitrogen purge rate is assumed to be reduced when the cask lid bolts and lid are being removed. CHPRC used the preceding purge equation to determine the duration before the hydrogen concentration increases to 1 Vol. % in the STS Cask for reduced nitrogen purge rates of 0.5 to 2.0 scfm, following purging the cask to the minimum achievable hydrogen concentration shown in Table 8 and Table 9. These reduced purge rate calculations were conducted for varying hydrogen generation rates for the sludge in the STSC and are shown in Table 10 and Table 11 with the calculation details shown in Appendix C.

The results shown in Table 10 and Table 11 that indicate "No limit" mean the reduced nitrogen purge rates are more than 100 times the hydrogen generation rate and therefore the hydrogen concentration in the STS cask will always remain less than 1 Vol. %. For example, as long as the hydrogen concentration in the STS cask was initially reduced to minimum hydrogen concentration (x(0)), a reduced nitrogen purge rate of 1.6 scfm will maintain the hydrogen concentration less than 1 Vol. % in the STS cask if the hydrogen generation rate is 650 liters/day or less.

Table 10. Time to Reach 1% Hydrogen in STS Cask for Reduced Nitrogen Purge Rates following initially purging at 4.5 scfm

Q_{src} H_2 generation Rate, Liters/day	x(0) Initial Vol. % H_2 in cask	Q_{purge} N_2 purge rate, rate scfm / Time (minutes)							
		0.5	0.75	1	1.25	1.5	1.6	1.8	2
400	0.22%	59.97	84.98	No limit	No limit	No limit	No limit	No limit	No limit
500	0.28%	40.90	51.29	72.53	No limit	No limit	No limit	No limit	No limit
600	0.33%	29.92	35.59	44.65	63.22	No limit	No limit	No limit	No limit
650	0.36	25.91	30.32	36.92	48.54	81.35	No limit	No limit	No limit
700	0.39%	22.59	26.09	31.10	39.13	55.65	70.60	No limit	No limit
750	0.41%	20.11	22.95	26.88	32.79	43.20	50.45	93.51	No limit
800	0.44%	17.70	20.04	23.17	27.66	34.89	39.32	55.48	No limit
900	0.50%	13.80	15.42	17.50	20.30	24.34	26.53	32.72	44.50
1000	0.55%	11.02	12.18	13.63	15.50	18.04	19.33	22.65	27.65

Table 11. Time to Reach 1% Hydrogen in STS Cask for Reduced Nitrogen Purge Rates following initially purging at 5 scfm

Q_{src} H_2 generation Rate, Liters/day	x(0) Initial Vol. % H_2 in cask	Q_{purge} N_2 purge rate, rate scfm / Time (minutes)							
		0.5	0.75	1	1.25	1.5	1.6	1.8	2
400	0.20%	61.13	86.21	No limit	No limit	No limit	No limit	No limit	No limit
500	0.25%	42.05	52.51	73.84	No limit	No limit	No limit	No limit	No limit
600	0.30%	31.08	36.82	45.96	64.63	No limit	No limit	No limit	No limit
650	0.32	27.33	31.82	38.53	50.27	83.22	No limit	No limit	No limit
700	0.35%	23.91	27.49	32.60	40.74	57.39	72.40	No limit	No limit
750	0.37%	21.33	24.26	28.28	34.28	44.81	52.11	95.28	No limit
800	0.40%	18.85	21.26	24.48	29.07	36.40	40.89	57.16	No limit
900	0.45%	15.08	16.78	18.96	21.87	26.03	28.27	34.59	46.51
1000	0.50%	**12.17**	13.40	14.94	16.91	19.55	20.89	24.32	29.45

After modelling purging of the STS cask, FAI modelled purging the STSC headspace using a nitrogen source at 2.7 psig and 26.7°C (80°F). These FAI calculations assume hydrogen continues to be generated at 490 liters/day for safety basis sludge and 10.6 liters/day for design basis sludge while purging of the STSC occurs (PRC-STP-00908 Table 5-1). The STSC is purged through the same piping network as the STS, which is shown in Figure 6-1. To account for incomplete mixing of nitrogen with the gases inside the STSC headspace, FAI reduced the exhaust flow by a mixing efficiency. FAI evaluated mixing efficiency values of 25% and 100%. NFPA-69 Annex D recommends using a mixing efficiency of 25% for ventilation calculations, unless a different value is technically justified. FAI calculated the time and the required quantity of nitrogen for purging the STSC headspace at 5 scfm and venting at 5, 10, or 15 scfm for case CV1 identified in Table 4 and mixing efficiencies of 25% and 100%. Results for purging the STSC headspace are shown in Figure 6-2 and Figure 6-3 for case CV1 (safety basis sludge compositions) at 25% mixing efficiency and 100% mixing efficiency. FAI has stated 100% mixing efficiency in the STSC headspace is conservative:

> "During purging of the STSC the gas supply and discharge ports are both on top. In the safety basis case it is expected that the heavier nitrogen will pass down through the hydrogen rich gas layer (essentially forming a negatively buoyant downward jet), entrain lighter gas, and accumulate from the bottom up within the STSC head space. However hydrogen evolving from the sludge will bubble upward through the overlying water layer and rise through the STSC head space, mixing with accumulated nitrogen. This situation is conducive to a well mixed gas space, so 100% mixing efficiency can be reasonably assumed."...
>
> "Finally, in the design basis case the hydrogen concentrations are low (maximum 5% in the STSC) and the densities of the purge gas and the process gas are not too different. It is likely that the gases will be well mixed and a 100% mixing efficiency can be justified" (PRC-STP-00908 Section 5.2.4).

The results for venting the STS cask with an STSC containing the safety basis sludge compositions (cases CV1L, CV1M and CV1H) result in larger 1 Vol. % hydrogen zones and LFL zones than results for venting the STS cask with an STSC containing the design basis sludge compositions (cases CV2L, CV2M and CV2H). Venting the STS cask at 5 to 15 cfm with the STSC containing safety basis sludge compositions results in a 1 Vol. % hydrogen plume height of approximately 12.4 to 19.3 ft. (3.76 to 5.88 m) above the vent pipe elevation (see Table 5). The LFL plume height is significantly lower; approximately 5.3 to 8.3 ft. (1.61 to 2.52 m) when venting at 5 to 15 cfm. The 1% hydrogen concentration zone and the LFL zone do not extend to the crane rail which is 25 to 26 ft. (7.6 to 7.9 m) above the canyon deck.

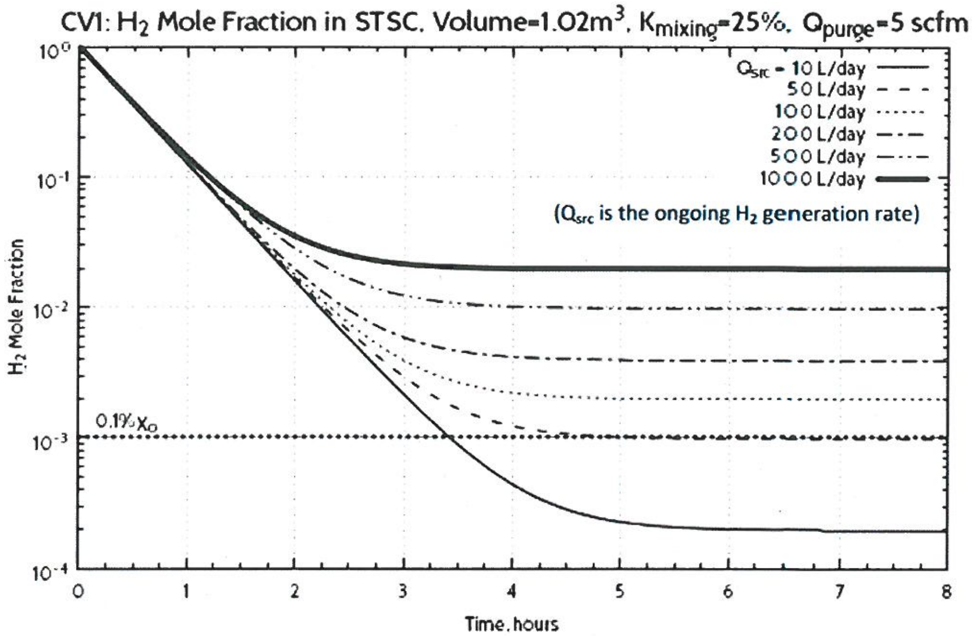

Figure 6-2 STSC Purging Results for Safety-Basis Case CV1 (25% Mixing)

(Note: Q_{src} in figure is the hydrogen gas generation rate from the sludge in the STSC. Hydrogen gas generation rates are 490 and 10.6 liters /day for safety basis and design basis sludge compositions, respectively.)

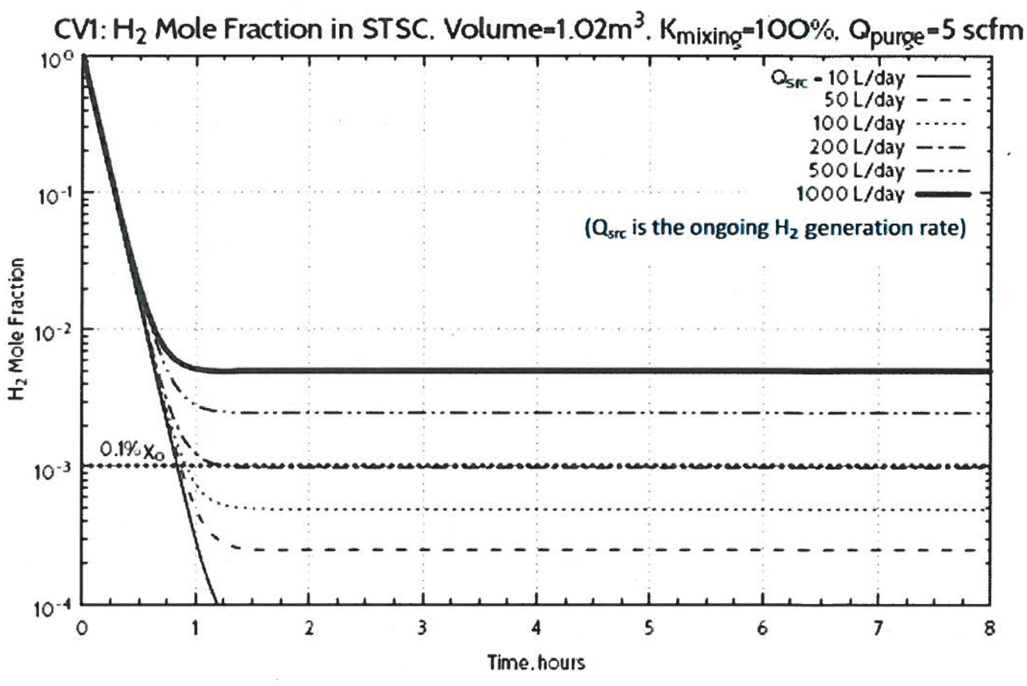

Figure 6-3 STSC Purging Results for Safety-Basis Case CV1 (100% Mixing)

(Note: Q_{src} in figure is the hydrogen gas generation rate from the sludge in the STSC. Hydrogen gas generation rates are 490 and 10.6 liters /day for safety basis and design basis sludge compositions, respectively.)

Venting the STS cask at 5 to 15 cfm with the STSC containing safety basis sludge compositions results in a 1% hydrogen plume diameter of approximately 4.1 to 6.4 ft. (1.25 to 1.94 m) centered on the vent pipe (see Table 5). Venting the STS cask at 5 to 15 cfm with the STSC containing safety basis sludge compositions results in a LFL hydrogen plume diameter of approximately 1.9 to 2.8 ft. (0.57 to 0.86 m) centered on the vent pipe (see Table 5). The opening from the tunnel (cell 2L) into the canyon is 16 ft. (~4.9 m) wide and 30.5 ft. (~9.3 m) long at the canyon deck. Cell 2L has a guard rail around the perimeter of the opening into the tunnel. The vent pipe for venting / purging the STS cask and purging an STSC is anchored to the north wall of cell 2L. The 1 Vol. % hydrogen concentration zone and the LFL zone do not extend beyond the guard rail around the perimeter of Cell 2L in the west, east, or south directions but would extend beyond the guard rail in the north direction.

Purging the vented STS cask with nitrogen at 5 scfm and 100% mixing efficiency takes 0.8 hours after venting when the STS cask venting rate is 5, 10, or 15 scfm and the STSC contains the safety basis sludge compositions (see Table 7). The hydrogen concentration in the STS cask can only be reduced to 1.0 Vol. % due to the ongoing generation of hydrogen in the STSC if the STSC contains the safety basis sludge compositions. The typical goal of ventilation (with air) in fire codes is to provide enough flow to maintain the environment at 25% LFL or less (i.e. less than 1 Vol. % hydrogen in air). The safety basis case exceeds this normal limit with a worst case hydrogen concentration of 1.0 Vol. %, but that is with mostly 1.0 Vol. % hydrogen in nitrogen, not in air. Note that per CGA P-23, *Standard for Categorizing Gas Mixtures Containing Flammable and Nonflammable Components*; the LFL of hydrogen in nitrogen is 5.7 Vol. %, so 25 Vol. % of that would be 1.42 Vol. % making the calculated safety basis case head space gas nonflammable prior to lid removal.

Purging the vented STS cask with nitrogen at 5 scfm and 100% mixing efficiency takes 17 to 18 minutes after venting when the STS cask venting rate is 5, 10, or 15 scfm and the STSC contains the design basis sludge compositions (see Table 7). The hydrogen concentration in the STS cask can be reduced to <0.1 Vol. % if the STSC contains the design basis sludge compositions.

The STSC can be purged with nitrogen at 5 scfm to achieve a hydrogen concentration of 0.4% in about 0.8 hours (47 minutes) using 8 kg of nitrogen as shown in Figure 6-3; assuming the 100 Vol. % hydrogen concentration initially in the STSC headspace, 100% mixing efficiency and safety basis sludge compositions (i.e. 490 liters/day hydrogen generation rate). Table 12 provides the results for purging the STSC headspace for case CV1 (safety basis sludge compositions) and CV2 (design basis sludge compositions) at 100% mixing efficiency.

Table 12. STSC Purge Timing for 5 scfm Purge Rate and 100% Mixing Efficiency

Purge Case Name	Venting Rate (scfm)	Target Vol. % H_2 in STSC	Time to Target Vol. % H_2	Nitrogen Required
CV1	5	0.40	0.8 hours (47 minutes)	8 kg
CV2	5	0.10	0.4 hours (26 minutes)	4.3 kg

6.1.1 Hydrogen Potentially Vented from STSC after Venting STS Cask

When the STS cask is vented, the pressure inside the STSC is reduced; since nozzles S2 and F2 on the STSC are equipped with NucFil™ filters, Stäubli® model SCB 20 automatic connectors and check valves that will allow flow into and out of the STSC when a 1 to 2 psig cracking pressure is reached. Therefore, the pressure inside the STSC will be a maximum of 2 psig after venting the STS cask. The total internal volume of an STSC without the insert is 3.93 m^3, excluding the internal volume of the STSC nozzles. The volume of gases contained in the STSC is therefore 0.97 m^3 for case CV1 ($0.97\ m^3 = 3.93\ m^3 - (0.4\ m^3 + 1.6\ m^3 + 0.96\ m^3)$).

The amount of hydrogen that could be vented from the STSC headspace if the check valves fails and/or the Stäubli® automatic connectors fail to seal was calculated using the following equations with results shown in Table 13. The volume percent hydrogen in the STSC headspace is obtained from the sludge transportation cases documented in PRC-STP-00688 and is maximized by assuming the STS cask is received at 80 psig.

Value	Equation
Liters Hydrogen	= STSC headspace volume * (2 psig) / (2 +14.7 psig) * H_2 Vol. %
Moles Hydrogen	= Liters Hydrogen * (1 mole / 22.4 liters)

Table 13. Hydrogen Moles Potentially Vented from STSC

Case Name	Sludge Type	Sludge Volume (m^3)	Cover Water (m^3)	STSC Headspace (m^3)	H_2 Vol. %	H_2 (liters)	H_2 (moles)
T5L	KW 210	1.6	1.54	0.79	85	80.42	3.59
T6Hm	KW 220 SSM	1.071 0.0254	2.1	0.76	74.3	68.04	3.04
T6Ht	KW 220 SSM	1.071 0.0254	2.1	0.76	77.7	71.15	3.18
T2L	KW 230 KE	0.4 1.6	0.96	0.97	66	76.67	3.42

Note: The volume percent hydrogen for cases T2L and T5L are from figures in PRC-STP-00688.
The volume percent hydrogen for cases T6Hm and T6Ht are from figures in Appendix A.

An STSC loaded with 1.6 m^3 of KW 210 sludge with 1.54 m^3 of cover water contains more hydrogen in the STSC headspace than other STSC loading configurations, as shown in Table 13. There are a maximum of 3.6 moles (7.2 grams) of hydrogen gas that could be vented from the headspace of the STSC containing 1.6 m^3 of KW 210 sludge if the check valves fails and/or the Stäubli® automatic connectors fail to seal.

6.1.2 Volume of Hydrogen Potentially Vented from Stäubli® Connectors

Stäubli® model SCB 20 automatic connectors and check valves are used on nozzles S2 and F2 on the STSC for connecting the nitrogen gas supply and vent line for purging hydrogen from the STSC. The potential loss of fluid at disconnect is 0.0030 cubic inches (4.92E-05 liters) from the Stäubli® model SCB 20 automatic connectors (See Appendix D for page 5 of Stäubli® brochure "SCB Clean-Break Quick-Release Coupling"). Assuming the gas vented during disconnect of the Stäubli® connector is 100% hydrogen, the mass of hydrogen potentially lost at disconnect for each Stäubli® connector is:

Mass Hydrogen = (Loss of Fluid at Disconnect) * (2 gram H_2/mole) * (STSC pressure / atmospheric pressure) / (22.4 liters/mole)

(4.92E-05 liters) * (2 gram H_2/mole) * ((2+ 14.7 psi) / 14.7 psi) / (22.4 liters/mole)

= 5 E-6 gram or 5 µg

6.2 Storing STSCs in T Plant Canyon Cells

FAI examined transient conditions for the cases shown in Table 14 for storing six STSCs containing K Basin sludge in a standard T Plant cell. One STSC in an overpack is assumed to contain the safety basis or design basis composition of the selected sludge type and five STSCs are assumed to contain the design basis composition of the selected sludge type. Each STSC is assumed to be equipped with a 2-inch diameter by 2-ft height vent pipe attached to nozzle F2. Cases S5F, S5FA, S5NF, and S5NFA are re-analyses using the revised model of cases CONS21TRFO and CONS21TRNO for storing 1.6 m^3 of KW 210 sludge in the STSC without the water filled insert. Cases S4F, S4FA, S4NF, and S4NFA are re-analyses using the revised model of cases SETS1TRFO and SETS1TRNO for storing 0.5 m^3 of KW 230 sludge in the STSC with the water filled insert. The STP does not plan to load only Settler sludge in an STSC and therefore cases S1F, S1NF, S4F, SETS1TRFO, S4FA, S4NF, and SETS1TRNO are provided as information only. These cases were analyzed to compare the older model to the revised model.

Transient storage conditions for 20 days were evaluated. This evaluation includes cases with the exhaust ventilation fans operating (Table 15) and the fans inoperable (Table 16) with only natural draft convection occurring. Results for these cases are provided in Table 15 and Table 16 for the following evaluated parameters:

- Peak sludge temperature,
- Peak sludge power,
- Peak H_2 gas generation rate,
- Peak H_2 gas concentration in the T Plant cell,
- Peak H_2 gas concentration in the STSC

Table 14. Cases Analyzed for T Plant Storage of KW Basin Sludge in STSCs with Vent Pipe Installed on STSC Nozzle F2

Case Name	Sludge Type	Sludge Composition	Sludge Volume (m^3)	STSC Type	Cover Water (m^3)	Ventilation (Fans On)	T Plant Temp. (°C)
S1-F	KW 230	Safety Basis	0.5	Insert	2.38	Yes	32
S1-NF	KW 230	Safety Basis	0.5	Insert	2.38	No	32
S2-F	KE over KW 230	Safety Basis	1.6 m^3 KE over 0.4 m^3 KW 230	No insert	0.96	Yes	32
S2-NF	KE over KW 230	Safety Basis	1.6 m^3 KE over 0.4 m^3 KW 230	No insert	0.96	No	32
S3-F	KE over KW 230	**Design Basis**	1.6 m^3 KE over 0.4 m^3 KW 230	No insert	0.96	Yes	32
S3-NF	KE over KW 230	**Design Basis**	1.6 m^3 KE over 0.4 m^3 KW 230	No insert	0.96	No	32
S4F	KW 230	Safety Basis	0.5 m^3	Insert	2.38	Yes	32
SETS1TRFO	KW 230	Safety Basis	0.5 m^3	Insert	2.38	Yes	35
S4FA	KW 230	Safety Basis	0.5 m^3	Insert	2.38	Yes	35
S4NF	KW 230	Safety Basis	0.5 m^3	Insert	2.38	No	32
SETS1TRNO	KW 230	Safety Basis	0.5 m^3	Insert	2.38	No	35
S4NFA	KW 230	Safety Basis	0.5 m^3	Insert	2.38	No	35
S5F	KW 210	Safety Basis	1.6 m^3	No insert	1.6	Yes	32
CONS21TRFO	KW 210	Safety Basis	1.6 m^3	No insert	1.6	Yes	35
S5FA	KW 210	Safety Basis	1.6 m^3	No insert	1.6	Yes	35
S5NF	KW 210	Safety Basis	1.6 m^3	No insert	1.6	No	32
CONS21TRNO	KW 210	Safety Basis	1.6 m^3	No insert	1.6	No	35
S5NFA	KW 210	Safety Basis	1.6 m^3	No insert	1.6	No	35
S6Fm	SSM uniformly mixed with KW 220	Safety Basis	0.0254 m^3 SSM with 1.071 m^3 KW 220	No insert	2.1	Yes	32
S6Ft	KW 220 with SSM contained in a thin layer	Safety Basis	0.0254 m^3 SSM with 1.071 m^3 KW 220	No insert	2.1	Yes	32
S6NFm	SSM uniformly mixed with KW 220	Safety Basis	0.0254 m^3 SSM with 1.071 m^3 KW 220	No insert	2.1	Yes	32
S6NFt	KW 220 with SSM contained in a thin layer	Safety Basis	0.0254 m^3 SSM with 1.071 m^3 KW 220	No insert	2.1	Yes	32

Cases S1-F, S1-NF, S2-F, and S2-NF use 0.163 g/cc U-metal for KW 230 sludge
Cases S4F, SETS1TRFO, S4FA, SETS1TRNO, S4NF, and S4NFA use 0.144 g/cc U-metal for KW 230 sludge

Table 15 and Table 16 demonstrate for the same initial T Plant temperature the effect of the revised FAI models is:

- Slight increase (5% to 10%) in the predicted maximum sludge temperature
- Approximately 40% increase in the peak hydrogen generation rate when 1.6 m^3 of KW 210 sludge is contained in the STSC
- Approximately 15% increase in the peak hydrogen generation rate when 0.5 m^3 of KW 230 sludge is contained in the STSC with the water filled inner core.
- Peak hydrogen concentrations in the T Plant cell and STSC headspace increase by about 10% when 1.6 m^3 of KW 210 sludge is contained in the STSC
- Peak hydrogen concentrations in the T Plant cell and STSC headspace decrease by about 10% when 0.5 m^3 of KW 230 sludge is contained in the STSC with the water filled inner core

FAI stated the effect of the model revisions are: "In general, there are small changes in timing and temperature and significant increase in hydrogen production. The increase in hydrogen production, however, results in only a marginal increase in hydrogen concentration in the STSC and does not change the conclusions" (PRC-STP-00893 Volume 3 page 68). Therefore, cases evaluated with the previous FAI model provide valid thermal and gas generation information. It is important to re-emphasize the STP does not plan to load only Settler sludge in an STSC and therefore cases S1F, S1NF, S4F, SETS1TRFO, S4FA, S4NF, and SETS1TRNO are provided as information only for comparing the FAI model revisions.

