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Consequences of Select Boiling Waste Scenarios for Waste Feed Delivery

B. Malinovic and M. G. Plys, Fauske & Associates, Inc. for
CH2M HILL Hanford Group, Inc.
Richland, WA 99352
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The purpose of the calculation documented here is to quantify thermal phenomena and predict consequences for select double-shell tank heat-up scenarios for waste feed delivery safety applications.

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

CH2MHILL
Hanford Group, Inc.

Richland, Washington

Contractor for the U.S. Department of Energy
Office of River Protection under Contract DE-AC27-99RL14047

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Prepared By
B. Malinovic
M. G. Plys
Fauske & Associates, Inc.
for CH2M HILL Hanford Group, Inc.

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CH2MHILL
Hanford Group, Inc.

P. O. Box 1500
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Consequences of Select Boiling Waste Scenarios for Waste Feed Delivery

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1. B. Malinovic and M.G. Plys, "Consequences of Select Boiling Waste Scenarios for Waste Feed Delivery," FAI/01-42, Rev. 1, October 2001.

2. Letter, B. Malinovic (FAI) to J. Davis (CH2M HILL) and J. Williams (Fluor Federal Services), "DST Boiling Source Term with HADCRT 1.4," BOMALIN031303, March 13, 2003.

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CONSEQUENCES OF SELECT BOILING WASTE SCENARIOS FOR WASTE FEED DELIVERY

Submitted To:

CH2M Hill Hanford Group, Inc.
P.O. Box 1500
MSIN R1-49
Richland, WA 99352-1500

Prepared By:

Boro Malinovic and Martin G. Plys
Fauske & Associates, Inc.
16W070 West 83rd Street
Burr Ridge, Illinois 60527
TEL: (630) 323-8750
FAX: (630) 986-5481

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1.0 PURPOSE

The purpose of this calculation is to quantify thermal phenomena and predict consequences for select double-shell tank (DST) heat-up scenarios for waste feed delivery safety applications. This work extends previous tank bump analyses [Epstein, et al., 2000; and Epstein, et al., 2000a] by focusing on selected scenarios in which extended loss of cooling leads to waste boiling and aerosol generation. The HADCRT code, Version 1.3, is used to provide a best-estimate, coupled simulation of both thermal-hydraulic and aerosol transport phenomena. The physical model employed considers boiling aerosol generation, aerosol agglomeration and gravitational sedimentation in the tank headspace, aerosol removal from steam condensation, and aerosol transport from the headspace to the environment and through ventilation flow paths. Thus, the net result of the calculation is the time history of aerosol release to the immediate vicinity of an underground DST.

2.0 ASSUMPTIONS AND TECHNICAL BASES

2.1 HADCRT 1.3 Computer Program

The computation tool for DST source term analysis is the HADCRT Code, Version 1.3. HADCRT 1.3 was developed and validated under the FAI Quality Assurance Program. The HADCRT technical basis and its validation are discussed in the User's Manual [Plys, et al., 2001].

HADCRT is a multi-compartment thermofluid facility model that also considers aerosol formation and entrainment. Individually modeled compartments (regions) in a facility are connected via an arbitrary network of flow paths (junctions) and joined by (or contain) a list of heat conductors. A region contains gas, aerosol and liquid phases, with the gas space either well-mixed or stratified, depending on the application. Here we consider only well-mixed gas spaces in all regions, although the code is capable of dealing with stratified layers, as would be expected in, say, a fire hazards analysis. Gases and aerosols are exchanged through junctions between regions via uni-directional, pressure-driven flows and density-driven, counter-current flows. An operations model allows the user to specify liquid transfers between regions and control operation based on levels or time. Aerosols are released by various entrainment mechanisms or formed from vapor as a fog, agglomerate while suspended, and are deposited by gravity, condensation, or impaction.

2.2 HADCRT DST Model

In HADCRT calculations, the key assumptions are embedded in the inputs for the compartments or regions used for the DST (the nodalization, in other words), heat sinks that represent the waste, soil and DST structures, and junctions for inlet/out flow paths, as well as the ventilation system. Key features of the inputs are mentioned here, with input listings relegated to subsequent sections.

For DST thermal and source term analysis, the nodalization considers four major gas volumes: the primary DST volume (headspace and convective waste), the annulus, the condenser, and the environment. The environment is just a region so large that its pressure and temperature remain constant. Headspace and annulus regions are modeled in detail, as discussed in Section 4.0. The condenser is simply modeled as a relatively small volume connected to the headspace, with a very large heat sink surface area and pool of cold water. The large heat sink condenses water vapor entering from the headspace and adds it to the condensate pool. If the primary ventilation system is operating, the liquid transfer model maintains level in the DST by reflux from the condenser region to the DST whenever the convective layer level declines slightly. If primary ventilation is not operating in a scenario, there is no recirculation to the DST and the liquid transfer model dumps excess condensate into the environment.

There are five junctions in the model: (1) a filtered inlet from the environment to the headspace, (2) an outlet from the headspace to the condenser, (3) an inlet to the annulus, (4) an outlet for the annulus, and (5) a flow path from the condenser to the environment. Regions and connecting junctions are shown in Figure 2-1. Because none of the scenarios consider annulus ventilation, junctions to and from the annulus include a filter resistance and are just leakage flow areas to prevent unrealistic pressurization. Pressure drops include filter resistances but the decontamination factor is 1.0, in keeping with scenario definitions. A detailed model of the primary ventilation system was not required because pressure drops in the main condenser, HEME and HEPA/HEGA were accounted for in the flow path from the condenser to the environment. This junction also has a constant flow rate fan that pulls headspace gas through the condenser and exhausts to the environment. In the loss of ventilation scenarios, this flow rate is set to zero.

Heat sinks represent the non-convective layer, which can be modeled as a slab with volumetric heat generation, steel liners, concrete structures, and surrounding soil. Figure 2-2 shows all but one of the heat sinks. The heat sinks are the same regardless of the scenario, but in cases where the mixer pumps are operating, the non-convective layer is made arbitrarily thin (1 cm). An additional heat sink resides in the condenser and removes steam from the incoming stream, but is not pictured in Figure 2-2. Figure 2-2 shows the primary steel liner is divided into six vertical sections, in order to correctly model heat transfer from the liquid waste and

Figure 2-1: Regions and Junctions for DST Thermal and Source Term Analysis.

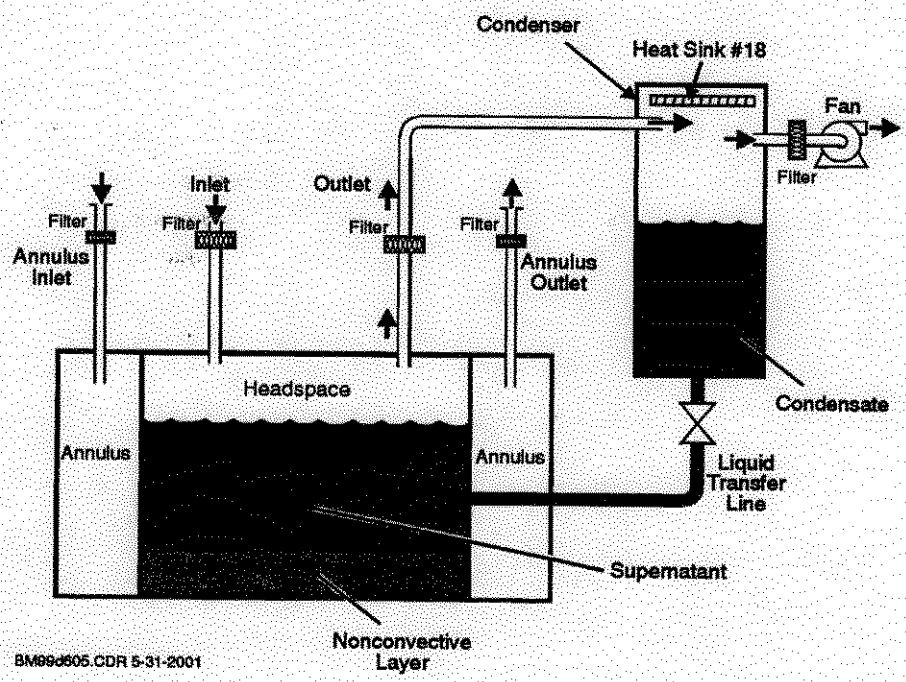
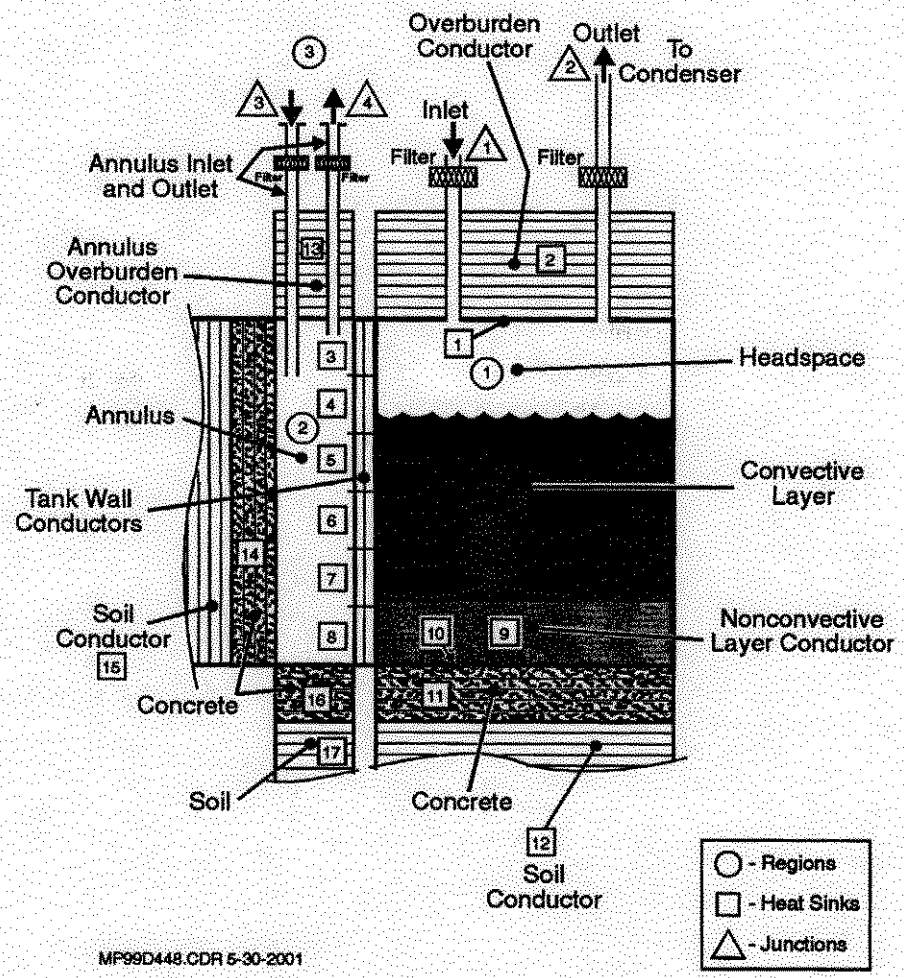