Table 15. Comparison of FAI Model Revisions for T Plant Exhaust Fans Operating

(Vent Pipe Installed on STSC Nozzle F2)

Case Name	Volume (m^3) and Type	Initial T Plant Temperature °C	Peak Sludge Temperature °C	Peak H_2 liter/day	Peak H_2 Concentration in STSC, %	Peak H_2 Concentration in Cell, %
S1F	0.5 m^3 KW 230	32	38.9	263	0.8	< 1E-04
S4F	0.5 m^3 KW 230	32	39.7	242	0.74	<0.1
SETS1TRFO	0.5 m^3 KW 230	35	39.2	268	0.86	<0.1
S4FA	0.5 m^3 KW 230	35	41.8	301	0.78	<0.1
CONS21TRFO	1.6 m^3 KW 210	35	39.9	231	0.91	<0.1
S5FA	1.6 m^3 KW 210	35	41.7	321	1.04	<0.1

Table 16. Comparison of FAI Model Revisions for T Plant Exhaust Fans Inoperable

(Vent Pipe Installed on STSC Nozzle F2)

Case Name	Volume (m^3) and Type	Initial T Plant Temperature °C	Peak Sludge Temperature °C	Peak H_2 liter/day	Peak H_2 Concentration in STSC, %	Peak H_2 Concentration in Cell, %
S1NF	0.5 m^3 KW 230	32	38.9	259	1.1	0.3
S4NF	0.5 m^3 KW 230	32	39.4	239	0.99	0.29
SETS1TRNO	0.5 m^3 KW 230	35	40.4	282	1.17	0.23
S4NFA	0.5 m^3 KW 230	35	43.2	322	1.11	0.25
CONS21TRNO	1.6 m^3 KW 210	35	41.3	248	1.16	0.22
S5NFA	1.6 m^3 KW 210	35	43.3	344	1.35	0.26

Table 17 and Table 18 provide the results for modeling the storage of 1.6 m^3 of KW 210 sludge (cases S5F and S5NF), 1.0 m^3 of KW 220 mixed with 0.0254 m^3 of segregated settler material (cases S6Fm, S6Ft, S6NFm, and S6NFt), and 0.4 m^3 of KW 230 sludge layered with 1.6 m^3 of KE sludge (cases S2F, S2NF, S3F, and S3NF). Results for these cases are provided in Table 17 and Table 18 for the following evaluated parameters:

- Peak sludge temperature,
- Peak sludge power,
- Peak H_2 gas generation rate,
- Peak H_2 gas concentration in the T Plant cell,

As shown in Table 17 with the T Plant exhaust fans operating at 17,500 cfm, the peak H_2 gas concentrations in the T Plant cell is less than 0.1%, the peak H_2 gas concentrations in the STSC is less than 1.1%, and the peak sludge temperature is maintained less than 51.4°C for all cases analyzed.

Table 17. T Plant Exhaust Fans Operating

(Vent Pipe Installed on STSC Nozzle F2)

Case Name	Volume (m^3) and Type	Initial T Plant Temperature °C	Peak Sludge Temperature °C	Peak H_2 liter/day	Peak H_2 Concentration in STSC, %	Peak H_2 Concentration in Cell, %
S2F	1.6 m^3 KE over 0.4 m^3 KW 230 (safety basis)	32	51.4	373	1.1	< 1E-04
S3F	1.6 m^3 KE over 0.4 m^3 KW 230 (design basis)	32	35.3	8	< 1E-03	< 1E-04
S5F	1.6 m^3 KW 210	32	39.5	270	0.91	<0.1
S6Fm	0.0254 m^3 SSM with 1.071 m^3 KW 220	32	40.2	225	0.71	<0.1
S6Ft	0.0254 m^3 SSM with 1.071 m^3 KW 220	32	41.9	256	0.79	<0.1

Table 18. T Plant Exhaust Fans Inoperable

(Vent Pipe Installed on STSC Nozzle F2)

Case Name	Volume (m^3) and Type	Initial T Plant Temperature °C	Peak Sludge Temperature °C	Peak H_2 liter/day	Peak H_2 Concentration in STSC, %	Peak H_2 Concentration in Cell, %
S2NF	1.6 m^3 KE over 0.4 m^3 KW 230 (safety basis)	32	50.7	363	1.4	0.4
S3NF	1.6 m^3 KE over 0.4 m^3 KW 230 (design basis)	32	35.0	8	0.17	0.1
S5NF	1.6 m^3 KW 210	32	39.2	265	1.21	0.31
S6NFm	0.0254 m^3 SSM with 1.071 m^3 KW 220	32	39.8	220	0.94	0.275
S6NFt	0.0254 m^3 SSM with 1.071 m^3 KW 220	32	41.5	250	1.04	0.295

The effect of the T Plant exhaust fans being inoperable is examined in Table 18. The peak H_2 gas concentrations in the T Plant cell is below 0.4%, while the peak H_2 gas concentration in the STSC increases to a maximum of 1.4% for all cases. The peak sludge temperature is a maximum of 50.7°C when the T Plant exhaust fans are inoperable.

The effect of assuming the design basis versus safety basis sludge compositions can be seen by comparing the results for cases S3-F and S3-NF with cases S2-F and S2-NF. An STSC containing 0.4 m^3 of design basis composition KW 230 sludge beneath a layer of 1.6m^3 of design basis composition KE sludge and 0.96 m^3 of water (cases S3-F and S3-NF) exhibits significantly lower peak sludge temperature, peak hydrogen gas generation rate, and hydrogen concentration in the T Plant cell and STSC headspace than an STSC containing these same sludge volumes with safety basis composition (cases S2-F and S2-NF).

6.2.1 Storing STSCs in T Plant Cells without Vent pipe Attached to STSC Nozzle F2

CHPRC modified the FAI FATE model for T Plant to evaluate storing STSCs in the T Plant cells without a vent pipe attached to STSC nozzle F2. CHPRC evaluated storing six STSCs containing K Basin sludge in a standard T Plant cell. One STSC in an overpack is assumed to contain the safety basis or design basis composition of the selected sludge type and five STSCs are assumed to contain the design basis composition of the selected sludge type. Each STSC is assumed not to be equipped with a 2-inch diameter by 2-ft height vent pipe attached to nozzle F2.

The results in Table 17 and Table 18 demonstrate that an STSC in an overpack containing the safety basis compositions for 1.6 m^3 of KE sludge layered over 0.4 m^3 of KW 230 has the maximum hydrogen concentration in the STSC headspace compared to the other cases. Therefore, CHPRC only considers STSCs containing 1.6 m^3 of KE sludge layered over 0.4 m^3 of

KW 230. The CHPRC modifications to the FAI FATE model and analyses are contained in Appendix B and summarized in this section.

CHPRC evaluated the following two cases;

- Case S2Fum: T Plant exhaust fans operating at 17,500 cfm. One STSCs is inside an overpack and contain safety basis compositions for 1.6 m^3 of KE sludge layered over 0.4 m^3 of KW 230. Five other STSCs are located in the same cell and each of these STSCs contain design basis compositions for 1.6 m^3 of KE sludge layered over 0.4 m^3 of KW 230. Vent pipe is not installed on nozzle F2 of each STSC.
- Case S2NFum: Same as Case S2Fum, except the T Plant exhaust fans inoperable.

The FATE model results are presented in Table 19. With the T Plant exhaust fans operating at 17,500 cfm and no vent pipe, the peak H_2 gas concentrations in the T Plant cell is less than 1E-04 Vol. %, the peak H_2 gas concentrations in the STSC is 1.1 Vol. %, and the peak sludge temperature is 51.4°C. With the T Plant exhaust fans inoperable, the peak H_2 gas concentrations in the T Plant cell is 0.4 Vol. %, while the peak H_2 gas concentration in the STSC increases to a maximum of 1.8 Vol. %. The peak sludge temperature is 50.7°C.

Table 19. Results for Storage of KW 230 Sludge Layered with KE Sludge

(Without Vent Pipe Installed on STSC Nozzle F2)

Case Name	T Plant Exhaust Fan	Initial T Plant Temperature	Peak Sludge Temperature	Peak H_2 Generation Rate	Peak H_2 Concentration in STSC	Peak H_2 Concentration in Cell, %
S2Fum	Operating	32 °C	51.4 °C	373 liter/day	1.1 Vol. %	< 1E-04 Vol. %
S2NFum	Inoperable	32 °C	50.7 °C	363 liter/day	1.8 Vol. %	0.4 Vol. %

6.3 Water Loss Rate during Storage at T Plant

In PRC-STP-00241 revision 1 and PRC-STP-00893 Volume 4, FAI evaluated the water loss rate in an STSC containing 1.6 m^3 of KW 210 or KW 220 sludge (cases CONS21TRLO or CONS22TRLO) or an STSC with the water filled insert containing 0.5 m^3 of KW 230 sludge (case SETS1TRLO) during storage at T Plant for one year. As previously stated, the STP does not plan to use the STSC with the water filled insert. PRC-STP-00241 revision 2 includes evaluation of the water loss from an STSC containing 0.4 m^3 of safety basis composition KW 230 sludge beneath a layer of 1.6 m^3 of safety basis composition KE sludge and initially 0.96 m^3 of water (case WL1). Water loss rates due to evaporation from the pool surface in the STSC, consumption by the uranium metal reaction with water, vapor stripping by hydrogen bubbles, and consumption were included in the FATE model, with results shown in Table 20.

About 12% of the initial water inventory is lost over a period of one year in T Plant for an STSC containing 1.6 m^3 of safety basis composition KW 210 (case CONS21TRLO) or 1.6 m^3 of safety basis composition KW 220 sludge (case CONS22TRLO). Up to 1.1 liters of water is lost per day when the uranium metal oxidation reaction with water takes place when the STSC contains 1.6 m^3 of safety basis composition KW 210 or KW 220 sludge. The uranium metal oxidation reaction rate is set at a reaction rate enhancement factor of 3 (see HNF-SD-SNF-TI-015 Vol. 2, Table 4-14) for these analyses to conservatively calculate the water loss rate. Once all the uranium metal has oxidized, the water loss rate averages a maximum of about 0.55 liters per day.

Table 20. Water Loss Rate Results Summary

Case Name	Sludge Type and Volume (m^3)	Fraction of Initial Water Lost in One Year	Peak Water Loss Rate, liter/day	Post Oxidation Water Loss Rate, liter/day
CONS21TRLO	1.6 m^3 KW 210	12.2%	1.1	0.55
CONS22TRLO	1.6 m^3 KW 220	11.9%	0.9	0.55
SETS1TRLO	0.5 m^3 KW 230 (STSC with an insert)	9.9%	1.3	0.7
WL1	0.4 m^3 KW 230 beneath 1.6 m^3 KE	16.8%	0.65	0.55

For an STSC containing 0.5 m^3 of safety basis composition Settler Tank sludge (case SETS1TRLO), about 10% of the initial water inventory is lost over a period of one year. The peak water loss rate is about 1.3 liters per day. The uranium metal oxidation reaction rate is set at a reaction rate enhancement factor of 3 (see HNF-SD-SNF-TI-015 Vol. 2, Table 4-14) for these analyses to conservatively calculate the water loss rate. Once all the uranium metal has oxidized, the water loss rate averages about 0.7 liters per day.

About 17% of the initial water inventory is lost over a period of one year in T Plant for an STSC containing 0.4 m^3 of safety basis composition KW 230 sludge beneath a layer of 1.6 m^3 of safety basis composition KE sludge (case WL1). Up to 0.65 liters of water is lost per day when the uranium metal oxidation reaction with water takes place. The uranium metal oxidation reaction rate is set at a reaction rate enhancement factor of 3 (see HNF-SD-SNF-TI-015 Vol. 2, Table 4-14) for these analyses to conservatively calculate the water loss rate. Once all the uranium metal has oxidized, the water loss rate averages about 0.55 liters per day.

6.4 Freezing Potential

FAI previously evaluated the time before the sludge temperature in an STSC drops from 25°C to 0°C for ambient T Plant conditions of minus (-)7°C (HNF-SD-SNF-TI-015 Vol. 2, Table 4-37). The previously evaluated potential for sludge to reach 0°C is documented in PRC-STP-00893 Volume 4 and summarized in this document for convenience. For this freezing potential analysis, the STSC is assumed to contain 1.6 m^3 of design basis composition KE Engineered Container sludge to provide a conservatively low sludge heat generation rate and minimize the time for the sludge temperature to reach 0°C. Table 21 summarizes the analyzed sludge freezing cases.

Assuming the canyon provides no heat sinks (overly conservative), and the exhaust ventilation system is operating at 17,500 cfm, the sludge could begin to freeze after 25 days. If heat transfer from canyon wall and floor to the canyon atmosphere is considered, the sludge could potentially begin to freeze after 65 days, assuming the exhaust ventilation system is operating at 35,800 cfm. The canyon air temperature is kept above freezing for the first 40 days due to heat released from the wall and floor. The lower canyon wall is 5-ft. thick and the upper canyon wall is 3-ft. thick. These walls were modeled as one-sided heat sinks; an adiabatic boundary condition is applied on the outer surface of the wall. If the adiabatic boundary condition is removed, so heat transfer between the canyon walls and outside ambient is also considered, the sludge could potentially begin to freeze after 39 days. The month of January has the most days on average with the temperature 32°F or below reported at the Hanford site for the period of 1912 through 1980 (Table 10, WHC-SD-TP-RPT-004). On average, the month of January has 11 days with the temperature 32°F or below. The most days when the temperature was 32°F or below at the Hanford site occurred in January 1979, which experienced 30 days with the temperature at 32°F or below (Table 2, PNNL-4622). Based on the historical temperature conditions, it is unlikely for the sludge and liquid in an STSC to freeze during storage at T Plant.

Table 21. Freezing Cases

Case Name	Initial T, °C	Ambient T, °C	Canyon Heat Sinks	Ventilation Flow Rate, CFM	Time to Freezing, days
COND2ETRFC2	25	-7	No Heat Sink	17,500	25
COND2ETRFC3	25	-7	1 Sided, faces canyon	35,800	65
COND2ETRFC4	25	-7	2 Sided, faces canyon and ambient	35,800	39

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Appendix A: CHPRC Modifications to FAI Thermal and Gas Generation Models for Analyses of KW220 Sludge Combined with Segregated Settler Material

This appendix provides an analysis for an STSC with KW 220 sludge combined with the segregated settler material. The segregated settler material (SSM) was created from the pretreatment and processing of the knockout pot (KOP) material conducted in fiscal year 2012. It consists of less than 600μm material, including uranium metal, uranium oxide, non-uranium materials (e.g., aluminum wire and Grafoil), water containing compounds (e.g., aluminum hydroxide solids) and other small particulate material captured on Integrated Water Treatment System strainers during processing of the KOP material. There is 94.6 kg of SSM, consisting of 63.8 kg of uranium metal; 1.25 kg of uranium oxide; and 29.55 kg of non-uranium materials, water-containing compounds, and other small particulate material.

The SSM was analyzed as being combined with KW 220 sludge in two configurations:

- Uniform mixture of SSM with KW 220 sludge loaded into an STSC (Case S6Fm and S6NFm).
- SSM combined with 0.079 m^3 of KW 220 sludge and loaded as a thin layer between two layers of KW 220 sludge in an STSC (Case S6Ft and S6NFt). The bottom layer of KW 220 sludge in the STSC is ~0.42 m^3 and ~0.57 m^3 of KW 220 sludge above the SSM thin layer.

Case S6Fm and S6Ft analyze storing the STSC containing the combined SSM and KW 220 sludge when the exhaust fans are operable at T Plant. Case S6NFm and S6NFt analyze storing the STSC containing the combined SSM and KW 220 sludge when the exhaust fans are inoperable at T Plant. The composition of the uniform mixture of SSM with KW 220 sludge and the thin layer of SSM combined with 0.079 m^3 of KW 220 sludge is described in the following sections.

STSC with a Uniform Mixture

The following table shows the properties resulting from combining the 1.071m^3 of KW 220 sludge with the 0.0254 m^3 of SSM. The sludge properties shown in the fourth column are the combined sludge properties. The bolded values were used as input values to the model. The remaining values in fourth column can be calculated directly from these input values. The fifth column shows sludge properties calculated by FATE at the start of the run. The agreement between the values in columns four and five confirms the FATE input conditions for the combined KW 220 sludge. A slightly larger sludge volume of 1.096 $m^3$was used to match the sludge levels in the existing FAI model. This larger volume needs 1.071 m^3 of KW 220 sludge to be mixed with the 0.0254 m^3 of segregated settler material although there is actually only 1.0m^3 of KW 220 sludge.

Table A-1 STSC Sludge properties with a Uniform Mixture				
Column 1	Column 2	Column 3	Column 4	Column 5
Property	Segregated Settler Material	KW220 sludge	STSC Total	Actual Starting Conditions From FATE
Volume, m^3	0.025	1.071	**1.096**	
Density, kg/m^3	3724	1720	**1766**	
U metal concentration, kg/m^3	2512	34.1	**91.5**	
Total U concentration, kg/m^3	2555	409	**459**	
Water volume fraction	40.0%	77.0%	**76.1%**	
Total sludge mass, kg	94.6	1842	**1936.2**	**1935**
Water mass, kg	10.1	823	**832.9**	**833.7**
Uranium Metal mass, kg	63.8	36.5	**100.3**	**100.2**
Non-uranium mass, kg	19.4	526.9	**546.3**	**544.0**
Decay Power	6.7	13.7	**20.4**	**20.4**

STSC with a Thin Sludge Layer

The following table shows the properties resulting from combining the $0.079 m^3$ of KW 220 sludge with the $0.0254\ m^3$ of SSM. The sludge properties shown in the fourth column are the sludge properties for the metal rich layer with the bold values in this column used as input values to the model. The fifth column shows the sludge properties for the remaining volume of KW 220 loaded on top of the thin layer. The sixth column gives the totals for the STSC. The agreement between the values in the columns confirms the match of the FATE input conditions to the combined KW 220 sludge properties for the STSC with the thin layer.

A slightly larger sludge volume of $1.096\ m^3$ was used to match the sludge levels in the existing FAI model. This larger volume needs $1.071\ m^3$ of KW 220 sludge to be mixed with the $0.0254\ m^3$ of segregated settler material although there is actually only $1.0 m^3$ of KW 220 sludge.

Table A-2 STSC Sludge Properties with a Thin Sludge Layer						
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Property	Segregated Settler Material	KW220 sludge	Thin layer	KW220 sludge	STSC Total	FATE Results
Volume, m^3	0.025	0.079	**0.1047**	**0.991**	1.096	
Density, kg/m^3	3724	1720	**2206**	**1720**	1766	
U metal concentration, kg/m^3	2512	34	**635**	**34**	92	
Total U concentration, kg/m^3	2555	409	**930**	**409**	459	
Water volume fraction	40.0%	77.0%	**68.0%**	**77.0%**	76.1%	
Total sludge mass, kg	94.6	136.3	230.9	1705.3	**1936.3**	**1935**
Water mass, kg	10.1	60.9	71.0	761.9	**833.0**	**834.1**
Uranium Metal mass, kg	63.8	2.7	66.5	33.8	**100.3**	**100.3**
Non-uranium mass, kg	19.4	39.0	58.4	487.9	**546.4**	**543.6**
Decay Power	6.7	1.0	7.7	12.7	**20.4**	**20.2**

CHPRC Modifications to the FATE Model

CHPRC used the updated FAI FATE model to assess four storage configurations (Cases S6NF, S6Fm, S6NFt, and S6Ft) of SSM combined with KW 220 sludge into an STSC. CHPRC modified the FATE model for Case S5NF to analyze storing the SSM combined with KW 220 sludge in an STSC at T Plant. The tables on the following pages (pages 43 through 49) show the changes to the FATE model for Case S5NF made by CHPRC to analyze Cases S6NF, S6Fm, S6NFt, and S6Ft.

The results are plotted below in Figure A-1 (page 50) through Figure A-12 (page 61). It is noted that the average T Plant room temperature during diurnal variation is about 35°C, but the cells are initialized at 32°C. Thus when ventilation is working (fans-on cases) the cells and STSC are warmed up slightly and the maximum hydrogen generation rate is slightly higher than in the fans-off cases. The plots for storage cases can be interpreted as follows:

- Page 1, Upper Left: Gas concentration in the STSC, volume (mole) fraction. This figure can be used to determine whether flammable conditions can occur.
- Page 1, Upper Right: Gas, water and wall temperatures, °C. The temperatures show the effect of diurnal variation in the ambient, with larger variations observed when ventilation fans are active.
- Page 1, Lower Left: Sludge temperature, °C. Temperature is shown at various elevations along the STSC centerline. A maximum in temperature indicates depletion of uranium metal.
- Page 1, Lower Right: Gas flow through STSC vents, kg/s. Outflow slightly exceeds inflow since gas is generated in the STSC. Since the gas density is about 1 kg/m3, this mass flow rate is numerically about equal to the volumetric flow rate in m3/s.
- Page 2, Upper Left: Sludge heat sources (Power, W). In the cases examined, reaction power always attains a maximum value exceeding decay power. The peak in reaction power corresponds to depletion of uranium metal and loss of reactive surface area, even as temperatures may be increasing. Sideward heat loss from sludge exceeds upward loss from the sludge surface. The peak in source power occurs before the peak in losses, so that the peak sludge temperature occurs between these times.
- Page 2, Upper Right: Hydrogen gas generation rate in the sludge, standard L/day. The gas generation rate corresponds to the reaction power. This figure can be used to determine cell venting requirements.
- Page 2, Lower Left: Gas flow through the cover blocks, kg/s. Counter-current exchange flow is negligible through the narrow gaps, rather flow is dominated by inflow (i.e. negative outflow) when ventilation fans are operating, or diurnal breathing when fans are off.
- Page 2, Lower Right: Gas concentration in the cell, volume (mole) fraction. Headspaces are initially air.
- Page 3, Upper Left: Gas temperatures in cells and canyon, °C.
- Page 3, Upper Right: Gas temperatures in ventilation system, °C.
- Page 3, Lower Left: Gas flow in ventilation system, kg/s.
- Page 3, Lower Right: Gas leakage flow to/from ambient, kg/s. With fans operating leakage is from ambient into both Cell and the canyon (air infiltration).