Figure 2-2: Heat Sinks for DST Thermal and Source Term Analysis.



headspace gas as a function of waste level. There are several composite layers, or sandwiches, formed by combining the individual heat sinks: (1) the dome and the overlying soil, (2) the bottom liner, bottom concrete, and underlying soil, (3) the annulus liner, annulus concrete wall, and adjacent soil, and (4) the concrete annulus floor and underlying soil. Thermal contact between layers is assumed to be very good.

Each of these heat sink surfaces can experience condensation, although the effect is most important for the headspace dome. Gravitational settling is considered only in the DST, and the only sedimentation area considered is the waste surface area itself. Aerosol settling in the ventilation flow paths is neglected for simplicity and conservatism as part of the scenario definition.

2.3 Assumptions for Scenarios Analyzed

- DST AZ-101 is analyzed for scenarios of interest, but DST AZ-102 is considered for code comparison and validation. As part of the code validation and model verification presented in Section 7, HADCRT results are compared to GOTH_SNF results for a DST AZ-102 mixing transient.
- Inputs for waste properties are from [Crea, et al., 2000]. This is for two reasons: the document is a recent compilation of many inputs needed for thermal analysis, and this allows a direct comparison of HADCRT results with GOTH_SNF results.
- Two mixer pumps operate at full speed and dissipate 440,000 W into the waste, which is equivalent to 600 horsepower.
- If the ventilation system is operating, the condenser heat sink and water temperature is maintained at 10°C (50°F) and the recirculation mode keeps DST supernatant level constant. In the recirculation mode, vapors from the waste are condensed and refluxed back to the DST to maintain level.
- If a scenario states that the ventilation system is not operating, the ventilation and reflux flow rates are set to zero.
- With one exception, ambient conditions are constant at 28°C (82°F) and 101,350 Pa. In a validation/verification exercise shown in Section 7, HADCRT results are compared against the thermocouple data from an actual DST transient where primary ventilation flow rate was degraded for about nearly two and a half

months. For the comparison against actual DST conditions, site weather data is used to determine the ambient conditions.

- Scenario definitions are per the communications listed in Section 9.
- For the safe storage scenario, total DST AZ-101 heat load is 71 kW, with 41 kW in the non-convective layer and 30 kW in the convective layer. Two heat load distributions are noted in the communications of Section 9, but the higher total is selected for source term analysis. The validation/verification exercise presented in Section 7, uses the best-estimate heat load of 61 kW.

3.0 METHODOLOGY

Two sets of analyses were developed: 1) an analysis of DST heat-up starting from safe storage conditions and excluding mixer pump operation, and (2) an analysis of heat-up with mixer pumps in operation. A first step in the analysis was to create initial conditions and obtain the correct temperature steady-state profile in surrounding tank structures and soil prior to the start of a transient. Such initial runs were necessary for both safe storage and mixer pump operation scenarios.

For the current safe storage conditions, an initial run lasting 115 days was made with the ventilation flow rate set to 1,000 cfm and condensate recirculation set to maintain the initial waste level. Initial temperature profiles were reasonable guesses, with the intent that the correct temperature profiles would evolve over time and emerge as the steady-state. Code results show that waste temperatures are steady after 115 days and equal to 49°C for the convective layer and 71°C (peak) for the non-convective layer. This is very close to the actual safe storage conditions of 48°C for the convective layer and 72°C for the non-convective layer peak [Epstein, et al., 2000]. Considering the uncertainty in the actual primary ventilation flow rate over such a period, this result is acceptable. Model and input verification are addressed in further detail in Section 7.

The next run was a "restart" from the initial run, but with ventilation and condensate recirculation flow rates set to zero. The restart occurred at 115 days, and went out to 550 days from time zero. The goals of this run were to compute the waste heatup rate for a loss of primary ventilation scenario and the subsequent boiling source term.

An initial run was also needed for the mixer pump scenarios. In the initial run, the temperature starts at a mixing temperature for the waste (the temperature obtained by instantly stirring the non-convective layer with the supernatant). This assumes that mixer pump operation is immediately effective in mobilizing the waste, which is a reasonable assumption for two 300 hp motors operating at full speed. An exact value for the mixing temperature is not important because it is merely an initial condition, so the value obtained by Crea, et al., [2000] for AZ-102 is used here. (Section 7 shows a verification/validation of the model by comparing

the results for Crea, et al., [2000] against HADCRT results for mixer pump operation in DST-AZ-102.) Primary ventilation system flow rate was set to 500 cfm. This value was chosen because it leads to conditions that exceed the AB temperature limits in the waste. The run lasted 115 days and attained a steady-state temperature of 95°C after 70 days or so. Waste temperature exceeded the AB limit after 18 days of mixer pump operation. This run establishes that a primary ventilation flow rate of 500 cfm would not prevent the waste from exceeding the AB temperature limit, but would prevent boiling.

In the loss of ventilation scenario run, restart occurred just before exceeding temperature limits at 18 days. The run proceeded for another 92 days. Heat up rate and boiling aerosol generation are reported.

In the recovery scenario, restart occurred at 26.6 days into the overall timeline. That is, the mixer pumps operate for 8.6 days without the ventilation system. This models a scenario where the ventilation system is recovered after boiling starts, with the intent to see how recovery effects source term.

4.0 INPUT DATA

Detailed discussion of code input variables is left to the User's Manual, but general input data for the calculations are discussed here and presented as tables. Complete input files are listed in Section 8. The intent is to convey major input values that affect tank heatup, aerosol generation, aerosol attenuation, and aerosol release to the site, and which differentiate between scenarios.

Waste properties and inventory are adapted from Crea, et al., [2000] and shown in Table 4-1. The main analyses use DST AZ-101 waste properties as a basis, but a run made with DST AZ-102 was made for the sake of verification/validation and comparison (see Section 7). The parameters shown in the table are for the safe storage conditions, but the inventories serve as the starting point for inputs to cases with mixer pump operation. In other words, the HADCRT input conserves the supernatant and particle masses indicated in Table 4-1.

Table 4-1:

General Inputs for Thermal Analysis of DST AZ-102 for Safe Storage Conditions. Adapted from [Crea, et al., 2000].