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* S5NF: *	<>	* S6NFm: *
* STSC containing 1.6m3 SB KW-210 Sludge *	<>	* STSC containing 1.0m3 SB KW-220 Sludge *
* 1.544 m3 of cover water * * * * Upper batch: * * 0.8 m3 KW Sludge from SCS-CON-210 * * Lower batch: * * 0.8 m3 KW Sludge from SCS-CON-210 * * *	<>	 * 1.0 m3 KW Sludge from SCS-CON-220 * * 0.0254 m3 of strainer material uniform mixed witth KW220 * * * » *
* *** BASE FILE S5NF.DAT *** *	<>	* *** BASE FILE S6NFm.DAT *** *
TLAST 1728000.0 ! End time (seconds) - 20 days	<>	TLAST 3456000.0 ! End time (seconds) - 40 days
QFIN 3 2 8 59	<>	QFIN 3 2 8 47 ! top of sludge now HS47
QSW 10 32 35 38 41 44 47 50 53 56 59	<>	QSW 6 32 35 38 41 44 47 ! top of sludge now HS47
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Left file: R:\PRC-STP-688 Supporting calculations\KW220 Transportation and Storage\T-Plant Storage\S5 (FAI)\S5NF\S5NF.DAT
Right file: R:\PRC-STP-688 Supporting calculations\S6\S6NFm well mixed\S6NFm.DAT
(continued)

Left		Right
HS-TI INDEX=47 END		HS-TI INDEX=47 END ! top of sludge now HS47
59,20 59,15 59,10 59,5 59,1 58,1 56,20 56,15 56,10 56,5 56,1 55,1 53,20 53,15 53,10 53,5 53,1 52,1 50,20 50,15 50,10 50,5 50,1 49,1	<>	58,1 55,1 52,1 49,1
VOLUME 2.38164	<>	VOLUME 2.8839
ELEVATION 1.06142	<>	ELEVATION 0.76550
ZTOP 1.39721 Z_LIQ 0.90580	<>	ZTOP 1.6918 Z_LIQ 1.223
	-+	AHSS1 1.70456 IREGS1 1
SINKS 50 LABEL SL-17 IORIHS 0 IGEOM 0 IMATHS 1 IMSLAB 20 IREGI 0 IREGO 0 TIINIT 32.0 TOINIT 32.0 XRI 0.00000 XRO 0.73660 AHS 0.20060 VHS 0.14776 ZTHS 0.85215 ZBHS 0.76546 XZHS 0.08668 XLHS 0.00000 END SINKS	+-	
IREGI 0	<>	IREGI 1
SINKS 53 LABEL SL-18 IORIHS 0 IGEOM 0 IMATHS 1 IMSLAB 20 IREGI 0 IREGO 0 TIINIT 32.0	+-	

Left file: R:\PRC-STP-688 Supporting calculations\KW220 Transportation and Storage\T-Plant Storage\S5 (FAI)\S5NF\S5NF.DAT
Right file: R:\PRC-STP-688 Supporting calculations\S6\S6NFm well mixed\S6NFm.DAT
(continued)

Left file		Right file
TOINIT 32.0 XRI 0.00000 XRO 0.73660 AHS 0.20060 VHS 0.14776 ZTHS 0.93883 ZBHS 0.85215 XZHS 0.08668 XLHS 0.00000 END SINKS		
IREGI 0	<>	IREGI 1
SINKS 56 LABEL SL-19 IORIHS 0 IGEOM 0 IMATHS 1 IMSLAB 20 IREGI 0 IREGO 0 TIINIT 32.0 TOINIT 32.0 XRI 0.00000 XRO 0.73660 AHS 0.20060 VHS 0.14776 ZTHS 1.02552 ZBHS 0.93883 XZHS 0.08668 XLHS 0.00000 END SINKS	+-	
IREGI 0	<>	IREGI 1
SINKS 59 LABEL SL-20 IORIHS 0 IGEOM 0 IMATHS 1 IMSLAB 20 IREGI 0 IREGO 0 TIINIT 32.0 TOINIT 32.0	+-	

Left file		Right file
XRI 0.00000 XRO 0.73660 AHSS1 1.70456 IREGS1 1 AHS 0.08309 VHS 0.06120 ZTHS 1.06142 ZBHS 1.02552 XZHS 0.03590 XLHS 0.00000 END SINKS		
IREGI 0	<>	IREGI 1
SANDWICH 46 1000.0 47 SANDWICH 49 1000.0 50 SANDWICH 52 1000.0 53 SANDWICH 55 1000.0 56 SANDWICH 58 1000.0 59	<>	SANDWICH 46 1000.0 47 ! top of sludge now HS47
! Sludge and STSC walls and insert	+-	
! SANDWICH 7 1000.0 8 1000.0 9 ! SANDWICH 10 1000.0 11 1000.0 12 ! SANDWICH 13 1000.0 14 1000.0 15 ! SANDWICH 16 1000.0 17 1000.0 18 ! SANDWICH 19 1000.0 20 1000.0 21 ! SANDWICH 22 1000.0 23 1000.0 24 ! SANDWICH 25 1000.0 26 1000.0 27 ! SANDWICH 28 1000.0 29 1000.0 30 ! SANDWICH 31 1000.0 32 1000.0 33 ! SANDWICH 34 1000.0 35 1000.0 36 ! SANDWICH 37 1000.0 38 1000.0 39 ! SANDWICH 40 1000.0 41 1000.0 42 ! SANDWICH 43 1000.0 44 1000.0 45 ! SANDWICH 46 1000.0 47 1000.0 48 ! SANDWICH 49 1000.0 50 1000.0 51 ! SANDWICH 52 1000.0 53 1000.0 54 ! SANDWICH 55 1000.0 56 1000.0 57 ! SANDWICH 58 1000.0 59 1000.0 60 ! SANDWICH 61 1000.0 62 1000.0 63 ! ! Cask ! ! SANDWICH 70 1000.0 71 1000.0 72	+-	

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Left file: R:\PRC-STP-688 Supporting calculations\KW220 Transportation and Storage\T-Plant Storage\S5 (FAI)\S5NF\S5NF.DAT
Right file: R:\PRC-STP-688 Supporting calculations\S6\S6NFm well mixed\S6NFm.DAT
(continued)

Left		Right
! SANDWICH 73 1000.0 74 1000.0 75 ! SANDWICH 76 1000.0 77 1000.0 78 ! SANDWICH 79 1000.0 80 1000.0 81		
! Axial conduction networks	+-	
32 35 38 41 44 47 50 53 56 59	<>	32 35 38 41 44 47 ! top of » sludge now HS47
20 20 20 20 20 20 20 20 20 20	<>	20 20 20 20 20 20
32 35 38 41 44 47 50 53 56 59	<>	32 35 38 41 44 47 ! top of » sludge now HS47
IHSSG 59 56 53 50 47 44 41	<>	IHSSG 47 44 41
IRSLDG 1	<>	IRSLDG 1 1 1
1 1 1 1 1 1	+-	
RHOSG 2035.91 1628.86 1628.86 1628.86 1628.86 1628.86 1985.19 1630.08 1630.08 1630.08 1630.08 1630.08 1630.08 1630.08 1630.08 1630.08 1630.08 1630.08 1630.08 1630.08	<>	RHOSG 1766 1766 1766 1766 1766 1766 1766 1766 1766 1766 1766 1766 1766 1766 1766 1766
FPORSG 0.71 0.71 0.71 0.71 0.71 0.71 0.71 0.71 0.71 0.71 0.71 0.71 0.71 0.71 0.71 0.71 0.71 0.71 0.71 0.71	<>	FPORSG 0.761 0.761 0.761 0.761 0.761 0.761 0.761 0.761 0.761 0.761 0.761 0.761 0.761 0.761 0.761 0.761
RHOUM 0.00 64.21 64.21 64.21 64.21 64.21 0.00 64.76 64.76 64.76 64.76 64.76 64.76 64.76 64.76 64.76 64.76 64.76 64.76 64.76	<>	RHOUM 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5
RHOUT 673.35 128.30 128.30 128.30 128.30 128.30 606.43 129.84 129.84 129.84 129.84 129.84 129.84 129.84 129.84 129.84 129.84 129.84 129.84 129.84	<>	RHOUT 459 459 459 459 459 459 459 459 459 459 459 459 459 459 459 459

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Left file: R:\PRC-STP-688 Supporting calculations\KW220 Transportation and Storage\T-Plant Storage\S5 (FAI)\S5NF\S5NF.DAT

Right file: R:\PRC-STP-688 Supporting calculations\S6\S6NFm well mixed\S6NFm.DAT

(continued)

Left file		Right file
FGASSG 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00	<>	FGASSG 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
KSLDG 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7	<>	KSLDG 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7
! QSLDG 0.03952 0.03952 0.03952 ! 0.03952 0.03952 0.03952 0.03952 ! 0.03952 0.03952 0.03952 0.03952 ! 0.05881 0.05881 ! 0.05881 0.05881 0.05881 0.05881 ! 0.05881 0.05881 0.05881 QSG 0.059412	<>	QSLDG 0.04050 0.04050 0.04050 0.04050 0.04050 0.04050 0.04050 0.04050 0.04050 0.04050 0.04050 0.04050 0.04050 0.04050 0.04050 0.04050
DUOX 7500.0	<>	DUOX 7530.0
FWUOX 288.6	<>	FWUOX 270
59,20 59,10 59,1 56,20 56,10 56,1 53,20 53,10 53,1 50,20 50,10 50,1	+-	

Beyond Compare v3.1.11

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Mode: Differences, Ignoring Unimportant

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Right file: R:\PRC-STP-688 Supporting calculations\S6\S6Fm well mixed\S6Fm.DAT

Left file		Right file
* S5F: EXHAUST FANS ON, STACK VOLUMES MODIFIED FOR STABILITY *	<>	* S6Fm: EXHAUST FANS ON, STACK VOLUMES MODIFIED FOR STABILITY *
* *** BASE FILE S5NF.DAT *** *	<>	* *** BASE FILE S6NFm.DAT *** *

Beyond Compare v3.1.11

9/16/2014 5:44:44 AM | Text Compare | Page 1

Mode: Differences, Ignoring Unimportant
Left file: R:\PRC-STP-688 Supporting calculations\S6\S6NFm well mixed\S6NFm.DAT
Right file: R:\PRC-STP-688 Supporting calculations\S6\S6NFt single layer\S6NFt.DAT

Left file		Right file
* S6NFm: *	<>	* S6NFt: *
* STSC containing 1.0m3 SB KW-220 Sludge *	<>	* STSC containing 1.0m3 KW-220 Sludge *
* 0.0254 m3 of strainer material uniform mixed with KW220 *	<>	* 0.0254 m3 of strainer material in 104L single layer *
* *** BASE FILE S6NFm.DAT *** *	<>	* *** BASE FILE S6NFt.DAT *** *
IHSSG 47 44 41 38 35 32 29 26 23 20 17 14 11 8 5 2	<>	IHSSG 47 44 41 38 35 32 29 26 23 20 17 14 11 8 5 2
IRSLDG 1 1 1	<>	IRSLDG 1 1 1 1 1 1
1 1 1 1 1 1 1 1	<>	1 1 1 1 1
RHOSG 1766 1766 1766 1766 1766 1766 1766 1766 1766 1766 1766 1766 1766 1766 1766 1766	<>	RHOSG 1720.0 1720.0 1720.0 1720.0 1720.0 2206.4 1720.0 1720.0 1720.0 1720.0 1720.0 1720.0 1720.0 1720.0 1720.0 1720.0
FPORSG 0.761 0.761 0.761 0.761 0.761 0.761 0.761 0.761 0.761 0.761 0.761 0.761 0.761 0.761 0.761 0.761	<>	FPORSG 0.77 0.77 0.77 0.77 0.77 0.68 0.77 0.77 0.77 0.77 0.77 0.77 0.77 0.77 0.77 0.77
RHOUM 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5 91.5	<>	RHOUM 34.1 34.1 34.1 34.1 34.1 635.0 34.1 34.1 34.1 34.1 34.1 34.1 34.1 34.1 34.1 34.1
RHOUT 459 459 459 459 459 459 459 459 459 459 459 459 459 459 459 459	<>	RHOUT 409.0 409.0 409.0 409.0 409.0 929.9 409.0 409.0 409.0 409.0 409.0 409.0 409.0 409.0 409.0 409.0
FGASSG 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00	<>	FGASSG 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
KSLDG 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7	<>	KSLDG 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7
QSLDG 0.04050 0.04050 0.04050 0.04050 0.04050 0.04050 0.04050 0.04050	<>	QSLDG 0.03130 0.03130 0.03130 0.03130 0.03130 0.07907

Beyond Compare v3.1.11

Figure A-1 KW220 and Segregated Settler Material, Uniform Mixture, STSC/Overpack in Normal Cell, 3x Reaction Multiplier, Two Unfiltered Vents, Fans off

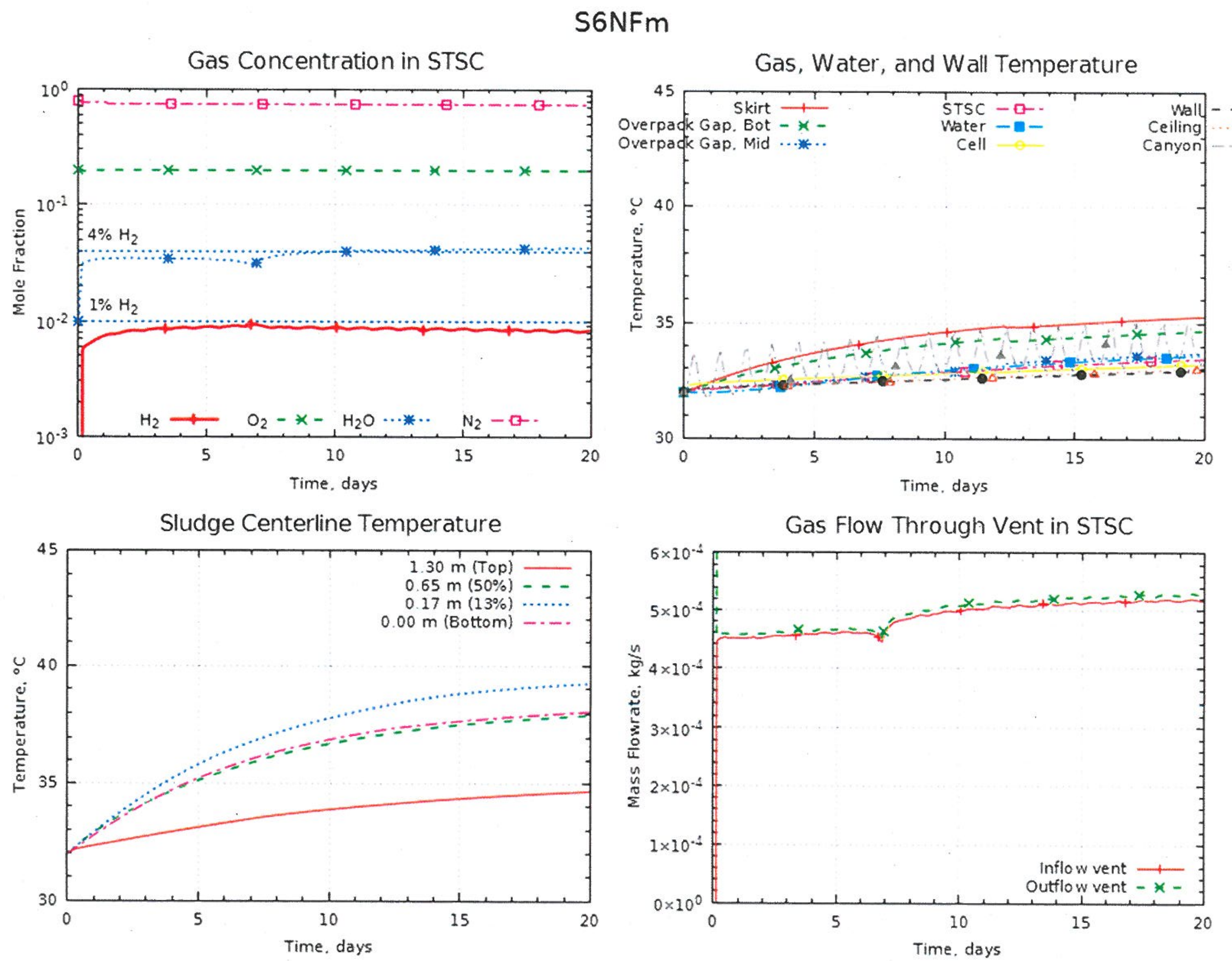


Figure A-2 KW220 and Segregated Settler Material, Uniform Mixture, STSC/Overpack in Normal Cell, 3x Reaction Multiplier, Two Unfiltered Vents, Fans off

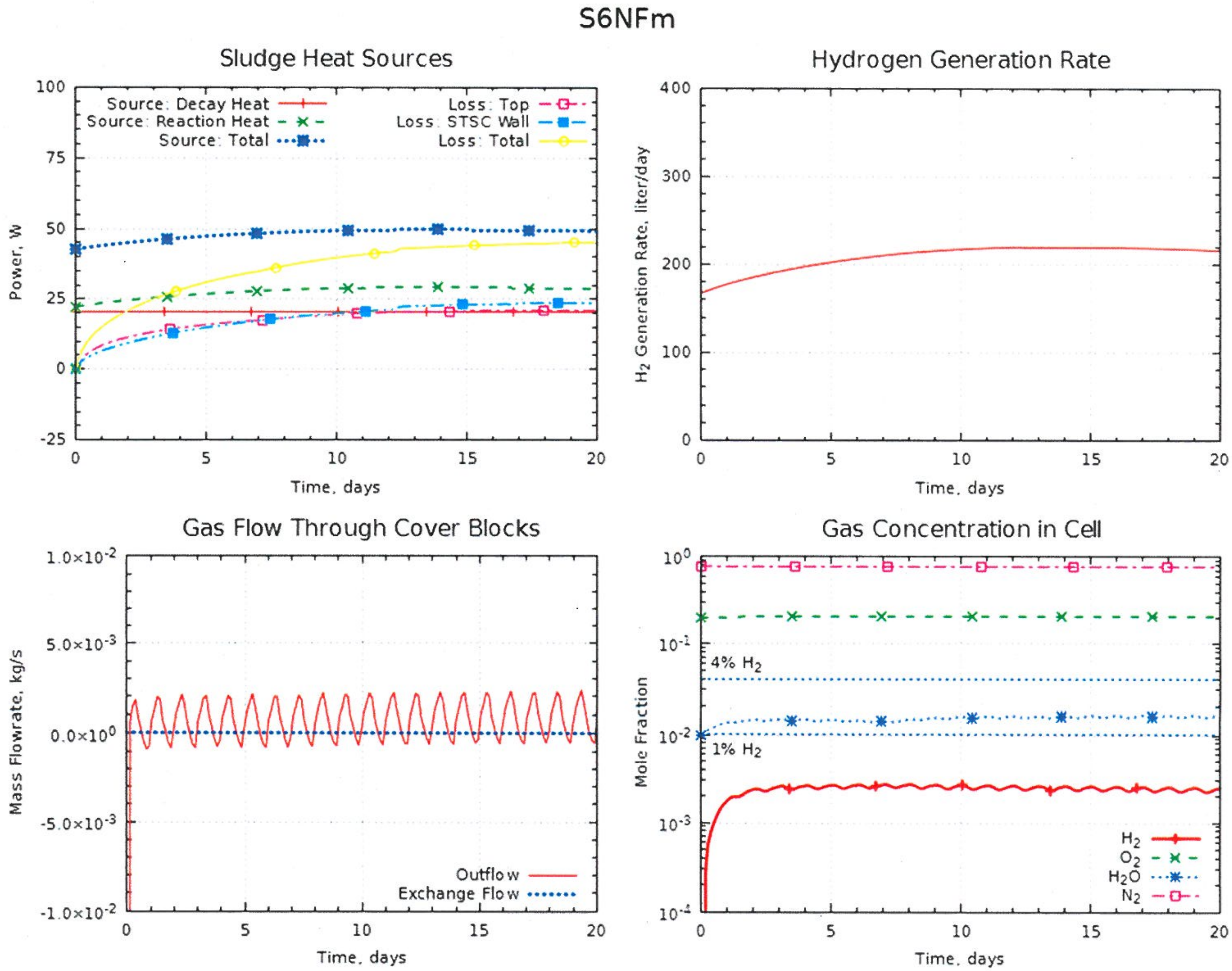


Figure A-3 KW220 and Segregated Settler Material, Uniform Mixture, STSC/Overpack in Normal Cell, 3x Reaction Multiplier, Two Unfiltered Vents, Fans off

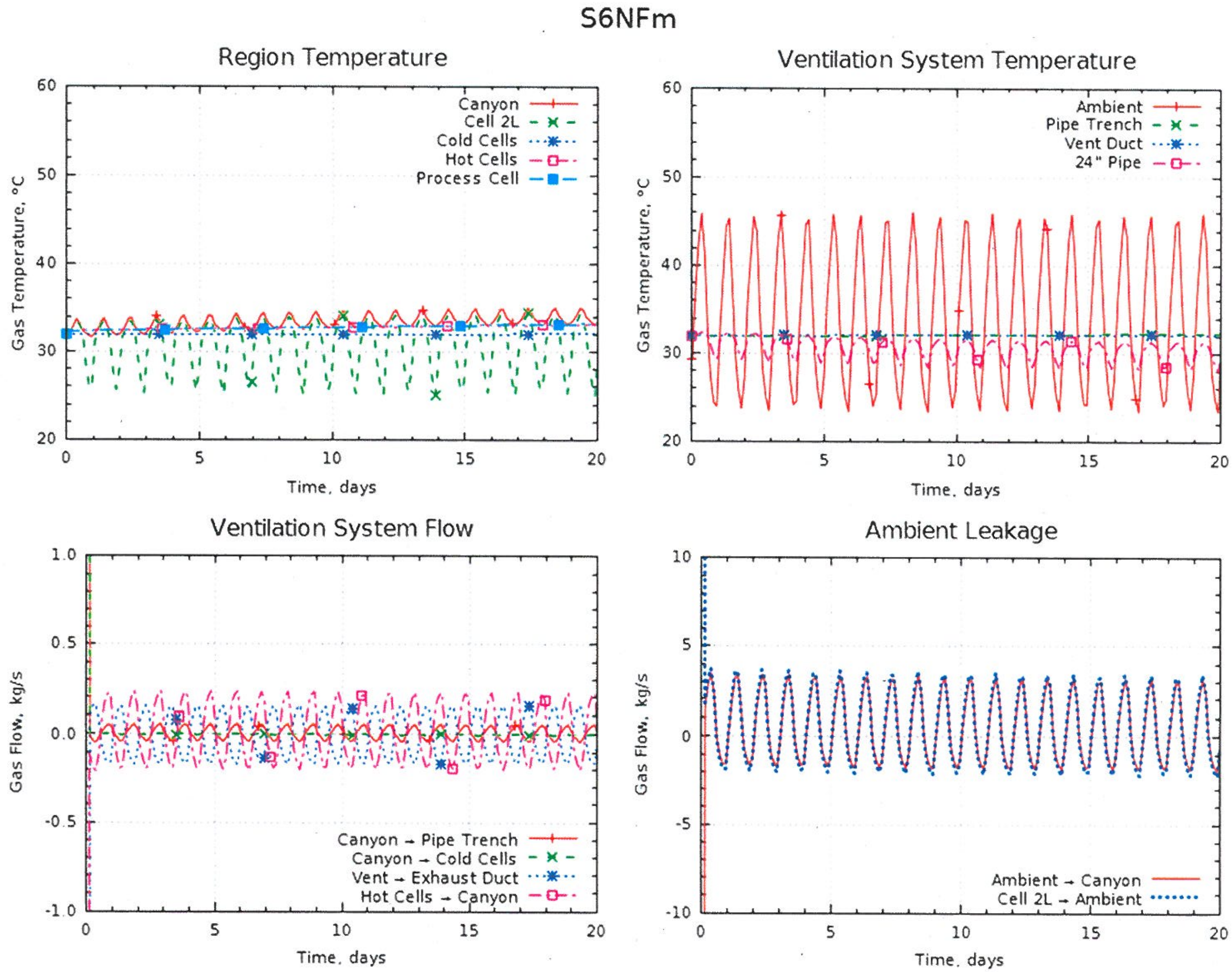


Figure A-4 KW220 and Segregated Settler Material, Thin Sandwiched Layer, STSC/Overpack in Normal Cell, 3x Reaction Multiplier, Two Unfiltered Vents, Fans off