Waste Property	Tank 241-AZ-101 Parameter Value	Tank 241-AZ-102 Parameter Value
Liquid Volume	114,400 ft^3 (3,240,000 L)	124,700 ft^3 (3,531,000 L)
Solids Volume	1,448 ft^3 (41,000 L)	2,200 ft^3 (62,300 L)
Total Waste Volume	116,231 ft^3 (3,281,000 L)	126,900 ft^3
Liquid Density	73.66 lbm/ft^3 (1.18 gm/cm^3)	68.64 lbm/ft^3 (1.1 gm/cm^3)
Solids Density	199.8 lbm/ft^3 (3.2 gm/cm^3)	237.1 lbm/ft^3 (3.8 gm/cm^3)
Liquid Heat Capacity	0.7643 Btu/lbm-°R (3.2 kJ/kg°C)	1.0 Btu/lbm-°R
Solids Heat Capacity	0.2627 Btu/lbm-°R (1.1 kJ/kg°C)	0.2 Btu/lbm-°R
Liquid Specific Heat Generation Rate	0.01408 Btu/lbm-h (0.0091 watts/kg)	0.009 Btu/lbm-h (0.0058 watts/kg)

Table 4-1:

General Inputs for Thermal Analysis of DST AZ-102 for Safe Storage Conditions. Adapted from [Crea, et al., 2000].

Waste Property	Tank 241-AZ-101 Parameter Value	Tank 241-AZ-102 Parameter Value
Solids Specific Heat Generation Rate	0.5262 Btu/lbm-h (0.34 watts/kg)	0.2544 Btu/lbm-h (0.1644 watts/kg)
Thermal Conductivity of Aqueous Solution	0.35 Btu/h-ft-°R	0.35 Btu/h-ft-°R
Thermal Conductivity of Solids	5.0 Btu/h-ft-°R	5.0 Btu/h-ft-°R
Sludge	47,000 gal (6,283 ft^3)	95,000 gal (127,000 ft^3)
Supernatant Liquid	812,000 gal (108,500 ft^3)	854,000 gal (114,200 ft^3)
Sludge Depth	17 in. 16 to 17.75 in.	34.5 in.
Weight Fraction of Solids	0.45	0.42
Volume Fraction of Solids	0.23	0.17

For the initial AZ-101 run, HADCRT region inputs are listed in Table 4-2. "Volume" includes both liquid and gas (free) volumes, with gas volume continually updated as a function of liquid level. Region floor area is used to compute liquid level and is just volume divided by the ceiling height, which is 411 m^2 in the primary DST region, as is the sedimentation area. The bottom of the DST is arbitrarily selected to be zero as an elevation reference. The bottom of the primary DST volume is then the top of the non-convective layer, which is 43 cm thick. Initial waste temperatures are estimates of the current safe storage conditions.

Condenser values are contrived and unimportant so long as the heat sinks in the region condense steam and there is a pool available to replenish liquid lost by evaporation. A liquid transfer model takes water from this pool and dumps it back to the DST to maintain level, while condensate from heat sinks simply falls back into the water pool. Condenser free volume is 10 m^3 and the pool volume is 990 m^3, which is large enough to maintain temperature despite inflows and outflows. The condenser bottom is placed at the 16 m elevation, which means that its bottom is 1.0 meter above the environment flow, and the top is at the 1,016 m elevation. A large, thin heat sink with artificially high thermal conductivity is placed at the 1,015 m elevation

Table 4-2: HADCRT Region Inputs.				
Inputs	**Primary DST Volume**	**Annulus**	**Ambient**	**Condenser**
Region Number	1	2	3	4
Volume, (m^3)	5,338	623.78	1.00E+10	1,000
Sedimentation Area, (m^2)	411	0	0	0
Elevation, (m)	0.429	0	15	16
Gas Temperature, (°C)	45	28	28	10
Pressure, (Pa)	101,350	101,350	101,350	101,350
Height, (m)	12.99	11	1.00E+06	1,000
Liquid Level, (m)	7.47	0.01	0	990
Liquid Temperature, (°C)	49	28	28	10

to ensure that large heat transfer and condensation rates remove nearly all water vapor from the incoming stream.

Heat sinks are listed in Table 4-3. There are eighteen heat sinks in all and nodalization is shown in Figure 2-2. There are several composite heat sinks; these are heat sinks made up of layers of individual heat sinks. Heat sinks 9, 10, 11, and 12 are the non-convective layer, liner, concrete, and soil, respectively, and are conjoined to form a composite heat sink. Other composite heat sinks, or "sandwiches" are comprised of: (1) the dome liner and overlying soil, (2) the annulus concrete wall and soil, and (3) the annulus floor and underlying soil. Thermal resistance between layers is assumed to be nil, which is reasonable because there are no air gaps. The non-convective layer is always modeled as a heat sink here, because heat sinks may have a volumetric heat generation rate and allow for a temperature profile calculation based on boundary conditions of convection to the overlying pool and conduction to the liner with no resistance. Naturally, in the safe storage scenario, heat sink 9 reflects the thickness and thermal properties of the non-convective layer and the region 1 pool reflects the supernatant properties. In mixer pump scenarios, heat sink 9 is made arbitrarily small (1 cm) with no heat generation, while the pool has the properties of the mixed waste.

Table 4-3 contains a few entries that require explanation. Heat sinks are either planar or cylindrical, with the inner radius set to zero if the heat sink is planar. Heat sinks require boundary conditions, which, in the code, can consist of the following: (1) exposure to a gas or liquid region, (2) fixed temperature, (3) adiabatic, or (4) a variety of user-prescribed time-dependent conditions. The table shows a selection of boundary conditions for each side of the heat sink; because these boundary conditions are mutually exclusive some of the entries are left blank as non-applicable. Heat transfer correlations require a length, and these are shown by the row heading labeled "Natural Convection Length, m". For the dome and overlying soil, the natural convection length is the DST diameter of 22.88 m (75 ft). The row heading "Conduction Length" is used for models to approximate multi-dimensional heat transfer where heat sinks are in contact. Since the DST AZ-101 non-convective layer is very thin relative to its length, two-dimensional conduction networks are not used and these entries are just place keepers. The table also shows that the number of calculation nodes is small (3, the minimum necessary for a finite-difference solution) where temperature gradients are not large, and large (20) where important temperature gradients are expected.

For the condenser heat sink, the entry "ideal" denotes that this material has a thermal conductivity of 1,000 W/m/K, which is an artificial value, so as to rapidly condense steam. This heat sink is one meter high and resides between the 1,015 and 1,016 m elevations. The thermal conductivity is set to an artificially high value so that the surface temperature on the outer surface (facing the gas in Region 4) will always be close to the surface temperature at the inner face, which is fixed at 10°C. An artificially high natural convection length is also used to augment heat transfer rates. The combination of large surface, fixed temperature, and good conductivity mimic condenser functions, maintain gas region temperature, and remove incoming water vapor.

Junctions are listed in Table 4-4. The annulus openings are simply to prevent unrealistic pressurization and do not reflect any real dimensions; they can be considered effective leakage areas. The counter-current flow model is not used in any scenarios because it is conservative to prevent in-leakage of air during loss of ventilation scenarios. Filters inhibit counter-current flow, as well. No values relevant to counter-current flow (junction width, height, and length) are listed in Table 4-3 and the actual inputs shown in Section 8 are place keepers. For headspace junctions

Table 4-3: HADCRT Heat Conductor Inputs.					
Heat Sink Number	1	2	3	4	5
	DST Ceiling	Overlying Soil	Primary Wall first	Primary Wall second	Primary Wall third
Geometry	Planar	Planar	Cylinder	Cylinder	Cylinder
Material	Stainless	Soil	Stainless	Stainless	Stainless
Inside Radius, (m)	0	0	11.438	11.438	11.438
Outer Radius, (m)	0.01	4	11.448	11.448	11.448
One Side HS Area, (m^2)	411	411	358	143.891	143.891
Initial Inside Surface Temperature, (°C)	45	20	49	49	49
Initial Outside Surface Temperature, (°C)	45	45	49	49	49
Calculation Nodes	3	20	3	3	3
Inside Region Number	-	3	1	1	1
Inside, Fixed Temperature, (°C)	-	-	-	-	-
Outer Region Number	1	-	2	2	2
Outer Side, Fixed Temperature, (°C)	-	-	-	-	-
Natural Convection Length, (m)	22.88	22.88	5	2	2
Conduction Length, (m)	0	0	2.5	1	1
Bottom Elevation, (m)	12.99	13	8.75	7	5
Top Elevation, (m)	13	15.1433	12.98	8.75	7

Table 4-3: HADCRT Heat Conductor Inputs (continued).					
Heat Sink Number	6	7	8	9	10
	Primary Wall fourth	Primary Wall fifth	Primary Wall sixth	NCL	Tank Floor Liner
Geometry	Cylinder	Cylinder	Cylinder	Planar	Planar
Material	Stainless	Stainless	Stainless	NCL	Stainless
Inside Radius, (m)	11.44	11.44	11.44	0.00	0.00
Outer Radius, (m)	11.45	11.45	11.45	0.43	0.01
One Side HS Area, (m^2)	143.89	143.89	71.95	411.00	411.00
Initial Inside Surface Temperature, (°C)	54	54	54	64	54
Initial Outside Surface Temperature, (°C)	54	54	54	64	54
Calculation Nodes	3	3	3	20	3
Inside Region Number	1	1	1	-	-
Inside, Fixed Temperature, (°C)	-	-	-	-	-
Outer Region Number	2	2	2	1	-
Outer Side, Fixed Temperature, (°C)	-	-	-	-	-