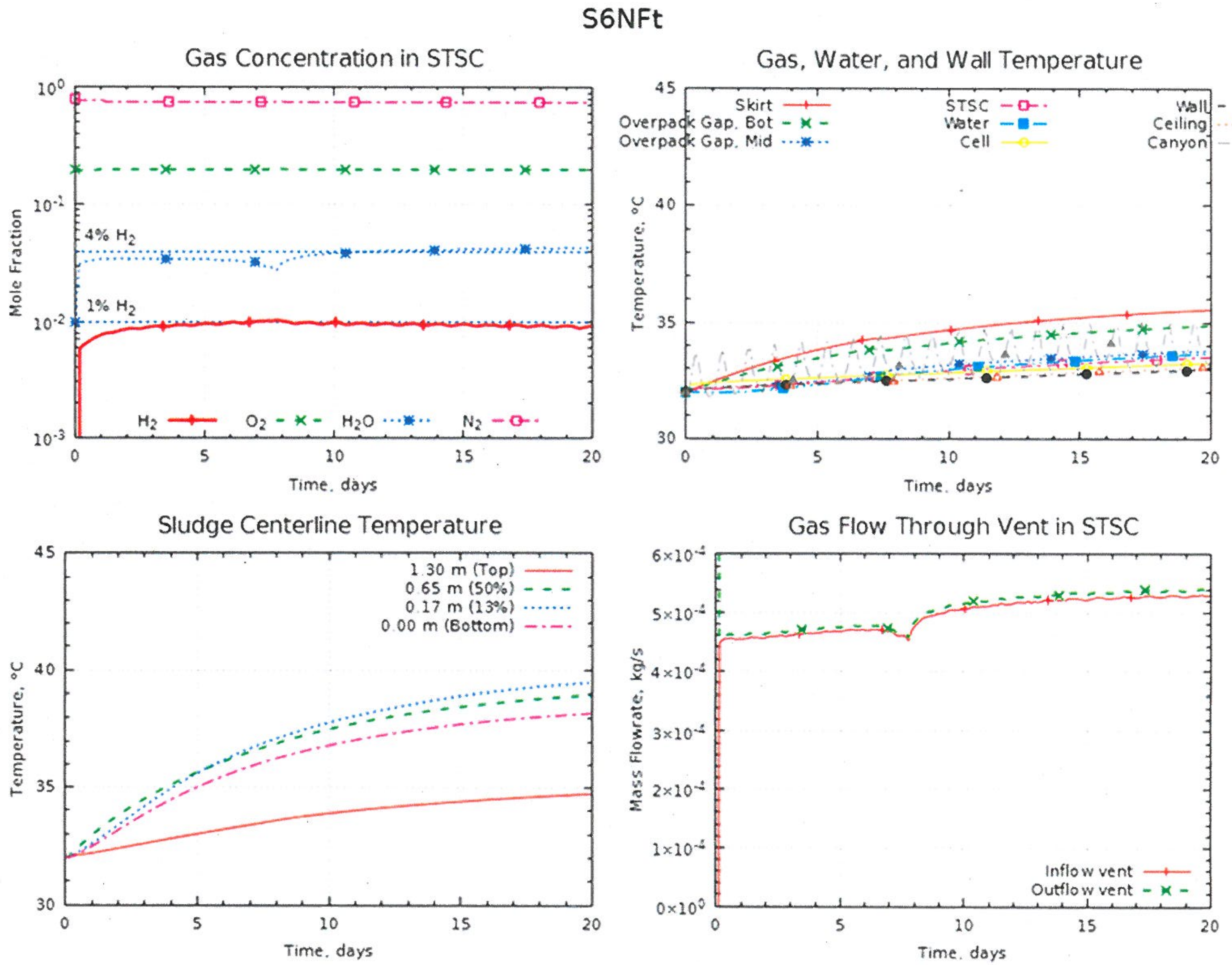


Figure A-5 KW220 and Segregated Settler Material, Thin Sandwiched Layer, STSC/Overpack in Normal Cell, 3x Reaction Multiplier, Two Unfiltered Vents, Fans off

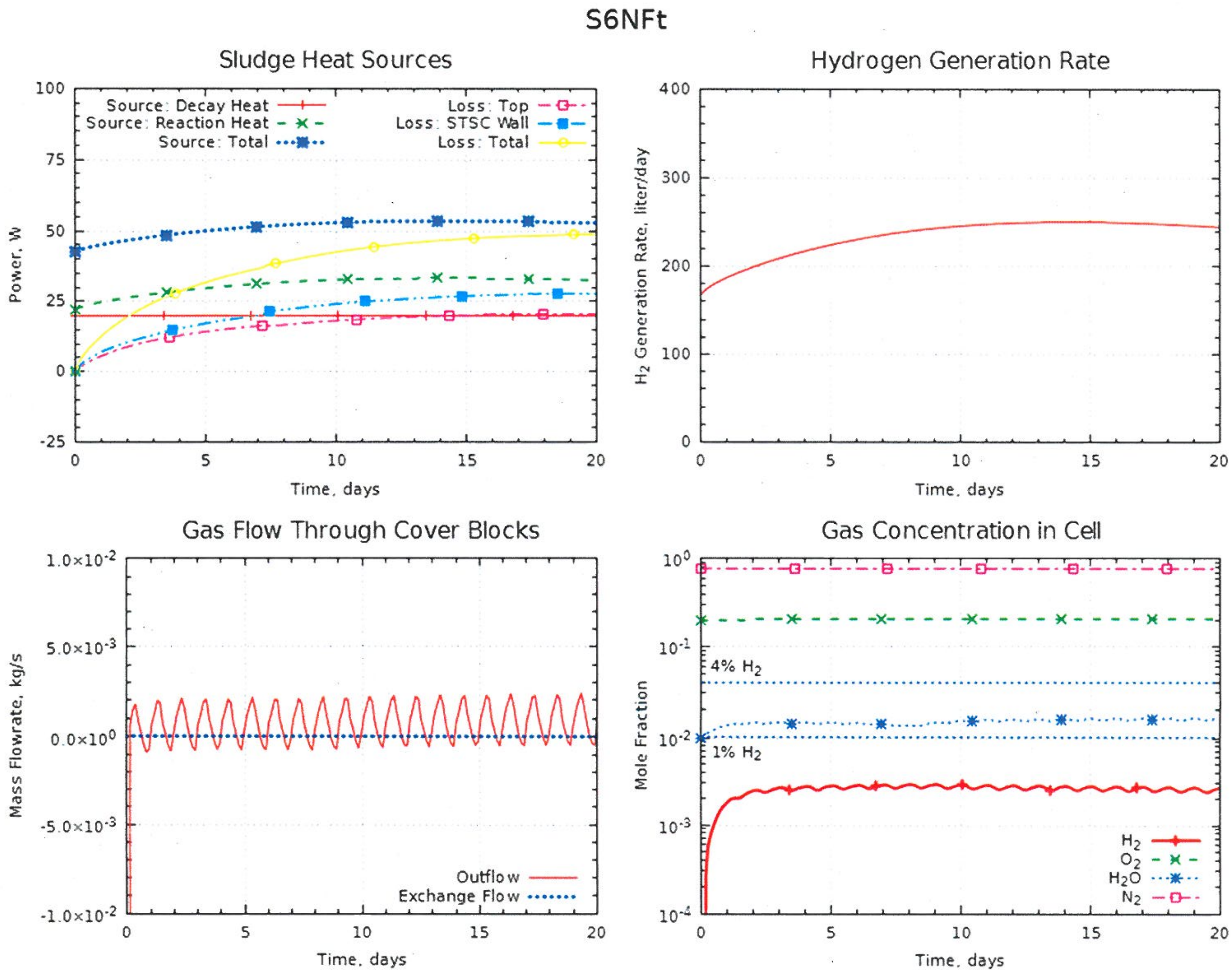


Figure A-6 KW220 and Segregated Settler Material, Thin Sandwiched Layer, STSC/Overpack in Normal Cell, 3x Reaction Multiplier, Two Unfiltered Vents, Fans off

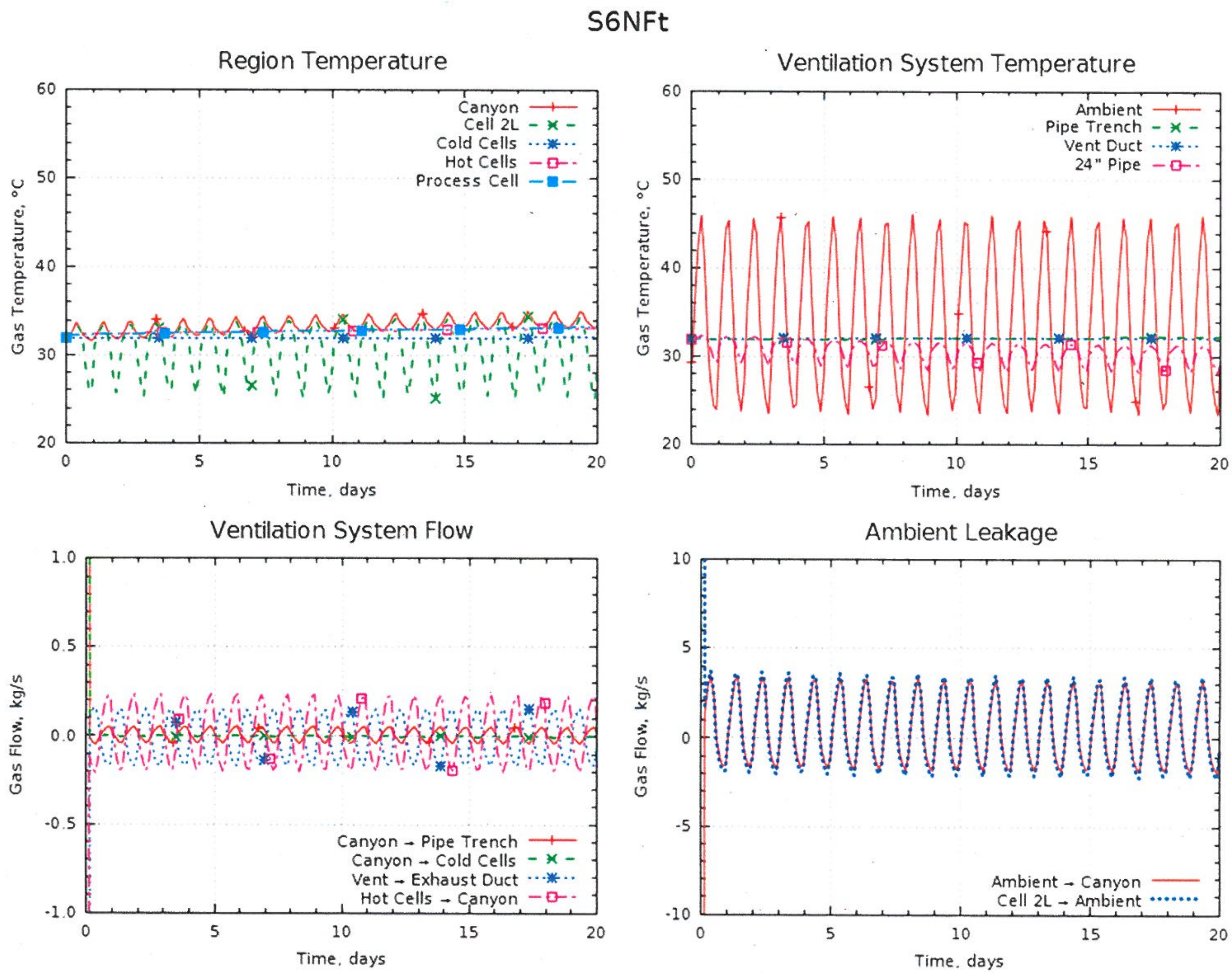


Figure A-7 KW220 and Segregated Settler Material, Uniform Mixture, STSC/Overpack in Normal Cell, 3x Reaction Multiplier, Two Unfiltered Vents, Fans on

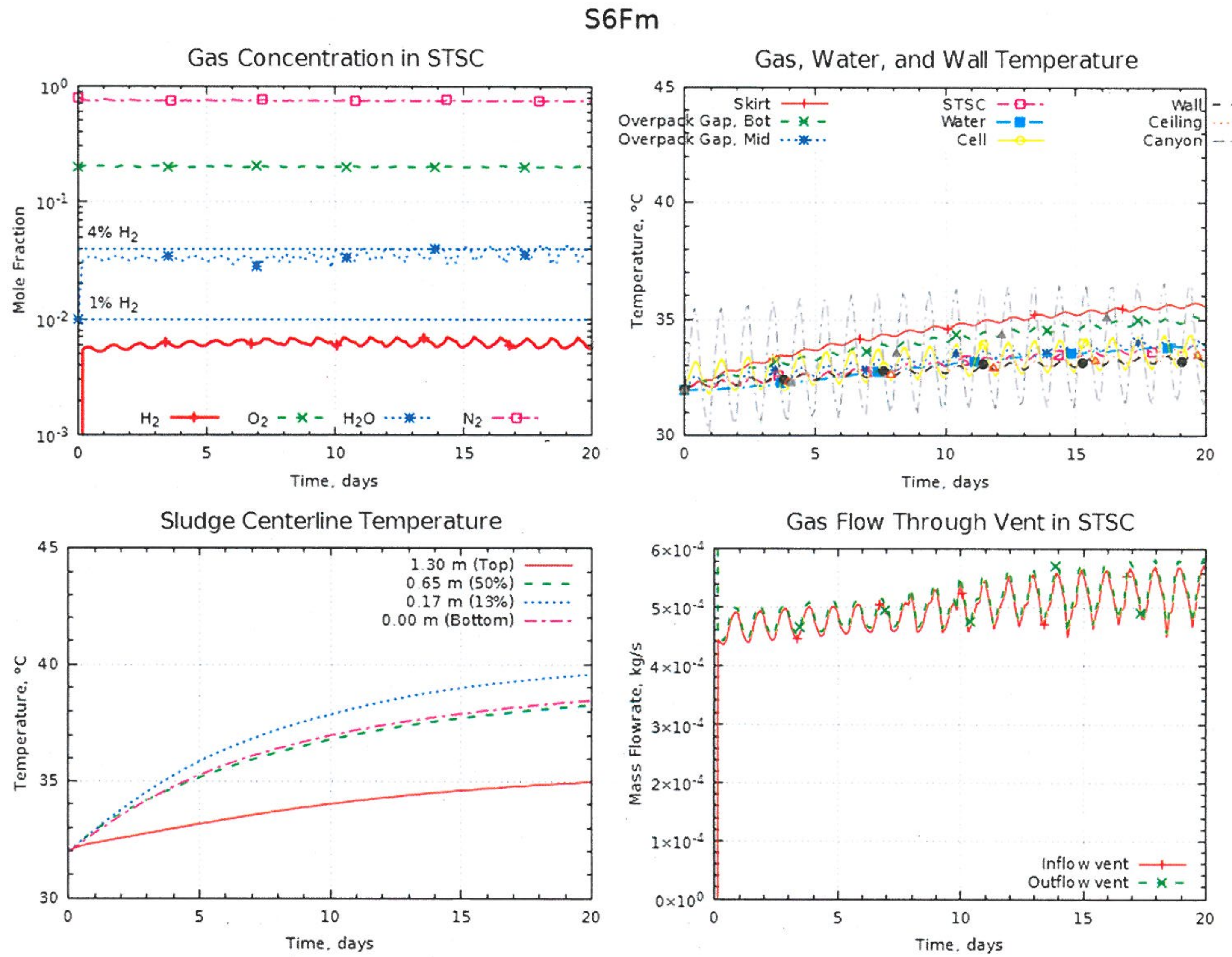


Figure A-8 KW220 and Segregated Settler Material, Uniform Mixture, STSC/Overpack in Normal Cell, 3x Reaction Multiplier, Two Unfiltered Vents, Fans on

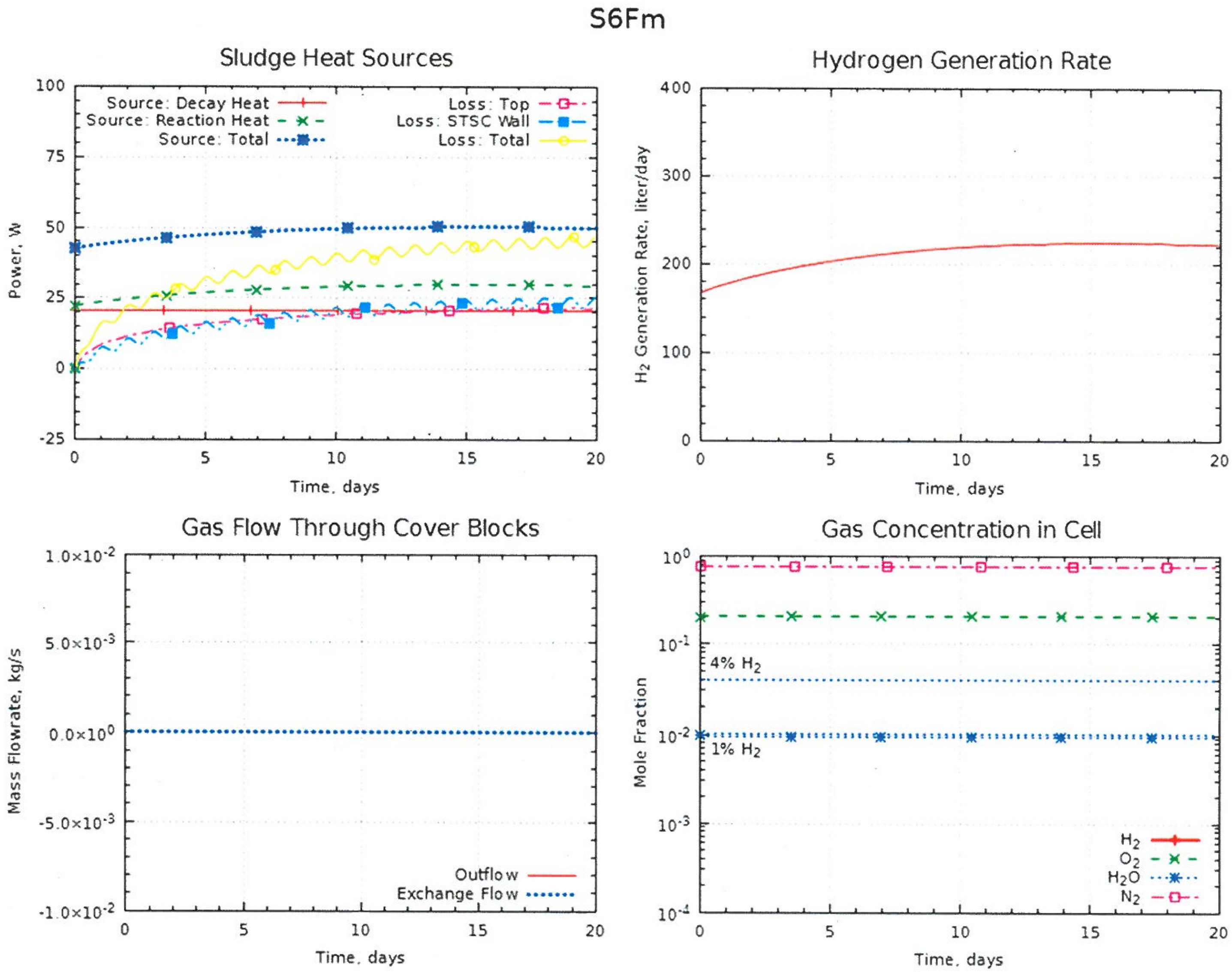


Figure A-9 KW220 and Segregated Settler Material, Uniform Mixture, STSC/Overpack in Normal Cell, 3x Reaction Multiplier, Two Unfiltered Vents, Fans on

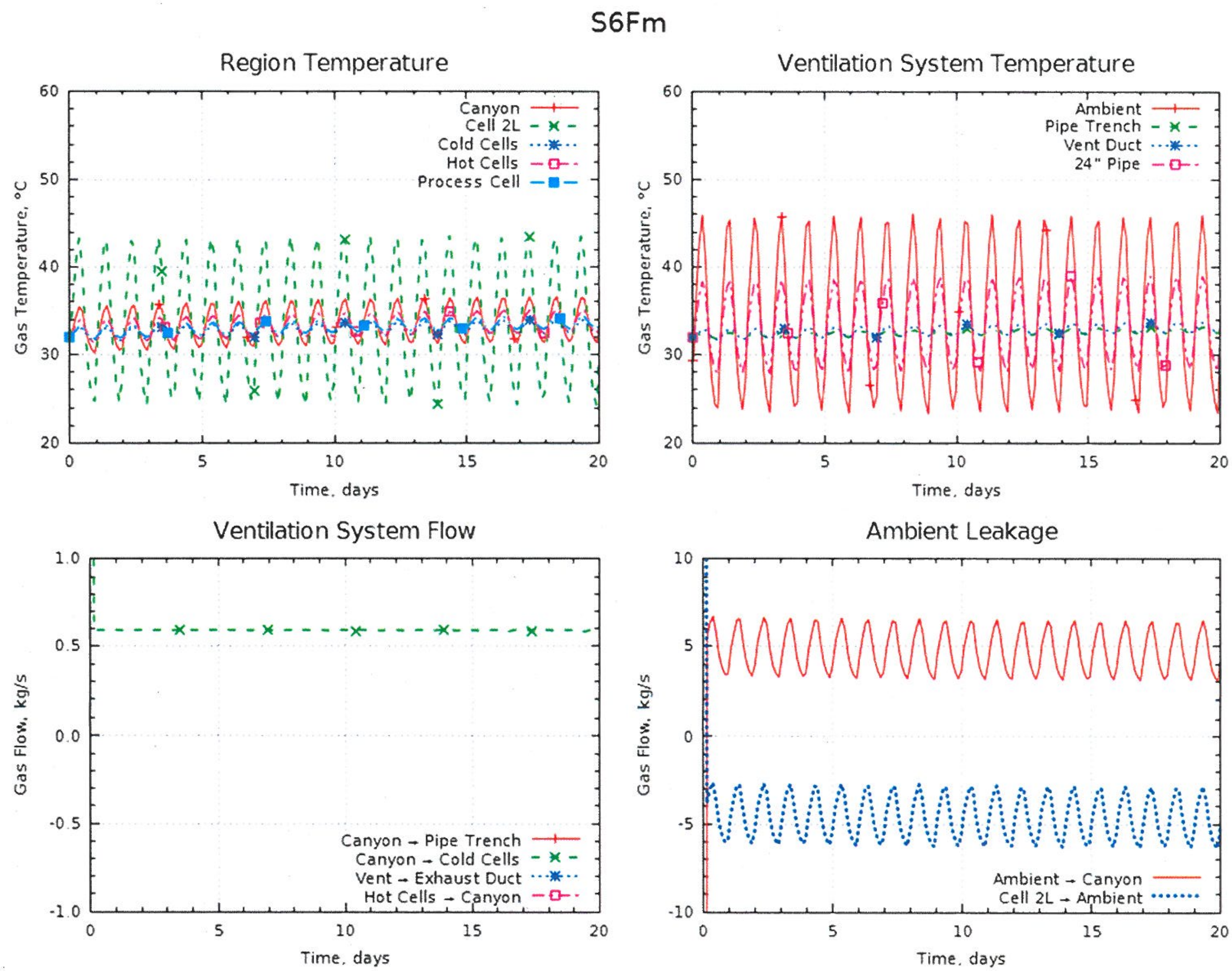


Figure A-10 KW220 and Segregated Settler Material, Thin Sandwiched Layer, STSC/Overpack in Normal Cell, 3x Reaction Multiplier, Two Unfiltered Vents, Fans on

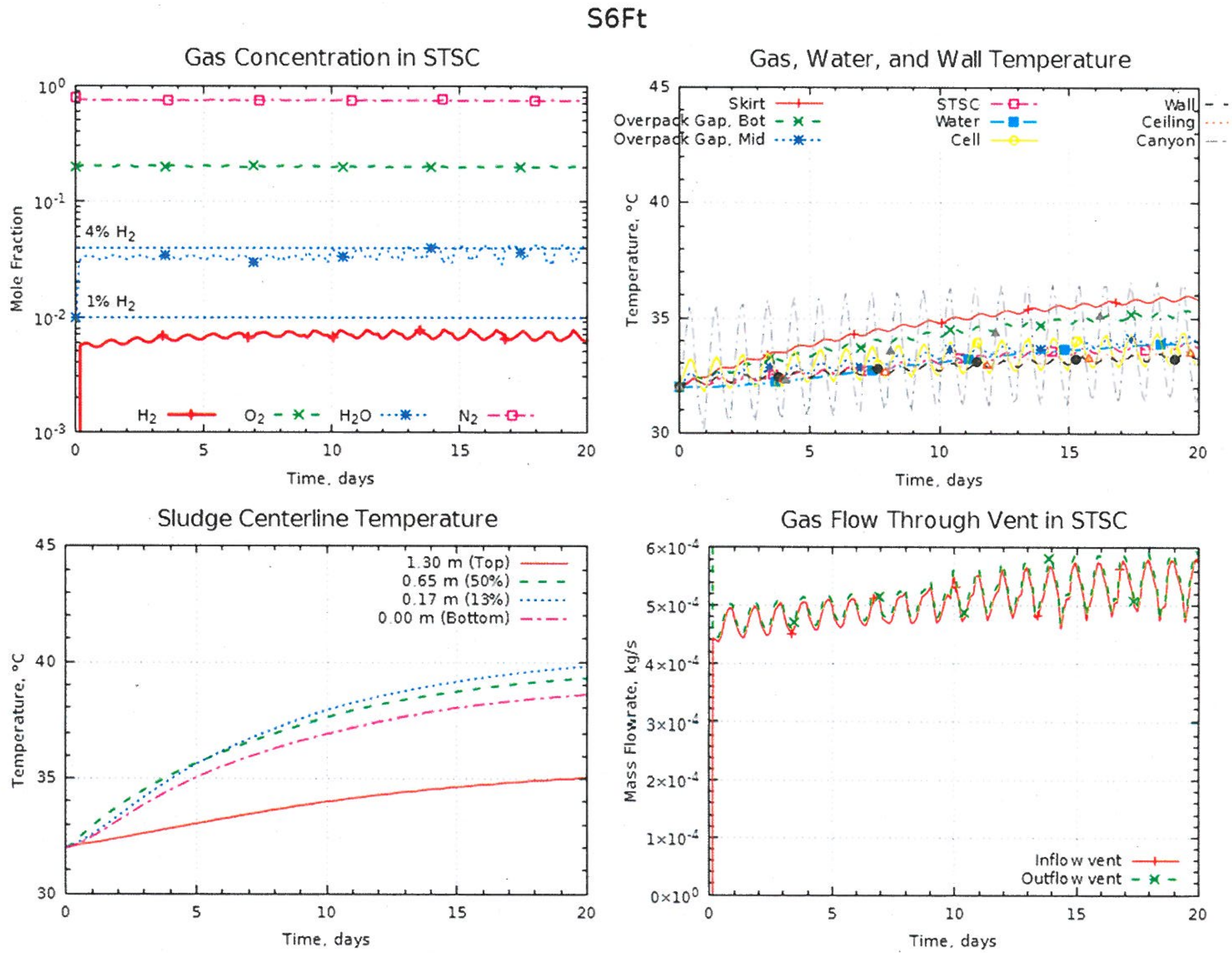


Figure A-11 KW220 and Segregated Settler Material, Thin Sandwiched Layer, STSC/Overpack in Normal Cell, 3x Reaction Multiplier, Two Unfiltered Vents, Fans on

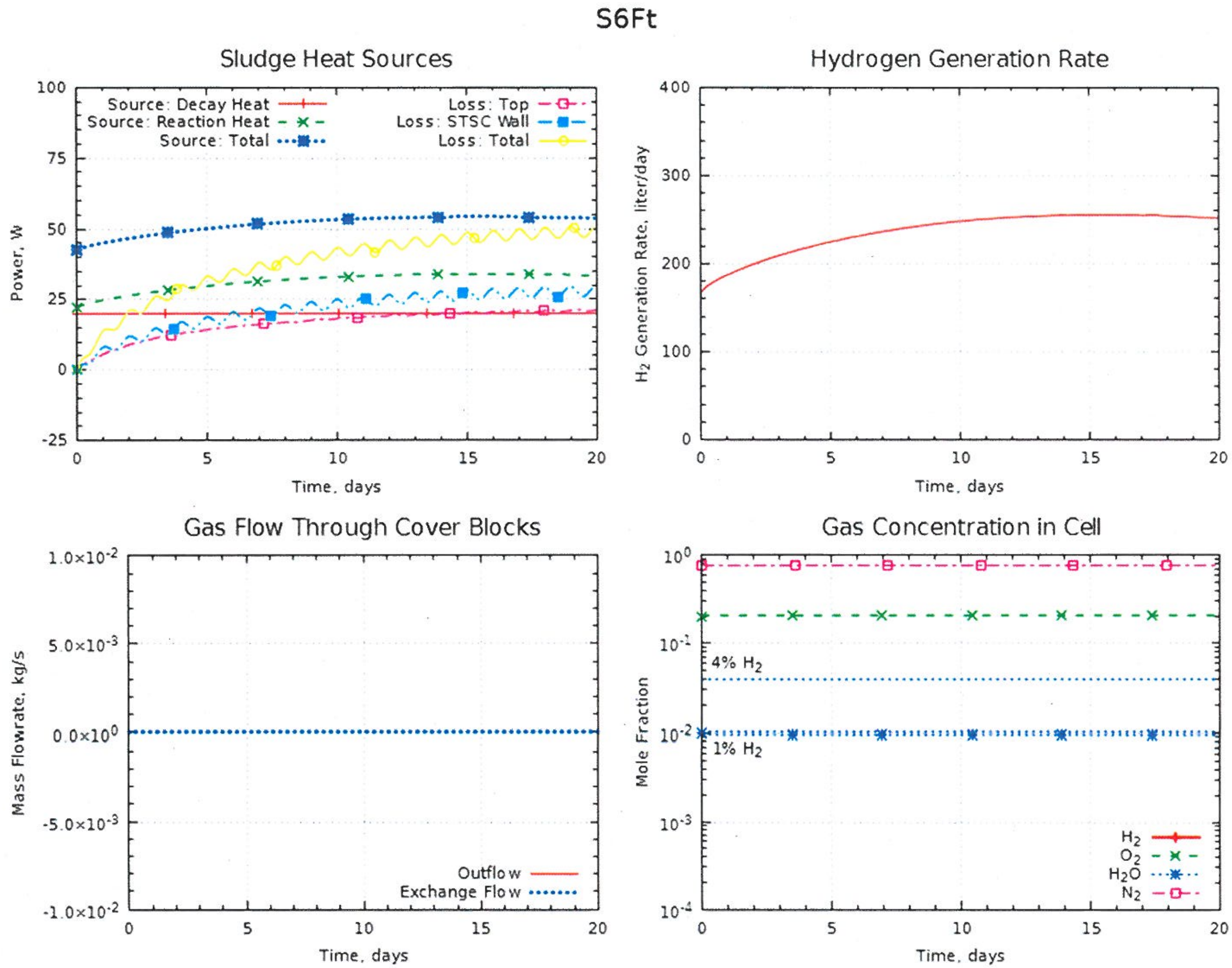
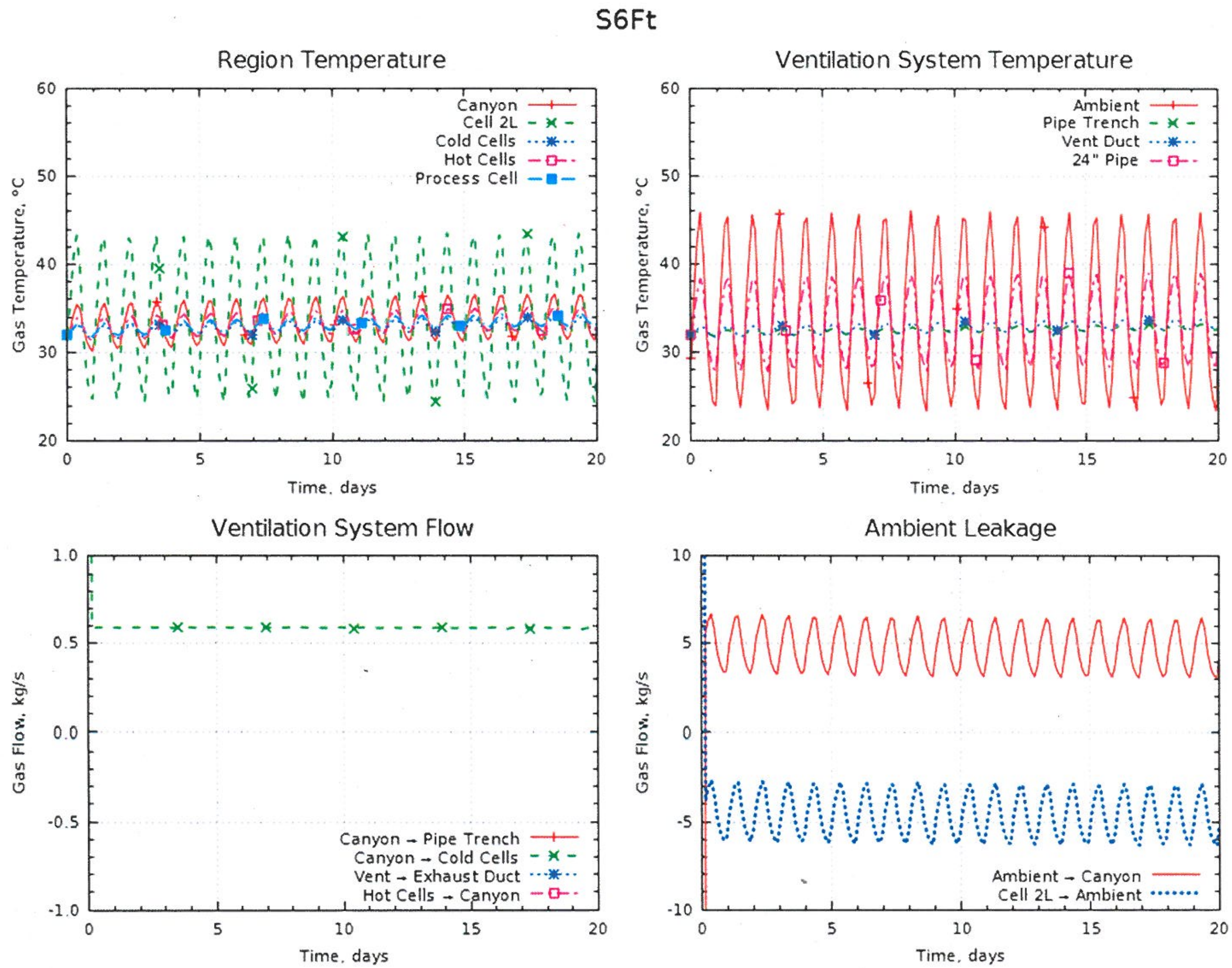


Figure A-12 KW220 and Segregated Settler Material, Thin Sandwiched Layer, STSC/Overpack in Normal Cell, 3x Reaction Multiplier, Two Unfiltered Vents, Fans on



Appendix B: CHPRC Modifications to FAI Thermal and Gas Generation Models for T Plant Storage of STSC without Vent Pipe on Nozzle F2

An STSC stored at T Plant is passively vented through two open vent pipes designed to establish a natural circulation flow in the STSC. The behavior of an STSC within T Plant cells has been previously analyzed with and without the T Plant exhaust ventilation fans operating. These previously analyzed cases are documented in this revision of PRC-STP-00241 and PRC-STP-00893, Volume 3 (FAI/14-0113, revision 1), *Thermal and Gas Analyses for Sludge Transportation and T Plant Storage*.

The original cases analyzed considered a nominal 2 inch inlet vent attached to the STSC shell nozzle S2 (Figure B-1) and a nominal 2 inch outlet vent attached to STSC flange nozzle F2 with an attached 2 ft vent stack assembly to enhance natural circulation. This appendix analyzes the passively vented STSC without the vent stack assembly attached to flange nozzle F2.

Table 17 and Table 18 in the main body of this document provide the results for cases analyzed with the vent stack assembly attached to STSC flange nozzle F2. Cases were analyzed with the T Plant exhaust fans operable (Table 17) and inoperable (Table 18). For each case analyzed, the T Plant cell is assumed to contain five STSC with the design basis sludge composition and one STSC in an overpack and containing the following sludge types and volumes:

- 1.6 m^3 of KE sludge layered over 0.4 m^3 of KW 230 using safety basis sludge compositions
- 1.6 m^3 of KE sludge layered over 0.4 m^3 of KW 230 using design basis sludge compositions
- 1.6 m^3 of KW210 sludge using safety basis sludge composition
- 1.071 m^3 of KW 220 sludge combined with 0.0254 m^3 of segregated settler material loaded as a thin layer in an STSC; safety basis sludge compositions
- 1.071 m^3 of KW 220 sludge well-mixed with 0.0254 m^3 of segregated settler material and the mixture loaded in an STSC; safety basis sludge compositions

The results in Table 17 and Table 18 demonstrate that an STSC in an overpack containing the safety basis compositions for 1.6 m^3 of KE sludge layered over 0.4 m^3 of KW 230 has the maximum hydrogen concentration in the STSC headspace compared to the other cases. Therefore, this appendix only considers an STSC in an overpack containing the safety basis compositions for 1.6 m^3 of KE sludge layered over 0.4 m^3 of KW 230. The T Plant cell also contains five other STSCs each loaded with design basis compositions of 1.6 m^3 of KE sludge layered over 0.4 m^3 of KW 230.

Figure B- 1 Nozzle S2 Elevation and Dimension Detail

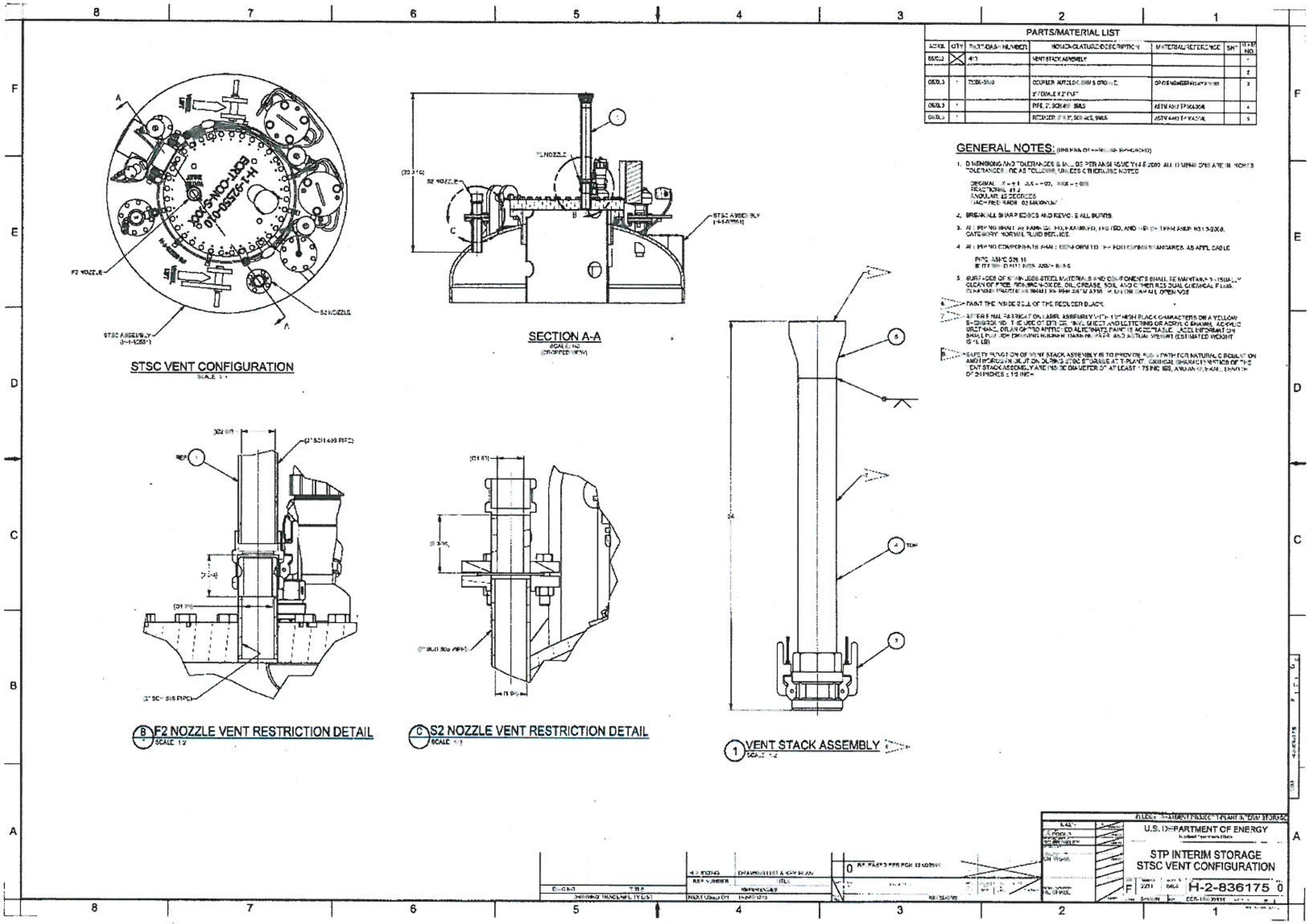


Table B-1 provide the results for the original modeling for the storage of 0.4 m^3 of KW 230 sludge layered with 1.6 m^3 of KE sludge (cases S2F, and S2NF) with the 2 ft vent stack assembly attached to STSC flange nozzle F2.

With the T Plant exhaust fans operating at 17,500 cfm, the peak H_2 gas concentrations in the T Plant cell is less than 1E-04 Vol. %, the peak H_2 gas concentrations in the STSC is 1.1 Vol. %, and the peak sludge temperature is 51.4°C.

With the T Plant exhaust fans inoperable, the peak H2 gas concentrations in the T Plant cell is 0.4 Vol. %, while the peak H2 gas concentration in the STSC increases to a maximum of 1.4 Vol. %. The peak sludge temperature is 50.7°C.

Table B-1 Original Results for Storage of KW 230 sludge layered with KE sludge with the Two-foot vent stack assembly.

Case Name	T Plant Exhaust Fan	Initial T Plant Temperature	Peak Sludge Temperature	Peak H_2 Generation Rate	Peak H_2 Concentration in STSC	Peak H_2 Concentration in Cell, %
S2F	Operating	32 °C	51.4 °C	373 liter/day	1.1 Vol. %	< 1E-04 Vol. %
S2NF	Not operable	32 °C	50.7 °C	363 liter/day	1.4 Vol. %	0.4 Vol. %

During storage, neither the F2 nor S2 vents have a filter, flow restriction, or bend. For a typical flow rate in the vent pipe of 5×10^{-4} kg/s (PRC-STP-00893-Vol 3 Figure 5-19 (case S2F) and Figure 5-22 (case S2NF)), a gas density of 1.1 kg/m^3, a viscosity of 2×10^{-5} Pa-s, and an inner diameter of 0.0508 m (2-inch), the Reynolds number of the flow is about 640. Therefore, laminar incompressible flow is expected in the vent pipes.

The frictional pressure drop in the F2 and S2 vent pipes can be evaluated. Assuming laminar flow in a circular tube, the Darcy friction factor f is related to the Reynolds number according to f = 64/Re, or 64/640 = 0.1. Each vent consists of multiple segments, each with a different diameter.

Tables B-3 has the calculations for the velocity head losses (K values) with friction, contraction and expansion, and exit and entrance effects including the vent stack assembly for the original FATE analysis for storage at T-Plant. Pertinent junction inputs for STSC vent paths to the cell are provided to calculate the FATE model parameter CJN. CJN is related to the effective discharge coefficient C_d according to the expression CJN = $1/C_d^2$.

The same calculations are repeated in the appendix for the passively vented STSC but without the vent stack assembly attached to flange nozzle F2. Table B-4 has the same information as Table B-3 but for the passively vented STSC but without the vent stack assembly attached to flange nozzle F2.

The parameter CJN for the passively vented STSC without the vent stack assembly attached to flange nozzle F2 was then used in the FATE model to determine hydrogen concentrations in the STSC headspace and T Plant cell when storing an STSC containing safety basis compositions of 1.6 m^3 of KE sludge layered over 0.4 m^3 of KW 230. FAI reviewed the FATE model changes made by CHPRC to analyze the passively vented STSC without the vent stack assembly attached to flange nozzle F2. The FAI letter documenting this review is included at the end of this appendix. CHPRC has incorporated into the FATE model the changes noted by FAI in their review.

The FATE model results are presented in Table B-2 for Case S2Fum, T Plant exhaust fans operating and Case S2NFum, T Plant exhaust inoperable. With the T Plant exhaust fans operating at 17,500 cfm and no vent stack assembly, the peak H_2 gas concentrations in the T Plant cell is less than 1E-04 Vol. %, the peak H_2 gas concentrations in the STSC is 1.1 Vol. %, and the peak sludge temperature is 51.4°C. With the T Plant exhaust fans inoperable, the peak H_2 gas concentrations in the T Plant cell is 0.4 Vol. %, while the peak H_2 gas concentration in the STSC increases to a maximum of 1.8 Vol. %. The peak sludge temperature is 50.7°C.

Table B-2 Results for Storage of KW 230 sludge layered with KE sludge without the Two-foot vent stack assembly.

Case Name	T Plant Exhaust Fan	Initial T Plant Temperature	Peak Sludge Temperature	Peak H_2 Generation Rate	Peak H_2 Concentration in STSC	Peak H_2 Concentration in Cell, %
S2Fum	Operating	32 °C	51.4 °C	373 liter/day	1.1 Vol. %	< 1E-04 Vol. %
S2NFum	Inoperable	32 °C	50.7 °C	363 liter/day	1.8 Vol. %	0.4 Vol. %

Table B-3 Calculation of Velocity Head Losses for STSC Vent Paths to/from the Cell with Vent Stack Assembly

W	5.00E-04	kg/s						
Mw	29.0							
P	1.00E+05	Pa						
T	45.0	C						
ρ	1.10	kg/m³						
μ	2.00E-05	kg/m-s						
D, nom	0.050	m	2	inches				
A, nom	1.963E-03	m²						
u	0.232	m/s						
Re	636.620		Re, calc					
f, Darcy	0.1005		64/Re					

Nozzle S2 (inlet) has coupler and no filter

Segment	L (in)	D (in)	fL/D	K, ent/exit	K, contact	K, expand	K, tot	K, min d
1 (top)	2.26	2.38	0.0957	0.780			0.876	0.194
2	3.56	1.63	0.220		0.264485	0.086467	0.571	0.571
3 (S2 nozz)	8.56	1.94	0.444	1			1.444	0.719
L_{tot} (in)	14.38	L_{tot} (m)	0.365					1.484
D_{min} (in)	1.63	D_{min} (m)	0.0414		L/D	8.822086		
A_{min} (in²)	2.087	A_{min} (m²)	0.00135					
K tot	1.484	(referenced to min diameter)			CJN	1.48	Cd	0.821
K tot	3.364	(referenced to 2" diameter)			CJN	3.36	Cd	0.545

Nozzle F2 (outlet) has 2 ft vent pipe and no filter

Segment	L (in)	D (in)	fL/D	K, ent/exit	K, contact	K, expand	K, tot	K, min d
1 (top)	24	2.07	1.1656	1			2.166	1.106
2	2.75	1.75	0.158		0.143	0.035	0.335	0.335
3	3.81	1.94	0.197	0.500			0.697	0.462
L_{tot} (in)	30.56	L_{tot} (m)	0.776					1.903
D_{min} (in)	1.75	D_{min} (m)	0.0445		L/D	17.46286		
A_{min} (in²)	2.405	A_{min} (m²)	0.00155					
K tot	1.903	(referenced to min diameter)			CJN 1.90		Cd 0.725	
K tot	3.247	(referenced to 2" diameter)			CJN 3.25		Cd 0.555	

References

[1] H-1-92550 Rev 1

[2] H-2-836175 Rev 0, Sht 1

[3] Leshikar markup 8/19/13

[4] PT Coupling Catalog, pg 150, part PF20C

[5] Crane manual (Tech. Paper No 410)

Table B-4 Calculation of Velocity Head Losses for STSC Vent Paths to/from the Cell without Vent Stack Assembly

W	5.00E-04	kg/s						
Mw	29.0							
P	1.00E+05	Pa						
T	45.0	C						
ρ	1.10	kg/m³						
μ	2.00E-05	kg/m-s						
D, nom	0.050	m	2	inches				
A, nom	1.963E-03	m²						
u	0.232	m/s						
Re	636.620		Re, calc					
f, Darcy	0.1005		64/Re					

Nozzle S2 (inlet) has coupler and no filter

Segment	L (in)	D (in)	fL/D	K, ent/exit	K, contact	K, expand	K, tot	K, min d
1 (top)	2.26	2.38	0.0957	0.780			0.876	0.194
2	3.56	1.63	0.220		0.264485	0.086467	0.571	0.571
3 (S2 nozz)	8.56	1.94	0.444	1			1.444	0.719
L_{tot} (in)	14.38	L_{tot} (m)	0.365					1.484
D_{min} (in)	1.63	D_{min} (m)	0.0414		L/D	8.822086		
A_{min} (in²)	2.087	A_{min} (m²)	0.00135					
K tot	1.484	(referenced to min diameter)			CJN	1.48	Cd	0.821
K tot	3.364	(referenced to 2" diameter)			CJN	3.36	Cd	0.545