Table 4-3: HADCRT Heat Conductor Inputs (continued).					
Heat Sink Number	6	7	8	9	10
	Primary Wall	Primary Wall	Primary Wall	NCL	Tank Floor
	fourth	fifth	sixth		Liner
Natural Convection Length, (m)	2.00	2.00	1.00	22.88	22.88
Conduction Length, (m)	1.00	1.00	0.03	11.00	0.00
Bottom Elevation, (m)	3.00	1.00	0.00	0.00	-0.01
Top Elevation, (m)	5.00	3.00	1.00	0.43	0.00

Table 4-3: HADCRT Heat Conductor Inputs (continued).					
Heat Sink Number	11	12	13	14	15
	Tank Floor	Soil	Soil	Soil	Annulus
	Concrete	Tank Bottom	Annulus Top	Annulus Wall	Concrete
Geometry	Planar	Planar	Planar	Cylinder	Cylinder
Material	Concrete	Soil	Soil	Soil	Concrete
Inside Radius, (m)	0.00	0.00	0.00	12.71	12.23
Outer Radius, (m)	0.46	30.00	4.00	112.71	12.71
One Side HS Area, (m^2)	411.00	411.00	411.00	1223.82	861.59
Initial Inside Surface Temperature, (°C)	49	12	20	49	49
Initial Outside Surface Temperature, (°C)	49	49	49	25	45
Calculation Nodes	20	20	20	20	20
Inside Region Number	-	-	3	-	2
Inside, Fixed Temperature, (°C)	-	12	-	-	-
Outer Region Number	-	-	2	-	-
Outer Side, Fixed Temperature, (°C)	-	-	-	20	
Natural Convection Length, (m)	0.00	0.00	0.76	0.00	11.00
Conduction Length, (m)	0.00	0.00	4.00	0.00	0.00
Bottom Elevation, (m)	-0.48	-10.48	10.99	0.00	0.00
Top Elevation, (m)	-0.01	-0.48	15.00	11.00	11.00

Table 4-3: HADCRT Heat Conductor Inputs (concluded).			
Heat Sink Number	16	17	18
	Annulus Bottom Concrete	Annulus Bottom Soil	Condenser
Geometry	Planar	Planar	Planar
Material	Concrete	Soil	Ideal
Inside Radius, (m)	0.00	0.00	0.00

Table 4-3: HADCRT Heat Conductor Inputs (concluded).			
Heat Sink Number	16	17	18
	Annulus Bottom Concrete	Annulus Bottom Soil	Condenser
Outer Radius, (m)	0.46	10.00	0.01
One Side HS Area, (m^2)	56.71	56.71	1000.00
Initial Inside Surface Temperature, (°C)	25	20	10
Initial Outside Surface Temperature, (°C)	45	45	10
Calculation Nodes	20	20	3
Inside Region Number	-	-	-
Inside, Fixed Temperature, (°C)	-	20	10
Outer Region Number	2	-	4
Outer Side, Fixed Temperature, (°C)	-	-	10
Natural Convection Length, (m)	0.76	0.00	1000.00
Conduction Length, (m)	0.00	0.00	0.00
Bottom Elevation, (m)	-0.46	-10.48	1015.00
Top Elevation, (m)	0.00	-0.48	1016.00

Table 4-4: HADCRT Junction Inputs.					
	Primary Inlet	**Primary Outlet**	**Annulus Inlet**	**Annulus Outlet**	**Condenser Outlet**
Number	1	2	3	4	5
Type	Normally Open	Normally Open	Normally Open	Normally Open	Normally Open
Upstream Region	Ambient	Headspace	Ambient	Annulus	Condenser
Downstream Region	Headspace	Condenser	Annulus	Ambient	Ambient
Area, (m^2)	0.03	0.03	0.07	0.07	0.03
Elevation w.r.t. to Upstream Region Floor, (m)	1	12	1	12	10
Elevation w.r.t. to Downstream Region Floor, (m)	12	1	12	1	10
Loss Coefficient	5	5	2	2	5
Filter Resistance, (Pa/(m^3/s))	1,000	10,000	1,000	1,000	15,000
Fan Type	N/A	N/A	N/A	N/A	Constant Q
Volumetric Flow Rate (m^3/s)	N/A	N/A	N/A	N/A	0.46

(1, 2, and 5), flow areas are based on the communications in Section 9, which indicate that the outlet to the condenser from the headspace is 8" OD. The inlet and the line from the condenser to the ambient are assumed to be the same diameter. Except for the annulus inlet and outlet, loss coefficients are estimates based on 100 length-to-diameter ratios.

Filter resistances were estimated as follows: the values for the primary inlet, annulus inlet, and annulus outlet are just nominal HEPA filter values taken from [FAI, 1994], while filter resistances for the primary outlet and condenser outlet reflect device pressure drops at the rated flow of 1,000 cfm. Pressure drops through other devices are described in the communications of Section 9. The pressure drop through the condenser is 18" w.g. (4,500 Pa) at 1,000 cfm (0.46 m^3/s), which results in a filter resistance of 10,000 $Pa/(m^3/s)$ after rounding up. Components downstream of the condenser have pressure drops as follows for the nominal 1,000 cfm flow: 11" w.g. for the common condenser (which is distinct from the DST condenser modeled by region no. 4), 11" for the HEME, and 5" w.g. for the HEPA/HEGA. This is a total of 27" w.g., so an effective filter resistance is 15,000 $Pa/(m^3/s)$. An assumption is that the linear relationship between resistance and pressure drop in a filter holds at all flow rates. There is some operating experience to support this assumption: the HEPA/HEGA filters have a pressure drop of 5" w.g. at 1,000 cfm for dirty filters, and a pressure drop of 1.5" w.g. at 400 cfm for clean filters. Moreover, the primary ventilation flow rates we are interested in are either reasonably close to the nominal value, or are very close to zero, at which point the exact values for pressure drop are not important.

Waste properties were specified in accord with Table 4-1, with a few exceptions noted below. Waste properties for the safe storage scenario are discussed first. In scenarios with operating mixer pumps, the NCL is arbitrarily small (1 cm) and has no volumetric heat generation, which makes its properties unimportant. This arrangement is most convenient for preparing input because with only slight modification, the safe storage nodalization shown in Figure 2-2 can also be used for the mixer pumps scenarios. The convective layer then reflects the homogenized properties of all the waste (solid + liquid) in the DST. Mixer pump heat load is treated as an external, uniformly distributed heat source rather than as a waste property.

The DST AZ-101 non-convective layer thickness is 43 cm (17 inches for "Sludge"). Because the NCL is treated as a heat sink, relevant properties are density, specific heat capacity, thermal conductivity, and volumetric heat generation. NCL density is readily calculated as a volume average, knowing the solids volume fraction (23%), the solids density (3.2 gm/cc), and the interstitial liquid density (1.18 gm/cc); NCL density is 1640 kg/m^3 (0.23 × 3.2 + 0.77 × 1.18 gm/cc). NCL specific heat capacity is a mass fraction average: 0.45 × 3,200 + 0.55 × 1,100 = 2,255 J/kg-C. Thermal conductivity is a volume average: 0.23 × 5 + 0.77 × 0.35 = 0.9 W/m-C, after unit conversion. The specific heat generation rates in Table 4-1 are not used to compute volumetric heat generation. Instead, the total heat load in the NCL is divided by the NCL volume, and is equal to 231 W/m^3 (41,000 W / (0.43 × 411 m^3)).

Convective layer depth is based on 812,000 gallons of supernatant and the 411 m^2 floor area, and is 7.47 m. Assuming the supernatant consists of water and dissolved solids, the solids fraction in the supernatant can be determined knowing the liquid density (1.18 g/cc), the solids density (3.2 g/cc), and the density of water. By volume, the supernatant is 8.18% solids. Solid mass fraction, x, is given by the formula:

$$1 = x\frac{\bar{\rho}}{\rho_s} + (1-x)\frac{\bar{\rho}}{\rho_\ell} \qquad (4\text{-}1)$$

Substituting in the values above gives x = 0.21. Solids decay heat (W/kg) is then 31,000 W / (0.21 × 7.47 × 411 × 1,180 kg), or 0.0407 W/kg. Convective layer density is then 0.0818 × 3,200 + (1 - 0.0818) × 1,000 = 1,180 kg/m^3. The code will calculate a liquid specific heat capacity based on mass fraction, which is written 0.21 × 1,000 + 0.79 × 4,200 = 3,528 J/kg-C. This is in slight disagreement with the value listed in Table 4-1 (3,200 J/kg-C) because the HADCRT code treats the liquid as two separate species and uses an appropriate average, rather than inputting a single heat capacity value for the liquid. The distinction between the two species that make up the liquid is important to source term analysis and must be maintained. Validation/verification undertaken in Section 7 demonstrates that this limitation does not introduce any noticeable error.