Nozzle F2 (outlet) has no vent and no filter

Segment	L (in)	D (in)	fL/D	K, ent/exit	K, contact	K, expand	K, tot	K, min d
1 (top)				no stack				
2	2.75	1.75	0.158	1		0.035	1.193	1.193
3	3.81	1.94	0.197	0.500			0.697	0.462
L_{tot} (in)	6.56	L_{tot} (m)	0.167					1.654
D_{min} (in)	1.75	D_{min} (m)	0.0445		L/D	3.748571		
A_{min} (in²)	2.405	A_{min} (m²)	0.00155					
K tot	1.654	(referenced to min diameter)			CJN 1.65		Cd 0.777	
K tot	2.822	(referenced to 2" diameter)			CJN 2.82		Cd 0.595	

The results for the no vent stack assembly cases are plotted below in Figure B-2 through B-7. Thus when ventilation is working (Case S2Fum) the cells and STSC are warmed up slightly and the maximum hydrogen generation rate is slightly higher than in the fans-off cases. The plots for storage cases can be interpreted as follows:

- Page 1, Upper Left: Gas concentration in the STSC, volume (mole) fraction. This figure can be used to determine whether flammable conditions can occur.
- Page 1, Upper Right: Gas, water and wall temperatures, °C. The temperatures show the effect of diurnal variation in the ambient, with larger variations observed when ventilation fans are active.
- Page 1, Lower Left: Sludge temperature, °C. Temperature is shown at various elevations along the STSC centerline. A maximum in temperature indicates depletion of uranium metal.
- Page 1, Lower Right: Gas flow through STSC vents, kg/s. Outflow slightly exceeds inflow since gas is generated in the STSC. Since the gas density is about 1 kg/m^3, this mass flow rate is numerically about equal to the volumetric flow rate in m^3/s.
- Page 2, Upper Left: Sludge heat sources (Power, W). In the cases examined, reaction power always attains a maximum value exceeding decay power. The peak in reaction power corresponds to depletion of uranium metal and loss of reactive surface area, even as temperatures may be increasing. Sideward heat loss from sludge exceeds upward loss from the sludge surface. The peak in source power occurs before the peak in losses, so that the peak sludge temperature occurs between these times.
- Page 2, Upper Right: Hydrogen gas generation rate in the sludge, standard L/day. The gas generation rate corresponds to the reaction power. This figure can be used to determine cell venting requirements.
- Page 2, Lower Left: Gas flow through the cover blocks, kg/s. Counter-current exchange flow is negligible through the narrow gaps, rather flow is dominated by inflow (i.e. negative outflow) when ventilation fans are operating, or diurnal breathing when fans are off.
- Page 2, Lower Right: Gas concentration in the cell, volume (mole) fraction. The cell initially contains air.
- Page 3, Upper Left: Gas temperatures in cells and canyon, °C.
- Page 3, Upper Right: Gas temperatures in ventilation system, °C.
- Page 3, Lower Left: Gas flow in ventilation system, kg/s.
- Page 3, Lower Right: Gas leakage flow to/from ambient, kg/s. With fans operating leakage is from ambient into both Cell and the canyon (air infiltration)

Figure B- 2

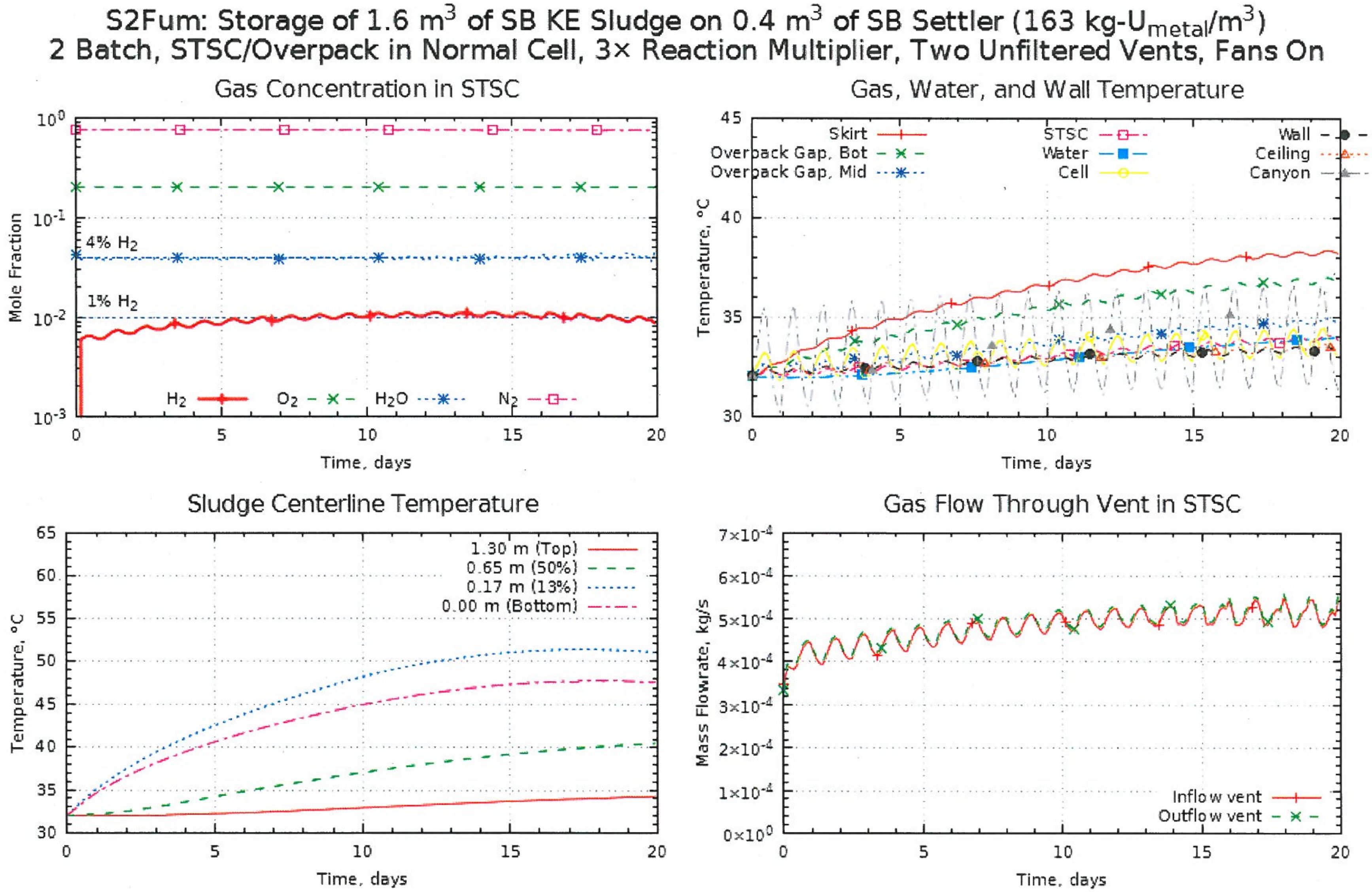

S2Fum: Storage of 1.6 m3 of SB KE Sludge on 0.4 m3 of SB Settler (163 kg-Umetal/m3)
2 Batch, STSC/Overpack in Normal Cell, 3× Reaction Multiplier, Two Unfiltered Vents, Fans On
Gas Concentration in STSC
Mole Fraction
4% H2
1% H2
H2
O2
H2O
N2
Time, days
Gas, Water, and Wall Temperature
Temperature, °C
Skirt
Overpack Gap, Bot
Overpack Gap, Mid
STSC
Water
Cell
Wall
Ceiling
Canyon
Sludge Centerline Temperature
1.30 m (Top)
0.65 m (50%)
0.17 m (13%)
0.00 m (Bottom)
Gas Flow Through Vent in STSC
Mass Flowrate, kg/s
Inflow vent
Outflow vent

Figure B- 3

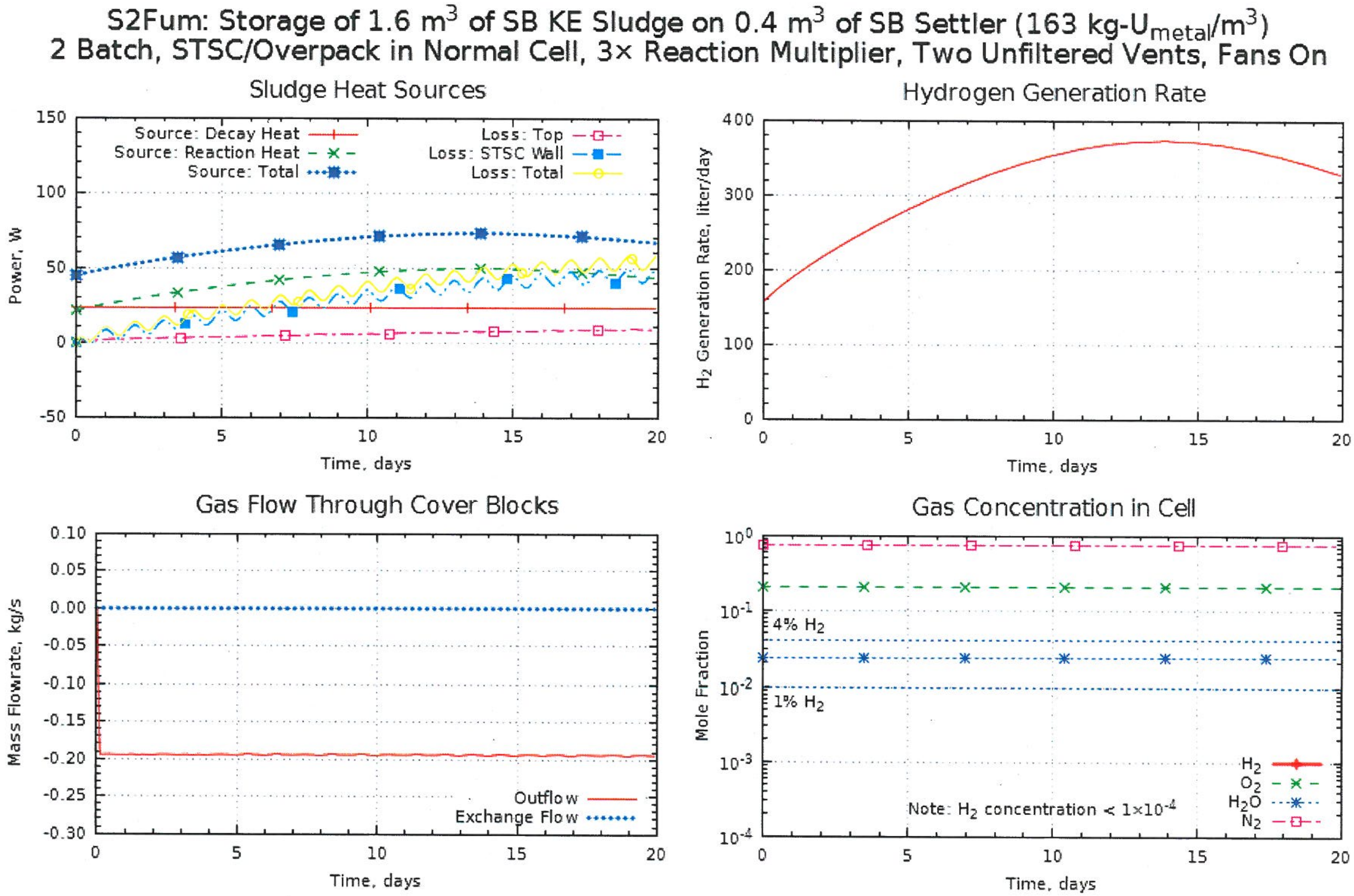

S2Fum: Storage of 1.6 m³ of SB KE Sludge on 0.4 m³ of SB Settler (163 kg-U metal/m³)
2 Batch, STSC/Overpack in Normal Cell, 3× Reaction Multiplier, Two Unfiltered Vents, Fans On
Sludge Heat Sources
Source: Decay Heat
Source: Reaction Heat
Source: Total
Loss: Top
Loss: STSC Wall
Loss: Total
Power, W
Time, days
Hydrogen Generation Rate
H2 Generation Rate, liter/day
Time, days
Gas Flow Through Cover Blocks
Mass Flowrate, kg/s
Outflow
Exchange Flow
Time, days
Gas Concentration in Cell
Mole Fraction
4% H2
1% H2
H2
O2
H2O
N2
Note: H2 concentration < 1×10-4
Time, days

Figure B- 4

S2Fum: Storage of 1.6 m^3 of SB KE Sludge on 0.4 m^3 of SB Settler (163 $kg\text{-}U_{metal}/m^3$)
2 Batch, STSC/Overpack in Normal Cell, 3× Reaction Multiplier, Two Unfiltered Vents, Fans On

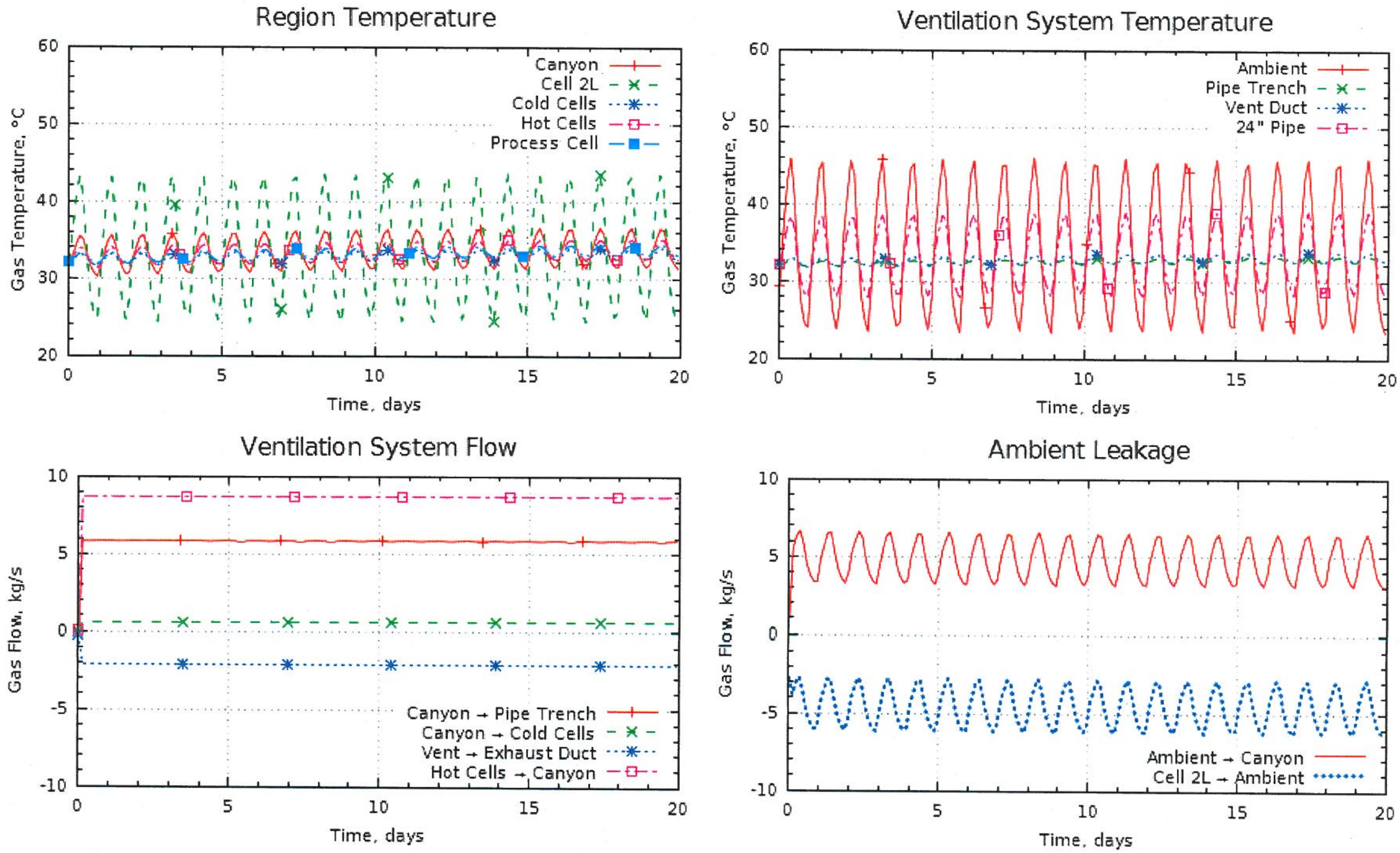


Figure B- 5

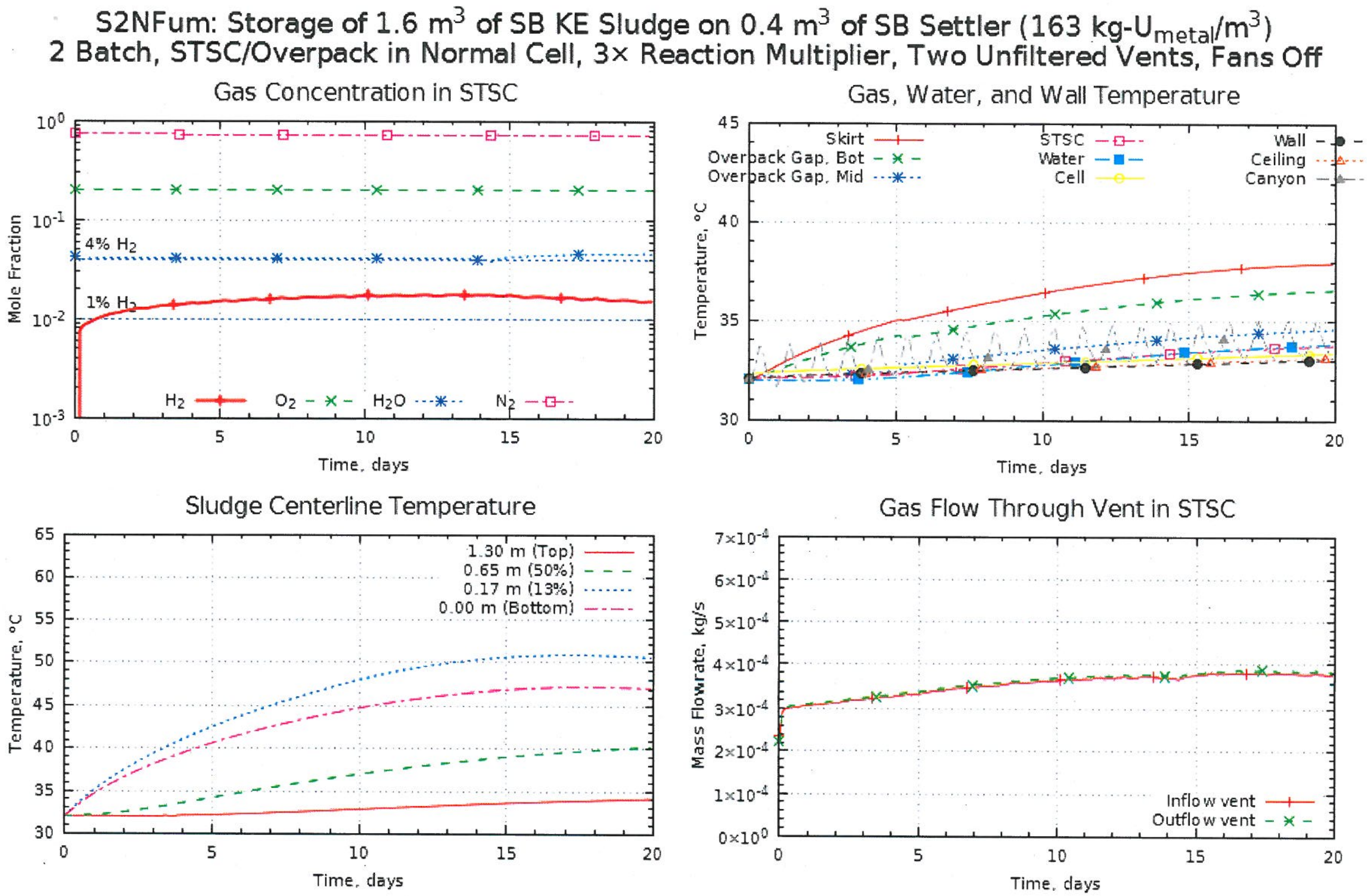

S2NFum: Storage of 1.6 m³ of SB KE Sludge on 0.4 m³ of SB Settler (163 kg-U_metal/m³)
2 Batch, STSC/Overpack in Normal Cell, 3× Reaction Multiplier, Two Unfiltered Vents, Fans Off
Gas Concentration in STSC
Mole Fraction
4% H2
1% H2
H2
O2
H2O
N2
Time, days
Gas, Water, and Wall Temperature
Temperature, °C
Skirt
Overpack Gap, Bot
Overpack Gap, Mid
STSC
Water
Cell
Wall
Ceiling
Canyon
Time, days
Sludge Centerline Temperature
Temperature, °C
1.30 m (Top)
0.65 m (50%)
0.17 m (13%)
0.00 m (Bottom)
Time, days
Gas Flow Through Vent in STSC
Mass Flowrate, kg/s
Inflow vent
Outflow vent
Time, days

Figure B- 6

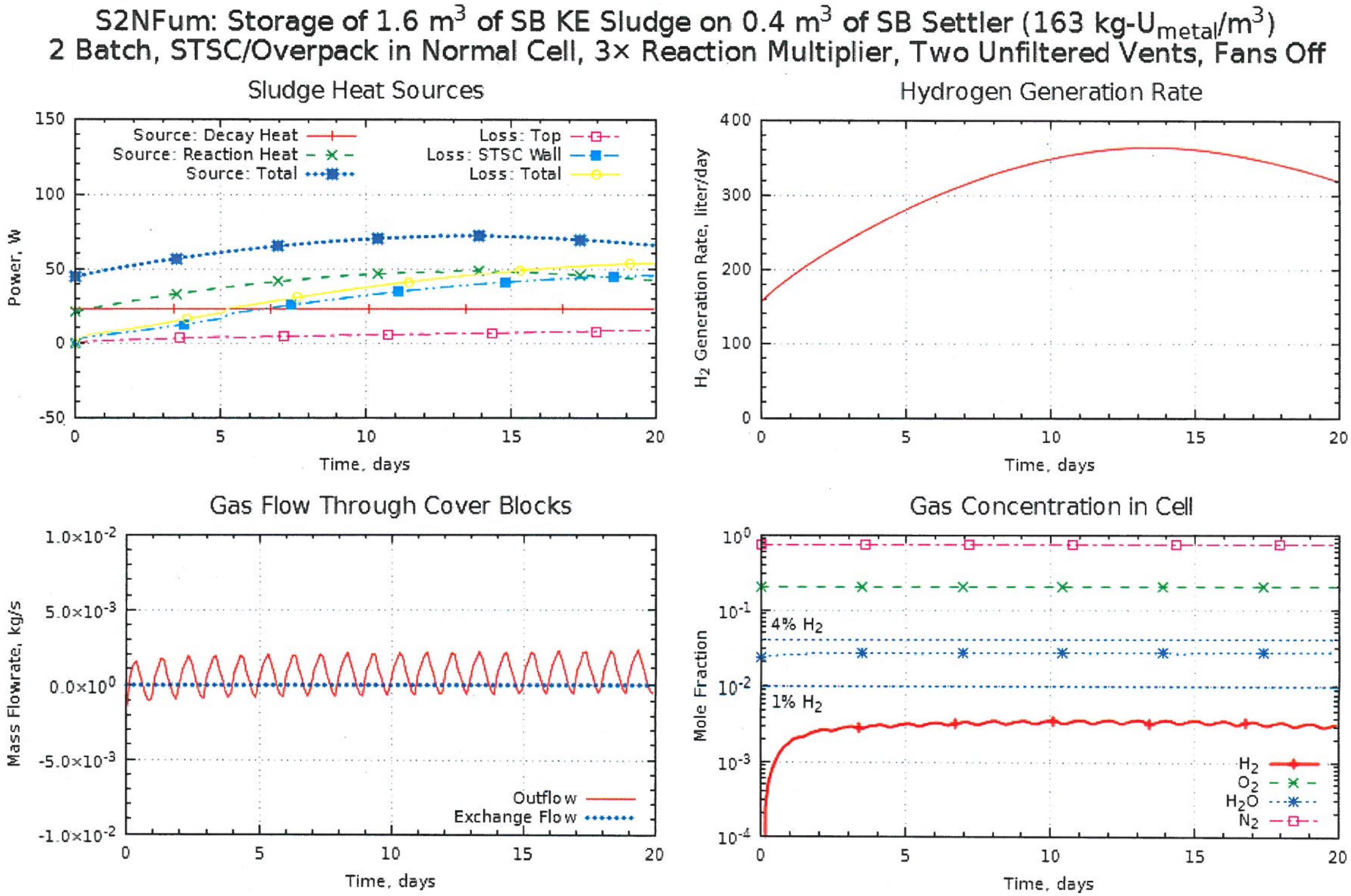
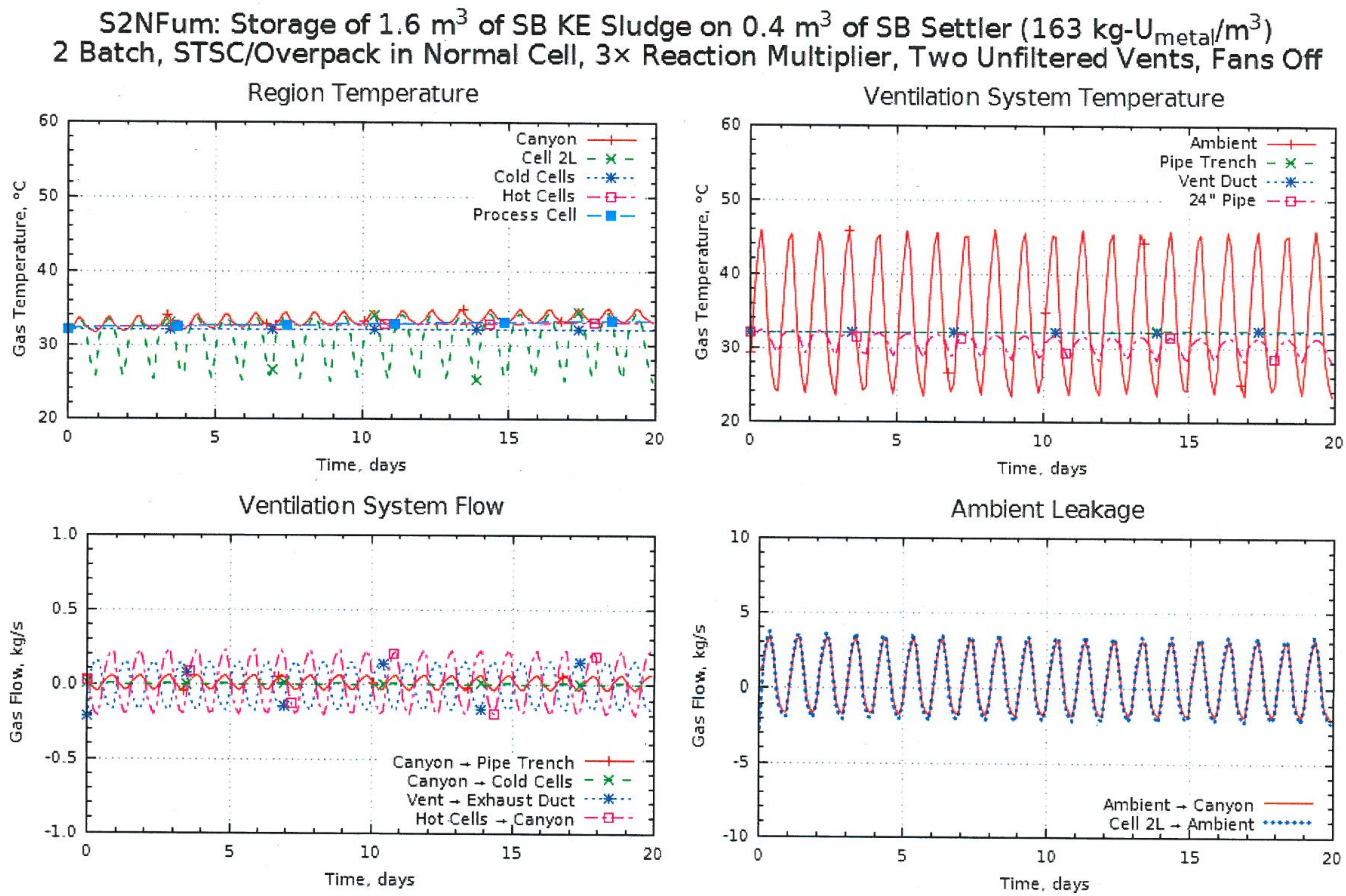

S2NFum: Storage of 1.6 m3 of SB KE Sludge on 0.4 m3 of SB Settler (163 kg-Umetal/m3)
2 Batch, STSC/Overpack in Normal Cell, 3× Reaction Multiplier, Two Unfiltered Vents, Fans Off
Sludge Heat Sources
Source: Decay Heat
Source: Reaction Heat
Source: Total
Loss: Top
Loss: STSC Wall
Loss: Total
Power, W
Time, days
Hydrogen Generation Rate
H2 Generation Rate, liter/day
Time, days
Gas Flow Through Cover Blocks
Outflow
Exchange Flow
Mass Flowrate, kg/s
Time, days
Gas Concentration in Cell
4% H2
1% H2
H2
O2
H2O
N2
Mole Fraction
Time, days

Figure B- 7


S2NFum: Storage of 1.6 m³ of SB KE Sludge on 0.4 m³ of SB Settler (163 kg-U_metal/m³)
2 Batch, STSC/Overpack in Normal Cell, 3× Reaction Multiplier, Two Unfiltered Vents, Fans Off
Region Temperature
Gas Temperature, °C
Time, days
Canyon
Cell 2L
Cold Cells
Hot Cells
Process Cell
Ventilation System Temperature
Ambient
Pipe Trench
Vent Duct
24" Pipe
Ventilation System Flow
Gas Flow, kg/s
Canyon → Pipe Trench
Canyon → Cold Cells
Vent → Exhaust Duct
Hot Cells → Canyon
Ambient Leakage
Ambient → Canyon
Cell 2L → Ambient

4/30/2015 7:12:49 AM Text Compare Page 1

Mode: Differences, Ignoring Unimportant

Left file: C:\Users\h0053127\Desktop\S2F and S2NF\S2NFum - unmitigated\S2NFum.DAT

Right file: C:\Users\h0053127\Desktop\S2F and S2NF\S2NF\S2NF.DAT

Left		Right
* S2NFum: unmitigated *	<>	* S2NF: *
* Vent Stack Assembly removed * * Path 2 upper level reduced from 4.421 m to 3.812m *	+-	
Z2JN 1.08831 3.812 XLJN 0.3637 0.1667	<>	Z2JN 1.08831 4.4212 XLJN 0.3637 0.7762
CJN 1.5 1.65	<>	CJN 1.5 1.9
17,16 17,8 17,1 11,14 14,7 14,1 8,12 8,6 8,1 5,10 5,5 5,1 2,8 2,8 2,1	<>	17,16 17,1 11,14 8,12 5,10 2,8

Beyond Compare v3.1.11

FAUSKE & ASSOCIATES, LLC
WORLD LEADER IN NUCLEAR AND CHEMICAL PROCESS SAFETY

DATE: August 3, 2015

TO: Ted Miller, Ralph Crowe

CC: Marty Plys, Jim Burelbach, Sung Jin Lee, Ben Doup, QA File 5.35.3

FROM: Bob Apthorpe RLA

SUBJECT: **Recommended Changes to FATE Models Simulating Removal of 2-foot Tailpipe from an STSC in Storage at T Plant**

Based on the July 29, 2015 memo *"Review of FATE Models Simulating Removal of 2-foot Tailpipe from an STSC in Storage at T Plant"*, the following changes are recommended to the draft FATE models previously reviewed:

- Change the value of CJN (loss coefficient) on Junction 1 (nozzle S2) to 1.48 from 1.5
- In the case with the vent stack assembly in place on Junction 2 (nozzle F2), change XLJN (counter-current circulation length) to 0.7763 m, CJN to 1.90, and Z2JN (downstream junction height above floor) to 4.4216 m.
- In the case without the vent stack assembly on Junction 2 (nozzle F2), change XLJN (counter-current circulation length) to 0.1667 m, CJN to 1.65, and Z2JN (downstream junction height above floor) to 3.812 m.

Case files which implement these changes are attached to this memo. Case S2NFUM1.DAT (page 2) modifies S2NFUM.DAT – the stack is not present. Case S2NFUM2.DAT (page3) modifies the original S2NFUM.DAT base file to add the ventilation stack.

The original case and the revised cases were run to check the behavior of the model. Transient results for these cases showing hydrogen concentration in the STSC and T Plant cell are shown in Figure 1 on page 4. There is an increase in hydrogen retained inside the STSC in the no-tailpipe case, however the results of all three cases are very similar and in no event does the hydrogen concentration in the STSC exceed 2%. The lower flammability limit (LFL) of hydrogen in dry air is 4%, so in all cases considered, there is no concern about flammability inside the STSC. Likewise, there is no appreciable accumulation of hydrogen in the T Plant cells; all reach a concentration of approximately 0.3% hydrogen, well below LFL. For more information on the transient results, see page 44 and pages 55-57 of FAI/14-0113, Rev. 1.

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-2-

Case File S2NFUM1.DAT

```
*-----------------------------------------------------------------
CONTROL
*-----------------------------------------------------------------
  TITLE
******************************************************************
*                                                                *
* S2NFUM1:   unmitigated                                         *
*                                                                *
*          STSC IN OVERPACK IN T-PLANT REGULAR CELL              *
*          STSC containing 1.6m3 SB KE on 0.4m3 SB Settler       *
*          Sludge, 3X reaction multiplier                        *
*          0.96 m3 of cover water                                *
*                                                                *
*          Upper batch:                                          *
*          1.6 m3 KE Sludge from SCS-CON-240, -250, and -260     *
*          Lower batch:                                          *
*          0.4 m3 Settler Sludge from SCS-CON-230                *
*                                                                *
*          EXHAUST FANS OFF, STACK MODELED                       *
*          COLD CELLS, VENT DUCT, PIPE TRENCH MODELED!           *
*          HOT CELLS OPEN TO CANYON (NO COVER BLOCKS)            *
*                                                                *
*          ONE SIDE OF T-CELL HAS 9 FT CONCRETE WALL             *
*          THE OTHER SIDE OF T-CELL HAS 7 FT CONCRETE WALL       *
*          T-CELL HAS 6 FT THICK COVER BLOCK                     *
*                                                                *
*          *** BASE FILE S2NFUM.DAT ***                          *
*                                                                *
*             Vent Stack Assembly removed                        *
*          Path 2 upper level reduced from 4.421 m  to 3.812m    *
*          Path 2 XLJN (junction length for countercurrent flow) *
*          corrected to 0.1667 m                                 *
******************************************************************
  END TITLE
END CONTROL

JUNCTIONS
  PATHS      1           2
    LABEL    VENT-IN     VENT-OUT
    IJTYP    1           1
    IR1      6           1
    IR2      1           6
    IHORIZ   1           1
    Z1JN     3.7388      1.35821
    Z2JN     1.08831     3.812
    XLJN     0.3637      0.1667
    XWJN     0.05080     0.05080
    XHJN     0.05080     0.05080
    AJN      1.346E-3    1.552E-3
    CJN      1.48        1.65
    FGAS1JN  1.0         1.0
  END PATHS
END JUNCTIONS
```

-3-

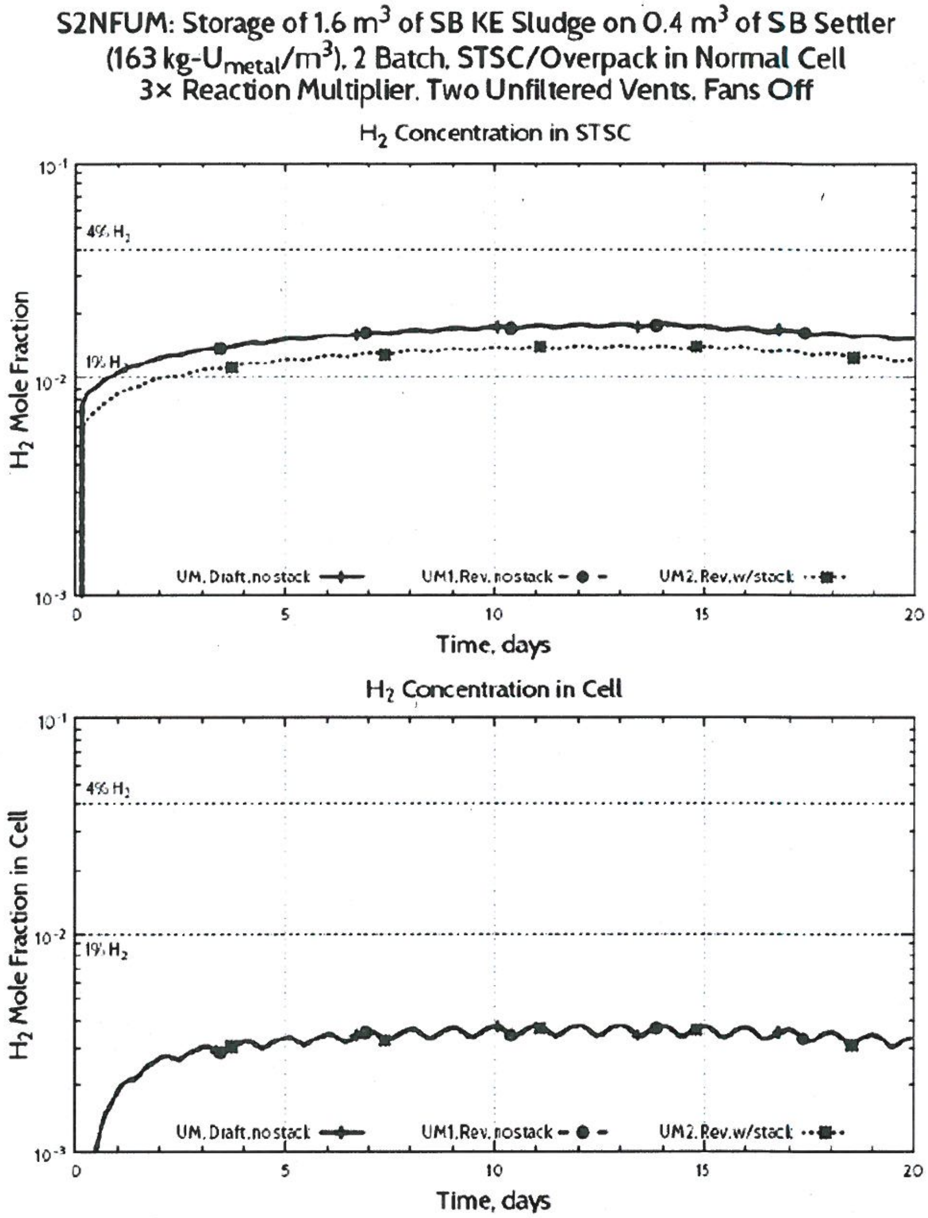
Case File S2NFUM2.DAT

```
*----------------------------------------------------------------
CONTROL
*----------------------------------------------------------------
  TITLE
*****************************************************************
*                                                               *
* S2NFUM2: Unmitigated; With stack & updated CJN               *
*                                                               *
*         STSC IN OVERPACK IN T-PLANT REGULAR CELL              *
*         STSC containing 1.6m3 SB KE on 0.4m3 SB Settler       *
*         Sludge, 3X reaction multiplier                        *
*         0.96 m3 of cover water                                *
*                                                               *
*         Upper batch:                                          *
*         1.6 m3 KE Sludge from SCS-CON-240, -250, and -260     *
*         Lower batch:                                          *
*         0.4 m3 Settler Sludge from SCS-CON-230                *
*                                                               *
*         EXHAUST FANS OFF, STACK MODELED                       *
*         COLD CELLS, VENT DUCT, PIPE TRENCH MODELED!           *
*         HOT CELLS OPEN TO CANYON (NO COVER BLOCKS)            *
*                                                               *
*         ONE SIDE OF T-CELL HAS 9 FT CONCRETE WALL             *
*         THE OTHER SIDE OF T-CELL HAS 7 FT CONCRETE WALL       *
*         T-CELL HAS 6 FT THICK COVER BLOCK                     *
*                                                               *
*         *** BASE FILE S2NFUM.DAT ***                          *
*                                                               *
*****************************************************************
  END TITLE
END CONTROL

JUNCTIONS
  PATHS     1           2
    LABEL   VENT-IN     VENT-OUT
    IJTYP   1           1
    IR1     6           1
    IR2     1           6
    IHORIZ  1           1
    Z1JN    3.7388      1.35821
!   Z2JN    1.08831     3.812
!                       +0.6096
    Z2JN    1.08831     4.4216
!   XLJN    0.3637      0.1667
!                       +0.6096
    XLJN    0.3637      0.7763
    XWJN    0.05080     0.05080
    XHJN    0.05080     0.05080
    AJN     1.346E-3    1.552E-3
    CJN     1.48        1.90
    FGAS1JN 1.0         1.0
  END PATHS
END JUNCTIONS
```

-4-

Figure 1: Comparison of draft and revised models of STSC in storage at T-Plant, with and without vent stack assembly



Appendix C: CHPRC Calculation for Nitrogen Purging the STS Cask

CHPRC CALCULATION COVER SHEET

Selection: 1 Identification

1. Calculation Number	2. Revision	3. Title
PRC-STP-00241	4	Appendix C: CHPRC Calculation for Nitrogen Purging the STS Cask

4. Purpose

Determine the duration required for nitrogen purging the STS Cask so that the minimum hydrogen concentration is achieved. These calculations were conducted at a purge rate of 4.5 scfm and 5 scfm and for varying hydrogen generation rates for the sludge in the STSC. Determine the duration before the hydrogen concentration increases to 1 Vol. % in the STS Cask for reduced nitrogen purge rates of 0.5 to 2.0 scfm, following purging the cask to the minimum achievable hydrogen concentration

5. Project/Program/Activity

SLudge Treatment Project

Section 2: Approval

6. Author	7. Checker
M. E. Johnson	R. H. Meichle R H Meichle 9/30/15
Print /Signature/Date	Print /Signature/Date

8. Title	Print/Sign/Date	ADD ROW
Title	Print/Sign	Date

Section 3: Summary of Revisions

9. Rev. No.	10. Description of Change	11. Affected Pages	12. Author	13. Checker ADD ROW
1	Expanded calculations to include reduced purge cases at 1.5 to 2.0 scfm. Previous calculations determined maximum duration before the hydrogen concentration reached 1% in the cask void space after venting / purging the cask at 4.5 or 5 cfm with nitrogen and then reducing the purge rate to 0.5 to 1.25 scfm.	all	MEJ	
				☒
				☒
				☒
				☒
				☒
				☒
				☒

Page 1 of 1 A-6004-793 (REV 1)

Prepared by:	Michael E. Johnson
Date:	29-Sep-15
Revision	1
Reviewed by:	
Date:	
Purpose:	Determining the maximum duration before the hydrogen concentration reached 1% in the cask void space after venting / purging the cask at 5 cfm with nitrogen and then reducing the nitrogen purge rate to 0.5. 0.75, 1.0, 1.25, 1.5, 1.6, 1.8, or 2.0 cfm
Approach:	Calculates the required time and theoretical minimum (steady state) hydrogen concentration in the STS cask, if the STS cask is purge at 4.5 cfm or 5 cfm versus hydrogen gas generation rates of 400 to 1000 liters/day. Use the theoretical minimum hydrogen concentration in the STS cask as the starting hydrogen concentration when the nitrogen purge rate is decreased from 5 cfm to 0.5. 0.75, 1.0, 1.25, 1.5, 1.6, 1.8, or 2.0 cfm to calculate the maximum duration when the cask reaches 1% hydrogen.
References	PRC-STP-00908, October 2014, *Analysis of Cask Venting, Cask Purging, and STSC Purging at T Plant, FAI/14-0114 by J. P. Burelbach and R. A. Apthorpe, Fauske and Associates LLC*

Known Values

Convert 1 cfm to m^3/sec		4.72E-04	m^3/sec
Cask Void volume		1.43	m^3
Basis:	PRC-STP-00908, page 32		

Assumptions:

1 Mixing efficiency for nitrogen purging of the STS cask is assumed to be 1.
Basis: PRC-STP-00908 page 29, Section 5.2.4

Equations

1 Steady-state hydrogen concentration in STS cask

Steady-state H_2 = $Q_{src} / K * Q_{purge}$

Basis: PRC-STP-00908 page 27, equation 5-11

2 Time to purge to specific hydrogen concentration in STS cask

Note: This equation is used both to determine time to purge the cask to the minimum hydrogen concentration (calculation 2) and to determine the time the hydrogen concentration increases to 1% at the reduced purge rate (calculation3)

t (sec) = $-V/(K * Q_{purge}) * LN[(x(t) - Q_{src} / (K * Q_{purge})) / (x(0) - Q_{src} / (K * Q_{purge}))]$

Basis: PRC-STP-00908 page 27, equation 5-10

where

V	is cask void volume
K	is mixing efficiency of purge with hydrogen in cask
Q_{purge}	is purge flow rate, m^3/sec
Q_{src}	is hydrogen generation rate, m^3/sec
x(t)	hydrogen mole fraction at time t
x(0)	hydrogen mole fraction at time zero
t	time, seconds

Calculations

1A Steady-state hydrogen concentration in STS cask - 5 cfm purge

	Steady State H_2 Concentration			
Q_{purge}		5 cfm	during cask purging	
	Q_{src} / Q_{purge}	Q_{src} Liter/day	Q_{src} m^3/sec	Q_{purge} m3/sec
	0.196%	400	4.63E-06	2.36E-03
	0.245%	500	5.79E-06	2.36E-03
	0.294%	600	6.94E-06	2.36E-03
	0.319%	650	7.52E-06	2.36E-03
	0.343%	700	8.10E-06	2.36E-03
	0.368%	750	8.68E-06	2.36E-03
	0.392%	800	9.26E-06	2.36E-03
	0.441%	900	1.04E-05	2.36E-03
	0.490%	1000	1.16E-05	2.36E-03

1B Steady-state hydrogen concentration in STS cask - 4.5 cfm purge

	Steady State H_2 Concentration			
Q_{purge}		4.5 cfm	during cask purging	
	Q_{src} / Q_{purge}	Q_{src} Liter/day	Q_{src} m^3/sec	Q_{purge} m3/sec
	0.218%	400	4.63E-06	2.12E-03
	0.272%	500	5.79E-06	2.12E-03
	0.327%	600	6.94E-06	2.12E-03
	0.354%	650	7.52E-06	2.12E-03
	0.381%	700	8.10E-06	2.12E-03
	0.409%	750	8.68E-06	2.12E-03
	0.436%	800	9.26E-06	2.12E-03
	0.490%	900	1.04E-05	2.12E-03
	0.545%	1000	1.16E-05	2.12E-03

2A Time to purge cask to minimum hydrogen concentration in STS cask

Q_{purge} 5 cfm during cask purging

	x(0)	x(t)	Q_{src}	Q_{purge}	t (sec)	t (minutes)	t (hours)
400	76.00%	0.20%	4.63E-06	2.36E-03	6.00E+03	100.0	1.67
500	76.00%	0.25%	5.79E-06	2.36E-03	5.86E+03	97.7	1.63
600	76.00%	0.30%	6.94E-06	2.36E-03	5.75E+03	95.9	1.60
650	76.00%	0.32%	7.52E-06	2.36E-03	6.70E+03	111.7	1.86
700	76.00%	0.35%	8.10E-06	2.36E-03	5.66E+03	94.3	1.57
750	76.00%	0.37%	8.68E-06	2.36E-03	6.35E+03	105.8	1.76
800	76.00%	0.40%	9.26E-06	2.36E-03	5.58E+03	93.0	1.55
900	76.00%	0.45%	1.04E-05	2.36E-03	5.51E+03	91.8	1.53
1000	76.00%	0.50%	1.16E-05	2.36E-03	5.44E+03	90.7	1.51

Note: 76% hydrogen concentration in STS cask after initial purging is from section 5.2.3 in PRC-STP-00908.