In the mixer pumps scenarios, properties are homogenized values for all waste in the DST. Total mass fraction of solids is given by:

$$x = \frac{\text{mass of solids in NCL} + \text{mass of solids in CL}}{\text{total mass of waste}} \tag{4-2}$$

The mass of solids in the NCL is 130,073 kg (0.23 × 0.43 × 411 × 3,200 kg); mass of solids in the convective layer is 803,648 kg (0.0818 × 7.47 × 411 × 3,200 kg); and total mass of waste is 3,914,405 kg (0.43 × 411 × 1,180 + 7.47 × 411 × 1,180 kg). Overall solids mass fraction is then 24%. Decay heat, in terms of J/kg, is therefore 71,000 W / (803,648 kg + 103,073 kg), or 0.07588 J/kg.

5.0 CALCULATIONS

Calculations were made for scenarios listed in Table 5-1. Each scenario is discussed below.

Table 5-1: Summary of HADCRT Run Scenarios.

Run Name	Input File Name	Description	Results
Safe Storage Scenarios			
Steady-State (SSSS)	SSSS.DAT	Run to approximate steady-state (115 days) temperature profile for safe storage conditions.	Steady-state temperature profiles in waste, structural materials, and soil.
Loss of Ventilation (SSLV)	SSLV.DAT	Restart of SSSS.DAT at 115 days with loss of ventilation; run to 550 days.	Waste temperature profile after loss of ventilation, time to boiling, aerosol generation, and source term due to boiling.
Retrieval Scenarios (Mixer Pumps Operate Indefinitely)			
Steady-State (RETSS)	RETSS.DAT	Run to approximate steady-state (115 days) temperature profile for mixer pump operation, with 500 cfm primary ventilation and no annulus ventilation.	Waste temperature during mixing, mixed-waste steady-state temperature equals 95°C.
Loss of Ventilation (RETLV)	RETLV.DAT	Restart of RETSS.DAT at 16 days with loss of ventilation; run for another 98 days or until supernatant inventory is substantially depleted.	Waste temperature profile after loss of ventilation, time to boiling, aerosol generation, and source term due to boiling.
Recovery (RETLVR)	RETLVR.DAT	Restart of RETLV.DAT at 26.5 days with ventilation recovery, recovery of ventilation after boiling.	Waste temperature profile after recovery, aerosol generation, and source term due to boiling.

5.1 Steady-State, Safe Storage

This scenario has already been discussed briefly in the methodology (Section 3.0). This run establishes realistic temperature profiles in DST structural materials and surrounding soil, with a primary ventilation flow rate of 1,000 cfm. Temperature response of the convective layer (supernatant), and the average non-convective layer temperature are shown in Figures 5-1. Starting from the (assumed) initial conditions for the run, waste temperatures reach steady-state at 115 days for all practical purposes. Initial conditions for the run were set to the expected steady-state temperatures; steady-state conditions would evolve regardless of initial conditions, but it is best to use available estimates. The convective layer temperature stays constant for the duration of the run, but NCL average dips a bit and recovers. This is because some of the temperatures in other heat sinks (namely, soil) do not have the correct steady-state profile. As the steady-state profile emerges in all heat sinks, the NCL average temperature increases to roughly the initial value. Liquid transfers from the condenser maintain waste at the original level, as shown in Figure 5-2.

5.2 Safe Storage Loss of Ventilation

This run is a restart of the safe storage, steady-state run, except with no ventilation. Temperature histories for the non-convective layer (NCL) top, non-convective layer average, and supernatant are shown in Figure 5-3. Temperature histories start at 115 days, the restart time, and extend to 550 days. The supernatant and NCL top temperature are very close and nearly lie on top of each other in the plot. Heatup is quasi-steady, in the sense both the convective layer and NCL have the same temperature rise rate of about 0.25°C/day. It takes over 200 days to boil, which occurs at 350 days and is evident by constant or nearly constant temperatures after that time. Waste level is shown in Figure 5-4. Prior to boiling, the level swells a bit as the temperature increases and liquid density decreases. After boiling the waste level decreases, as inventory is lost.

Figure 5-1: SSSS Run Temperature Plots for Convective Layer and NCL Average.

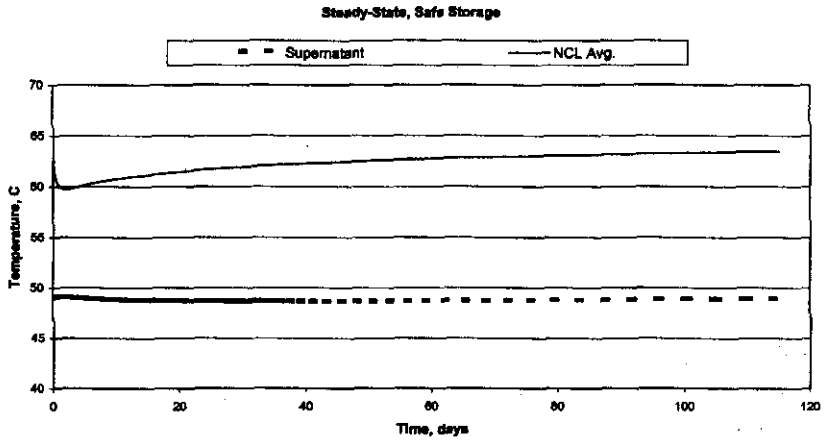


Figure 5-2: SSSS Run Waste Level.

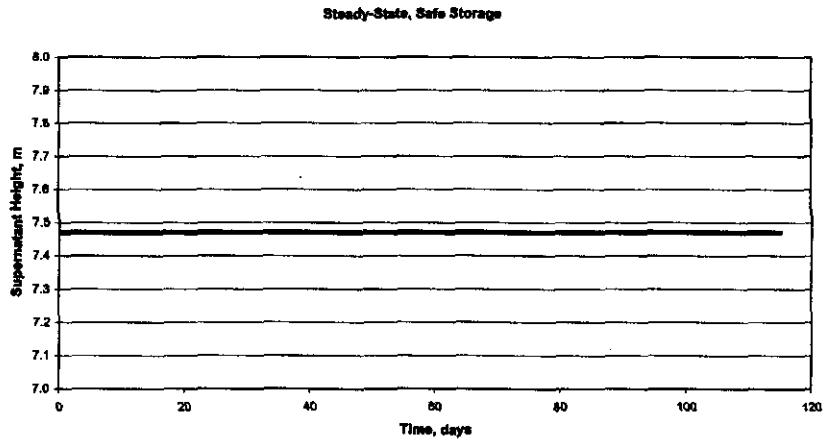


Figure 5-3:
SSLV Temperature Histories for NCL Top, NCL Average, and Convective Layer.

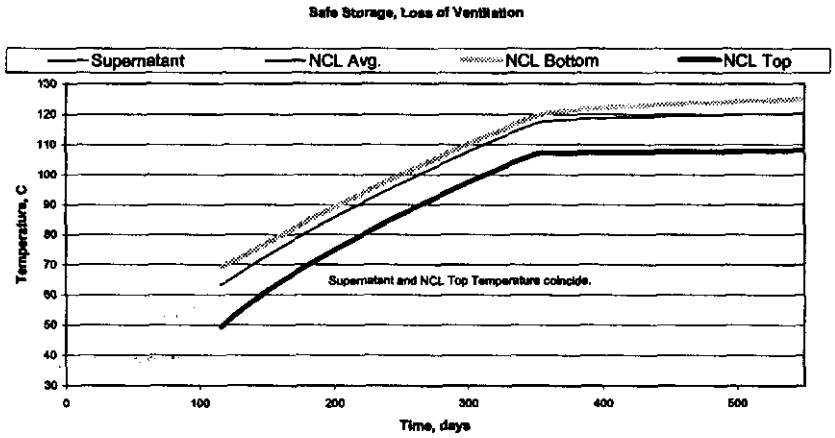
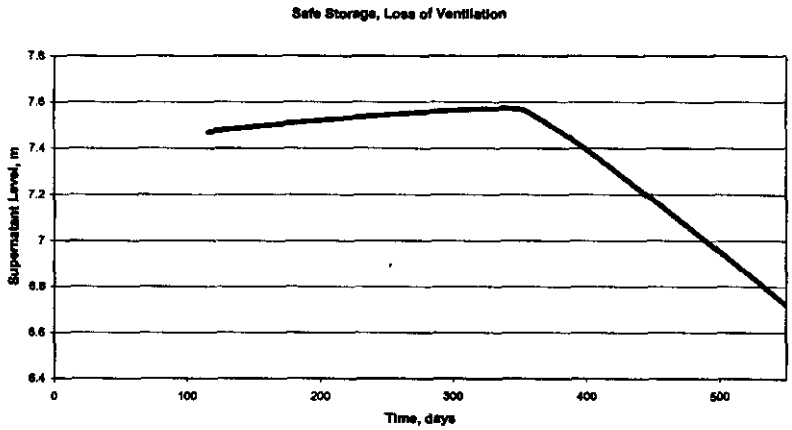


Figure 5-4: SSLV Convective Layer Height.



This heatup rate is about half that reported for a conservative, pure conduction analysis that did not account for either flow paths or evaporative cooling or sideward conduction; [Epstein, et al., 2000] i.e., a value of 0.40°C/day is reported in Section 9. In SSLV, evaporative cooling is partially effective, as shown by Figure 5-5, which is a plot of the steam mass fraction in the DST headspace, provided the steam mass fraction is less than unity. Steam mass fraction is very low for safe storage, steady-state conditions (5%), but it increases continually as ventilation is unavailable. Flow paths from the headspace to the environment provide heat removal, with most (roughly 90%) of the exit flow occurring in the "inlet" flow path because the path through the outlet, condenser, etc., incurs large pressure drops. This suggests that the details of the flow path between the headspace and the exhaust stack are not important because in a loss of ventilation scenario, most of the exiting flow is through the inlet, which has a comparatively small pressure drop. Headspace pressure increases just slightly to 101,500 Pa for the duration of the run. This means that the inlet HEPA filter will likely survive and perform its intended function, even though the model here accounts for filter pressure drop and not decontamination factor.

Aerosols are generated during boiling. Figure 5-6 shows the mass of waste aerosol in the environment; this is the source term because there is always very little waste in the annulus or the condenser. As a function of time, the amount released is roughly linear. Releases are about 0.06 kg/day.

Sensitivity runs validate the model by reproducing the results of hand calculations and identify the more realistic features that differentiate run SSLV from the previous results, namely evaporation, junction flow, and sideward heat conduction. In the first sensitivity case, the SSLV run was repeated with no junctions available for gas flow and termed SSLV1. In SSLV1, the heatup rate increased to 0.28°C/day, but the headspace pressure became unrealistically high (two or three bar), an obvious consequence of eliminating flow paths from the headspace. The heatup rate in SSLV1 is still considerably less than the conservative hand calculation, so a second case, SSLV2, was run with no sideward heat conduction and the following models turned off: junctions, condensation, fog formation, and aerosol settling. Setting heat transfer areas connecting the annulus to the environment to trivial values eliminated sideward heat conduction. Heatup rate in run SSLV2, 0.39°C/day, is in good agreement with the prior results (0.40°C/day),

Figure 5-5: SSLV Headspace Steam Mass Fraction.

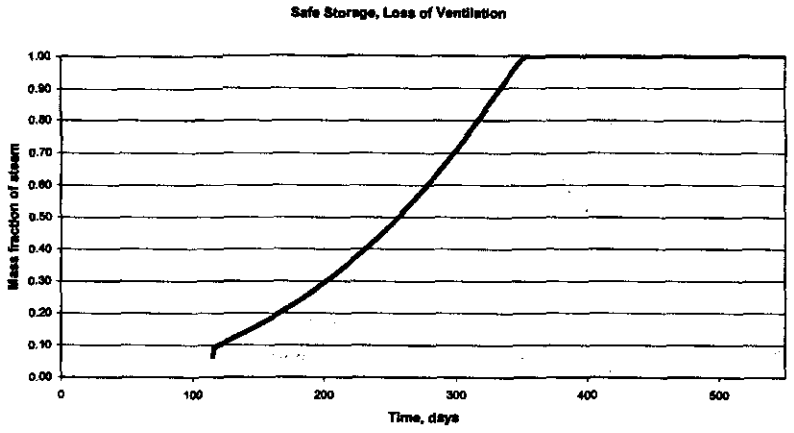
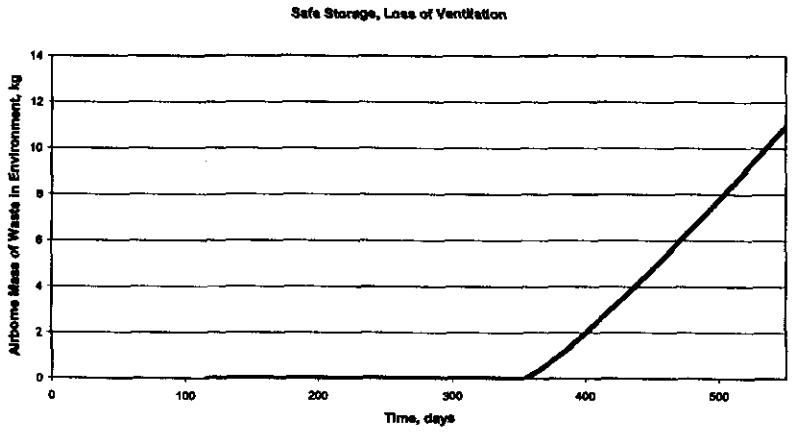


Figure 5-6: SSLV Waste Aerosol Released to the Environment.



which should be expected because SSLV2 uses the same assumptions as simple hand calculations.

Section 7.0 presents further verification/validation of the results model and the results obtained for SSLV. Section 7.0 compares DST AZ-101 thermocouple data for a degraded-ventilation transient against HADCRT results and demonstrates good agreement for waste heatup rates.

5.3 Retrieval Steady-State

This scenario has already been discussed briefly in the methodology (Section 3.0). This run is just to calculate the temperature history for indefinite mixer pump operation with 500 cfm primary ventilation and no annulus ventilation. Waste temperature response is shown in Figure 5-7. Note that because the waste is mixed, the average NCL and convective layer temperature plots coincide. Starting from the (assumed) initial mixing conditions for the run, waste temperatures reach steady-state at 40 days for all practical purposes. Waste temperatures exceed the AB limit of 195°F (90.4°C, 363.6 K) at 18 days, but never reach the boiling point. Liquid transfers from the condenser maintain liquid waste at the original level, as shown in Figure 5-8. In the retrieval scenario, all the waste is liquid and the level is 7.90 m (7.47 + 0.43 m), whereas in the safe storage scenario, the liquid waste level is 7.47 m and the NCL is 0.43 m. In the retrieval scenario, the NCL is made arbitrarily thin (1 cm).

Although not plotted, it is worth noting that the steady-state value of DST headspace steam mass fraction is 55.4%, which is much higher than the steady-state value in the SSSS scenario (6.5 %), as expected. The steady-state waste temperature and steam mass fraction in the RETSS case prove to be useful checks for transients like the retrieval scenario (RETLVR). If primary ventilation is lost briefly (several days), but then recovered, conditions must eventually return to the steady-state described here for RETSS. Waste temperature should return to 94°C and headspace steam mass fraction should return to 55.4%.

Figure 5-7: RETSS Waste Temperature History.

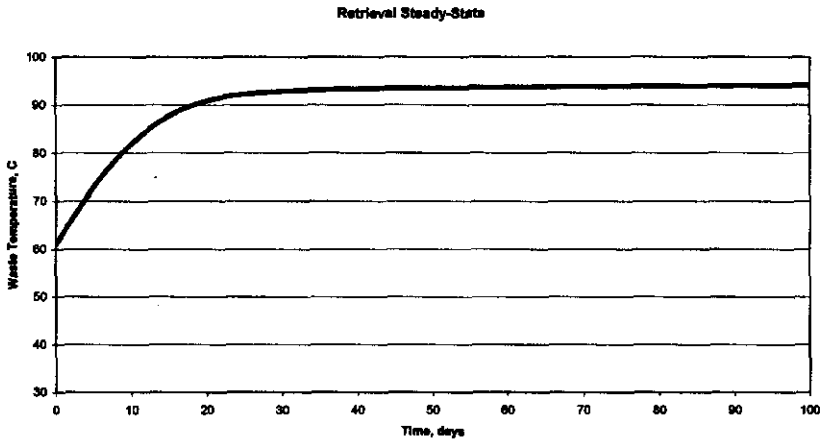
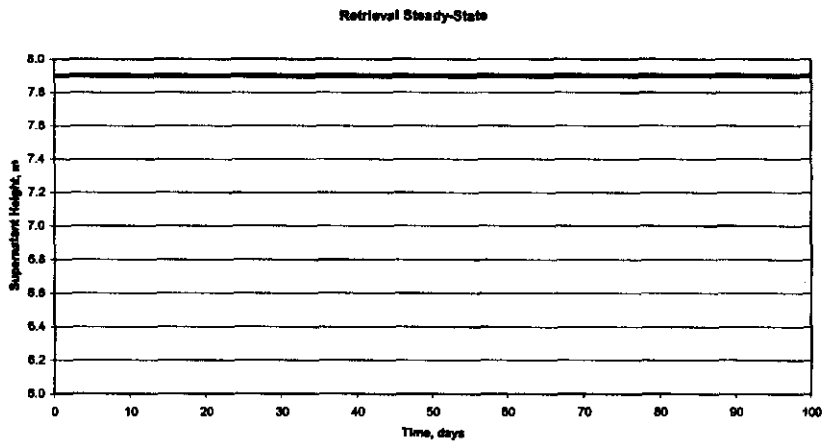


Figure 5-8: RETSS Waste Level.