2B Time to purge cask to minimum hydrogen concentration in STS cask

Q_{purge} 4.5 cfm during cask purging

	x(0)	x(t)	Q_{src}	Q_{purge}	t (sec)	t (minutes)	t (hours)
400	76.00%	0.22%	4.63E-06	2.12E-03	7.10E+03	118.3	1.97
500	76.00%	0.28%	5.79E-06	2.12E-03	6.95E+03	115.8	1.93
600	76.00%	0.33%	6.94E-06	2.12E-03	6.82E+03	113.7	1.89
650	76.00%	0.36%	7.52E-06	2.12E-03	6.38E+03	106.4	1.77
700	76.00%	0.39%	8.10E-06	2.12E-03	6.12E+03	102.0	1.70
750	76.00%	0.41%	8.68E-06	2.12E-03	7.41E+03	123.4	2.06
800	76.00%	0.44%	9.26E-06	2.12E-03	6.63E+03	110.5	1.84
900	76.00%	0.50%	1.04E-05	2.12E-03	6.05E+03	100.8	1.68
1000	76.00%	0.55%	1.16E-05	2.12E-03	6.48E+03	107.9	1.80

3A Maximum duration (minutes) before STS cask reaches 1% hydrogen concentration after purging at 5 cfm to minimum hydrogen concentration

	Q_{purge} m^3/sec	2.36E-04	3.54E-04	4.72E-04	5.90E-04	7.08E-04	7.55E-04	8.50E-04	9.44E-04
	Q_{purge} cfm	0.5	0.75	1	1.25	1.5	1.6	1.8	2
Q_{src} m^3/sec	Q_{src} liters/day								
4.63E-06	400	61.13	86.21	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!
5.79E-06	500	42.05	52.51	73.84	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!
6.94E-06	600	31.08	36.82	45.96	64.63	#NUM!	#NUM!	#NUM!	#NUM!
7.52E-06	650	27.33	31.82	38.53	50.27	83.22	#NUM!	#NUM!	#NUM!
8.10E-06	700	23.91	27.49	32.60	40.74	57.39	72.40	#NUM!	#NUM!
8.68E-06	750	21.33	24.26	28.28	34.28	44.81	52.11	95.28	#NUM!
9.26E-06	800	18.85	21.26	24.48	29.07	36.40	40.89	57.16	#NUM!
1.04E-05	900	15.08	16.78	18.96	21.87	26.03	28.27	34.59	46.51
1.16E-05	1000	12.17	13.40	14.94	16.91	19.55	20.89	24.32	29.45

Note:
Calculation that shows "NUM!" mean the hydrogen concentration in the cask would always be less than 1% at these conditions

3B Maximum duration (minutes) before STS cask reaches 1% hydrogen concentration after purging at 4.5 cfm to minimum hydrogen concentration

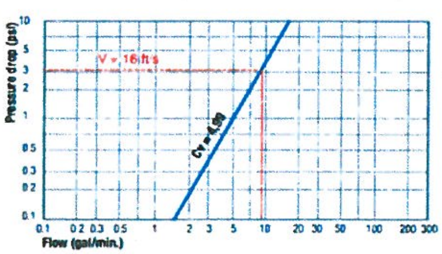
	Q_{purge} m^3/sec	2.36E-04	3.54E-04	4.72E-04	5.90E-04	7.08E-04	7.55E-04	8.50E-04	9.44E-04
	Q_{purge} cfm	0.5	0.75	1	1.25	1.5	1.6	1.8	2
Q_{src} m^3/sec	Q_{src} liters/day								
4.63E-06	400	59.97	84.98	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!
5.79E-06	500	40.90	51.29	72.53	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!
6.94E-06	600	29.92	35.59	44.65	63.22	#NUM!	#NUM!	#NUM!	#NUM!
7.52E-06	650	25.91	30.32	36.92	48.54	81.35	#NUM!	#NUM!	#NUM!
8.10E-06	700	22.59	26.09	31.10	39.13	55.65	70.60	#NUM!	#NUM!
8.68E-06	750	20.11	22.95	26.88	32.79	43.20	50.45	93.51	#NUM!
9.26E-06	800	17.70	20.04	23.17	27.66	34.89	39.32	55.48	#NUM!
1.04E-05	900	13.80	15.42	17.50	20.30	24.34	26.53	32.72	44.50
1.16E-05	1000	11.02	12.18	13.63	15.50	18.04	19.33	22.65	27.65

Note:
Calculation that shows "NUM!" mean the hydrogen concentration in the cask would always be less than 1% at these conditions

Appendix D: Stäubli® SCB 20 Automatic Clean-Break Quick-Release Coupling

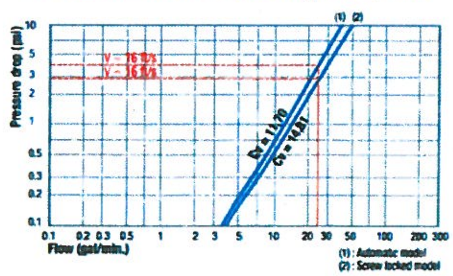
SCB 12

Nominal bore (inch)	1/2	
Cross section (sq. inch)	0.175	
Model	Auto.	Screw lock
Max. working pressure at 68°F (psi)	1160	2320
Max. connection pressure (psi)	29	72
Vacuum retention in connected and disconnected positions (SCCM)	0.06	0.06
Loss of fluid at disconnection (c.inch)	0.0012	0.0122



SCB 20

Nominal bore (inch)	13/16	
Cross section (sq. inch)	0.487	
Model	Auto.	Screw lock
Max. working pressure at 68°F (psi)	1450	2320
Max. connection pressure (psi)	14.5	72
Vacuum retention in connected and disconnected positions (SCCM)	-	0.06
Loss of fluid at disconnection (c.inch)	0.0030	0.0140



CONSTRUCTION

- Sockets and plugs: all stainless-steel 18/12 (AISI 316 L)
- Seals:
  - Nitrile (Standard)
  - Fluorocarbon (FPM): code **JV**
  - Ethylene-propylene (EPDM): code **JE**
  - Perfluoroelastomer (FFKM): code **JK**
- Springs: X 10 Cr Ni 18 8 stainless-steel
- Color sleeve to identify circuits: light-weight anodised alloy
- Protective dust cap for socket and plug: Chloroprene (Cr) or POM.H

For the screw-type model (VR)
- locking-sleeve is in cuproaluminium.

STÄUBLI 5

Braden, Janis K

From: Johnson, Michael E
Sent: Thursday, December 10, 2015 10:56 AM
To: Braden, Janis K
Subject: FW: Request to Publicly Release Fauske and Associated LLC figures in CHPRC document

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From: Burelbach, James P [mailto:Burelbach@Fauske.com]
Sent: Tuesday, October 28, 2014 10:39 AM
To: Johnson, Michael E
Cc: Fauske, H. Kristian (Kris); Fauske, AnnMarie; Plys, Martin G
Subject: RE: Request to Publicly Release Fauske and Associated LLC figures in CHPRC document

Mike,
yes you are permitted to release the figures as you described, provided that FAI is credited as the source of the figures.
regards,
Jim

James P. Burelbach, PhD
Manager, Waste Technology & Post-Fukushima Services

FAUSKE & ASSOCIATES, LLC
WORLD LEADER IN NUCLEAR AND CHEMICAL PROCESS SAFETY

Tel: +1 630 887 5221 16W070 83rd Street
Mob: +1 630 470 8884 Burr Ridge, IL 60527, USA
Fax: +1 630 986 5481 Main: +1 877 FAUSKE1
burelbach@fauske.com www.fauske.com

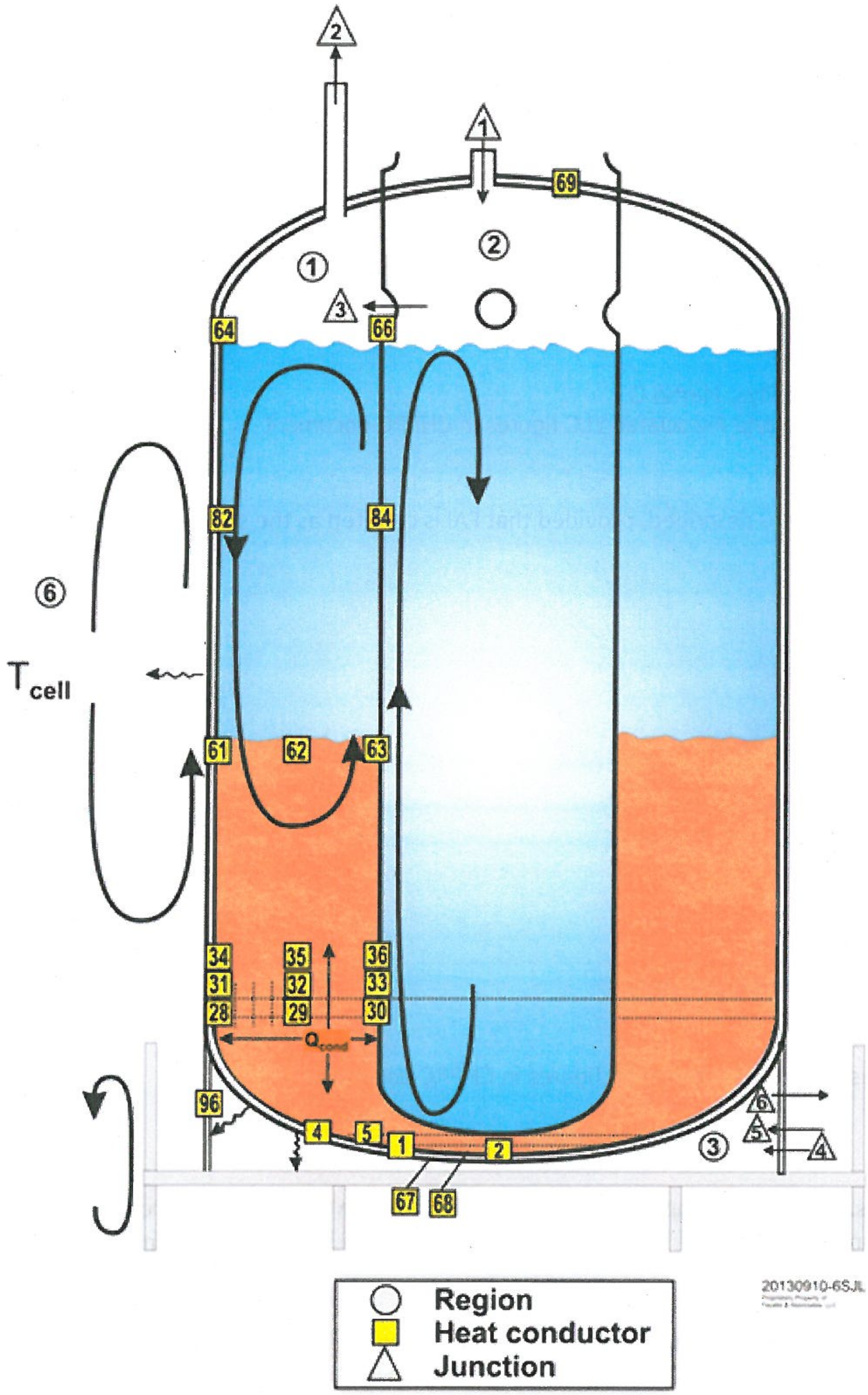
From: Johnson, Michael E [mailto:Michael_E_Johnson@rl.gov]
Sent: Tuesday, October 28, 2014 9:23 AM
To: Burelbach, James P
Subject: Request to Publicly Release Fauske and Associated LLC figures in CHPRC document

Jim,

I am requesting Fauske and Associates, LLC (FAI) approval to publicly release the following figures in a CH2M HILL Plateau Remediation Company (CHPRC) document discussing the T Plant thermal and gas analyses prepared by FAI under contract with CHPRC.

These figures depict the FAI model for the Sludge Transport and Storage Container and are labelled as "Proprietary Property of Fauske and Associates, LLC".

Michael E. Johnson
Senior Technical Advisor
CH2M HILL Plateau Remediation Company
Cell 509-430-3291
Office 509-372-3628



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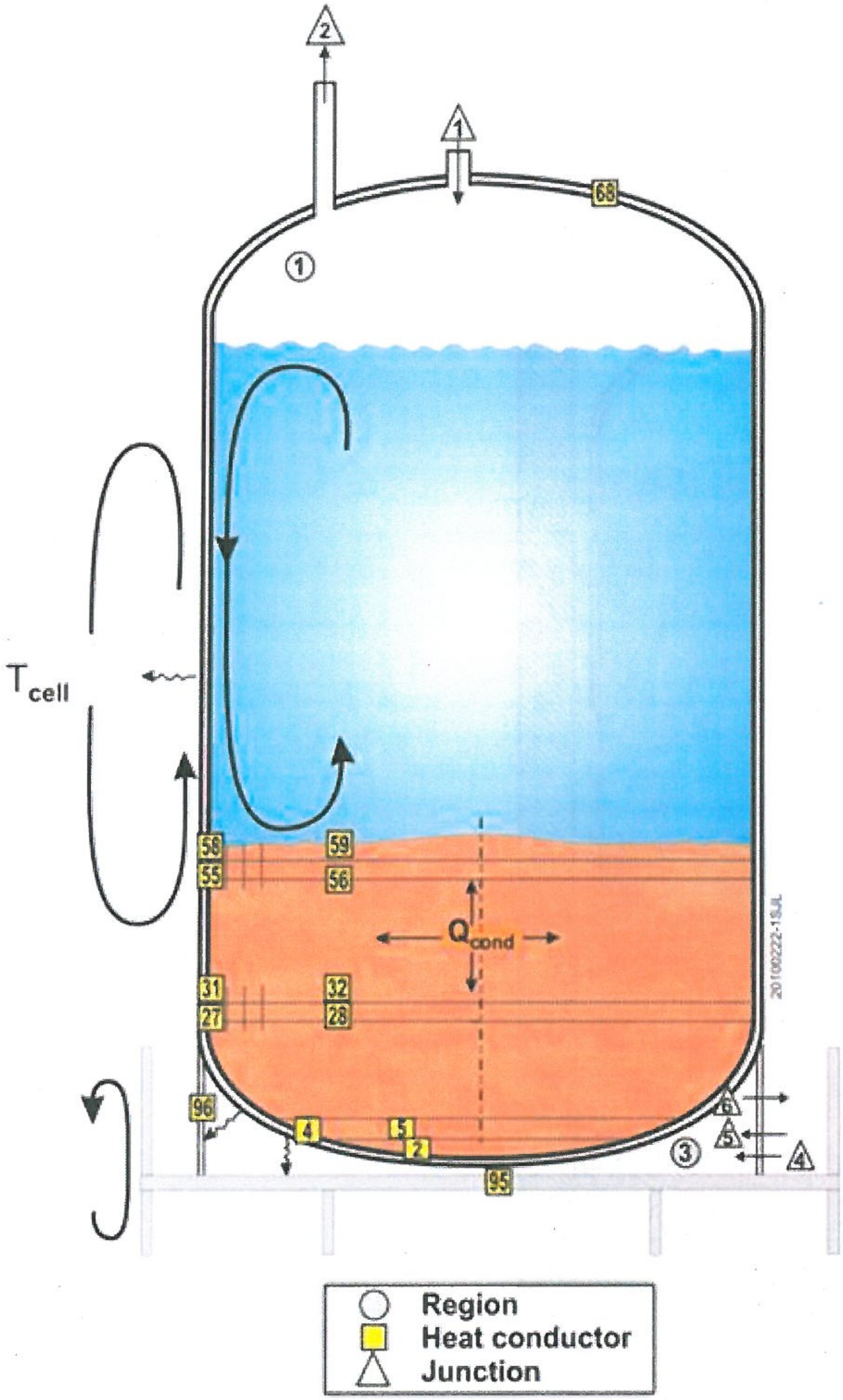
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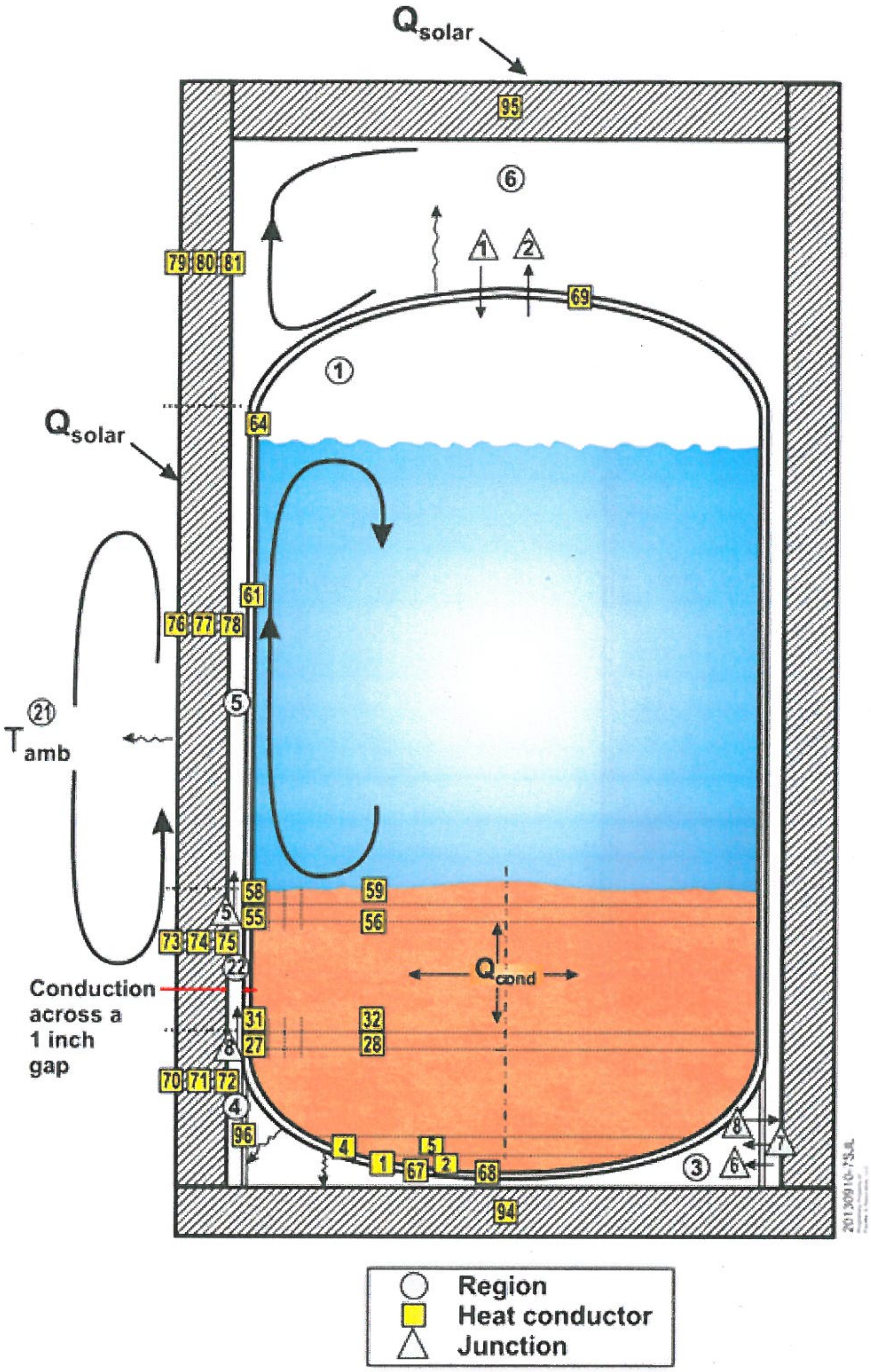
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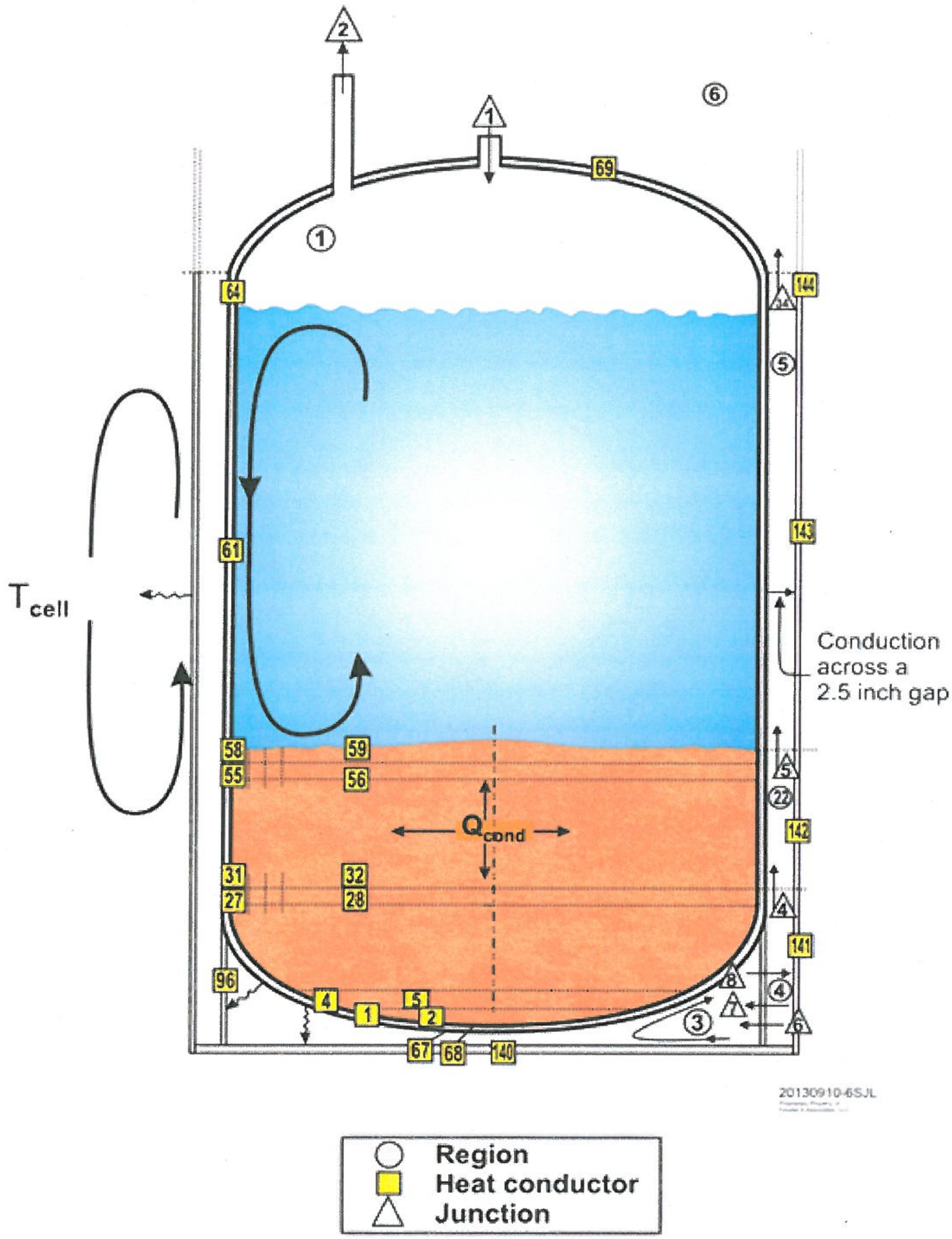
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Conduction
across a
2.5 inch gap
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20130910-6SJL
Region
Heat conductor
Junction