Validation of this run is discussed in Section 7. Validation runs use DST AZ-102, rather than the subject DST AZ-101, because the results of a RETSS run for DST AZ-102 are available in [Crea, et al., 2000]. HADCRT models for DST AZ-101 and DST AZ-102 differ only in waste properties. Validation of the model with DST AZ-102 is applicable to DST AZ-101 because with the mixer pumps operating, the difference in decay heat loads between the two DST is in trivial by comparison and the differences in waste properties are less significant because the waste is homogeneous.

5.4 Retrieval Loss of Ventilation

This run is a restart of the retrieval, steady-state run, except with no ventilation. Restart takes place at 16 days, which is just before AB temperature limits are exceeded in the RETSS run. Temperature history for the supernatant is shown in Figure 5-9. As in the steady-state run, the NCL temperature is the same as the supernatant temperature. Temperature history starts at 16 days, the restart time, and extends to 40 days. Boiling starts about eight days after the loss of ventilation. Figure 5-10 shows waste level. Results are carried out for only another 24 days because the loss of inventory means that the salt concentration in the liquid is continually increasing and the liquid properties are not well-known at some point.

As in the SSLV case, the headspace pressure increases somewhat, 101,900 Pa in the RETLV case, but not enough to threaten the integrity of HEPA filters. Therefore, the assumption here that filter pressure drop is accounted for but decontamination is not credited is very conservative. After boiling starts, the flow rate out the inlet is 0.181 kg/s and the flow rate to the condenser and out the stack is only 0.026 kg/s, which is as expected because pressure drops through the inlet flow path are much smaller. Also, condensation on the dome is about 0.015 kg/s after boiling starts. Thus, a mass balance shows that the boiling rate must be 0.181 + 0.026 + 0.017 = 0.224 kg/s, which is in excellent agreement with a simple, a priori estimate given as total heat load divided by latent heat of vaporization (500 kW divided by 2200 kJ/kg = 0.227 kg/s). This hand calculation works because with the mixer pumps on, most of the total heat load is removed by boiling rather than by conduction.

Figure 5-9: RETLV Waste Temperature History.

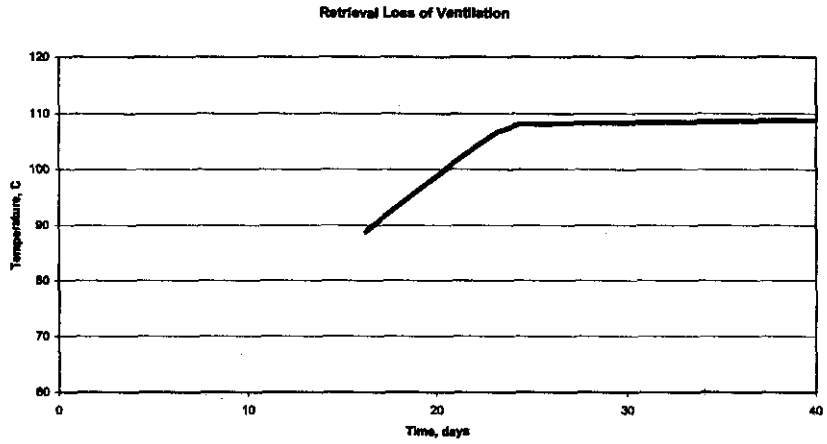
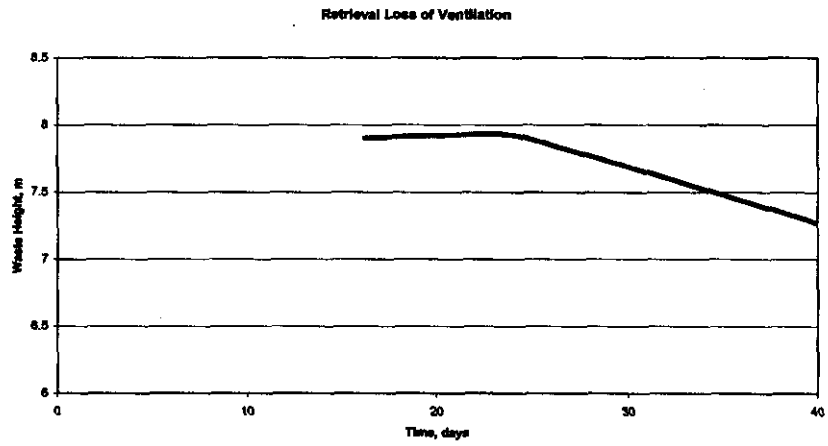


Figure 5-10: RETLV Waste Level.



Aerosols are generated during boiling. Figure 5-11 shows the mass of waste aerosol in the environment; this is the source term because there is always very little waste in the annulus or the condenser. As a function of time, the amount released is roughly linear at a rate of about 1.5 kg/day, rounded up. The waste release rate in RETLV after boiling is about 25 times the same value for the SSLV case. This is explained mainly by the difference in total heat load: 71 kW in the SSLV case, versus 500 kW in the RETLV case. Aerosol release rate is the product of DST headspace aerosol concentration and the exiting volumetric flow rate. But both of these factors vary (increase) with boiling flow rate, which is directly proportional to total heat load. In the steady-state, the exiting mass flow rate is equal to the boiling flow rate. Aerosol concentration in the DST headspace is a complicated function of sedimentation area, aerosol size distribution, temperature, etc., but clearly the aerosol concentration increase with increasing boiling flow rate, everything else held constant . As a result, the aerosol release rate varies exponentially with the total heat load.

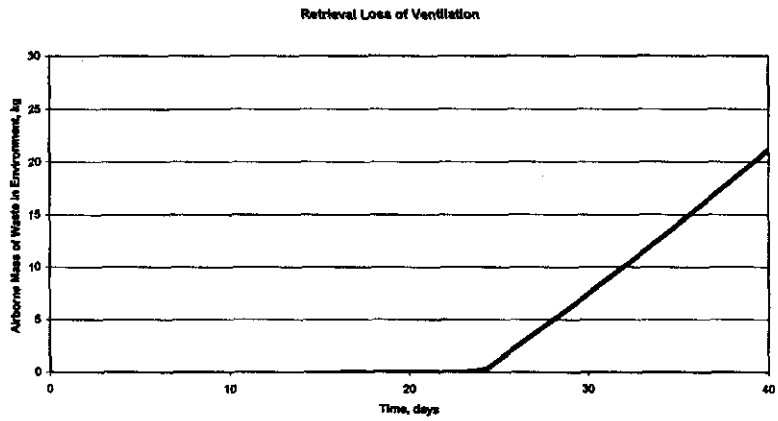
5.5 Recovery

This sequence is a restart of RETLV, but with primary ventilation and condensate recirculation recovery. It models recovery after boiling starts, with the intent of seeing how recovery affects the waste temperature and source term. For the three retrieval sequences, a timeline is as follows:

- Exceed the AB temperature limit at 18 days (Run RETSS),
- Start to boil at 24 days (Run RETLV, which restarts at 16 days with loss of primary ventilation and condensate recirculation), and
- Recover primary ventilation and condensate recirculation at 26.5 days (Run RETLVR).

In RETLVR, primary ventilation is recovered at 500 cfm and condensate recirculation is recovered at a volumetric flow rate of 0.0002 m^3/s, which is about equal to a priori boiling rate of 0.227 kg/sec. This choice is somewhat arbitrary, but it is reasonable because we know the

Figure 5-11: RETLV Waste Aerosol Released to the Environment.



ventilation system can operate at this flow rate. Condensate recirculation starts about 10,000 seconds after ventilation is recovered; this delay makes the restart easier numerically.

As shown in Figure 5-12, waste temperature starts dropping immediately, which means that boiling and aerosol production stop. Waste temperature drops immediately because primary ventilation clears the headspace of steam and allows evaporative cooling. Steam mass fraction in the headspace is shown in Figure 5-13. Section 5.3 notes that steady-state waste temperature and headspace steam mass fraction values in the RETSS scenario are 94°C and 55.4%, respectively. For the RETLV scenario, Figures 5-12 and 5-13 show that after 20 days, waste temperature and headspace steam mass fraction have returned to nearly the steady values reported for RETSS, as must be the case if inputs and the model are correct.

Waste level is shown in Figure 5-14. At the time of restart, the waste level is at 7.82 m, which is less than the initial value of 7.90 m because boiling has occurred for a few days. The steep negative slope at restart is caused by the delay in introducing condensate recirculation and reflects continued evaporation. In the figure, the waste level actually spans a small range – between 7.64 and 7.84 m. The slope is still negative up to 35 days, which indicates that it takes

Figure 5-12: RETLVR Waste Temperature History.

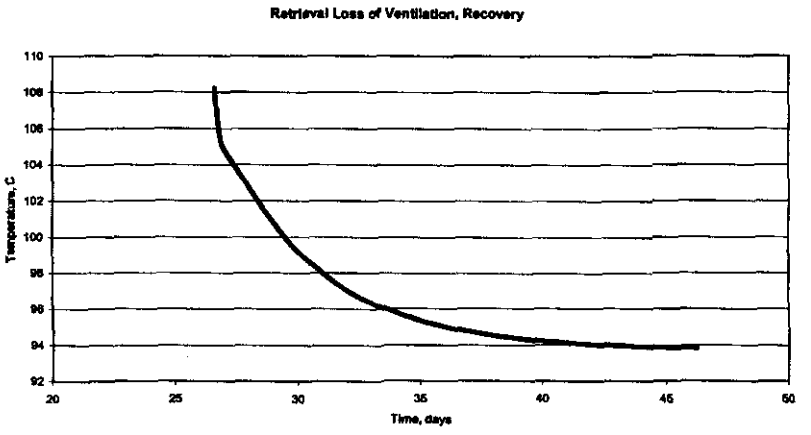


Figure 5-13: RETLVR Headspace Steam Mass Fraction.

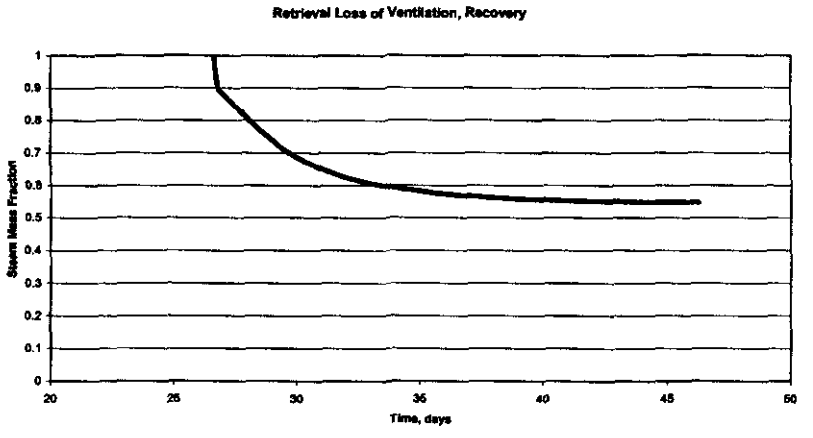
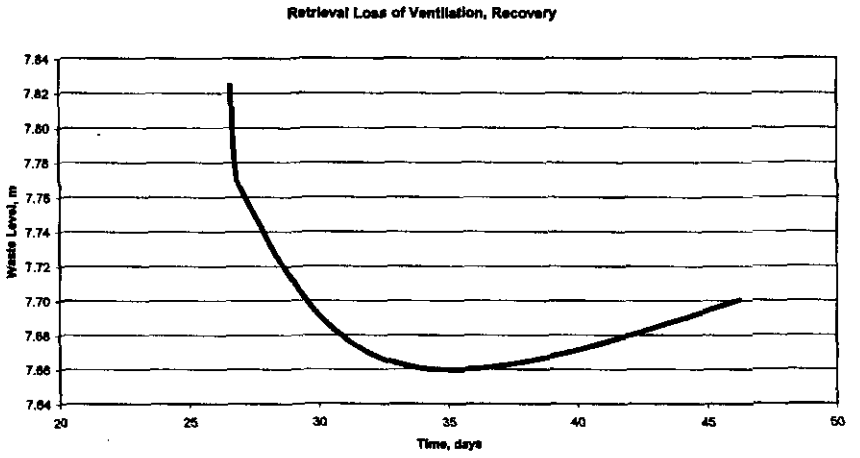


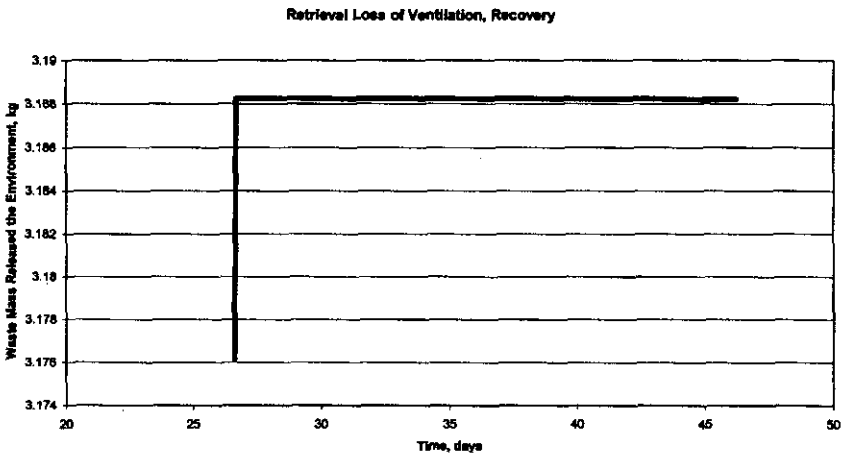
Figure 5-14: RETLVR Waste Level.



time for the fixed recirculation rate to catch up with evaporation. Eventually, the condensate addition rate exceeds evaporation, which declines as the waste cools, and waste level recovers. Despite the appearance, the plot's narrow waste level span shows the assumed boundary condition for condensate recirculation (set roughly equal to boiling or evaporation rate) has been applied correctly.

The amount of waste released to the environment initially increases once primary ventilation starts, but remains constant after boiling stops. Figure 5-15 shows that at first, the ventilation flow expels waste aerosol to the environment, but once boiling stops, there is no longer any waste aerosol in the headspace.

Figure 5-15: RETLVR Waste Aerosol Released to the Environment.



6.0 RESULTS AND CONCLUSIONS

Heatup and source term calculations have been performed for both safe storage and retrieval scenarios. The main conclusions are listed below.

- Time to saturated condition (boiling) calculations performed here for the safe storage scenario without ventilation show that previous calculations are conservative by about 50%. That is, it takes about 50% longer than suggested by simple hand calculations. Starting from safe storage conditions it would take about 200 days to get to saturated conditions.
- Under the safe storage scenario (no mixer pumps), the source term is about 0.06 kg per each day of boiling.
- Time to boiling in the retrieval scenario (two mixer pumps operating at full speed) is about eight days after loss of ventilation.
- Under the retrieval scenario, the source term is about 1.5 kg per each day of boiling.
- Recovery of primary system ventilation quickly decreases the waste temperature, thereby halting boiling and aerosol generation.

7.0 HADCRT DST THERMAL MODEL VERIFICATION

7.1 HADCRT - GOTH_SNF Comparison

To verify that the HADCRT code can be used to model DST thermal transients, HADCRT results are compared against the GOTH_SNF results of [Crea, et al., 2000]. From this reference, we use "Case 6" which can be described as follows:

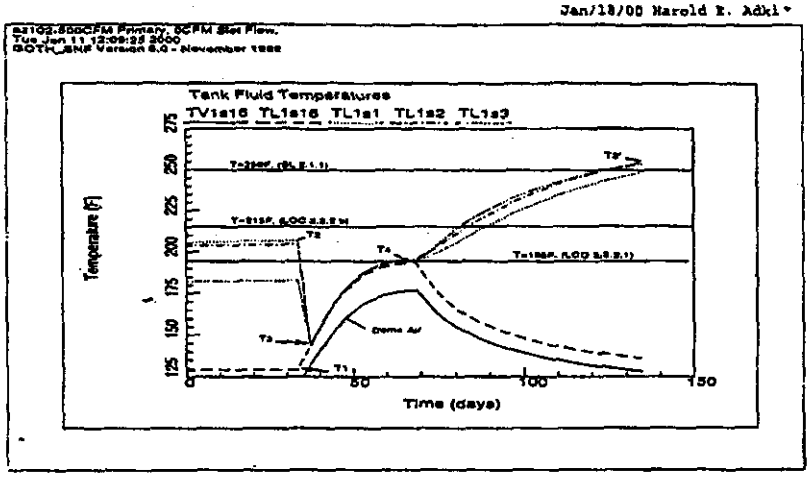
- Mixer pump operation for 36 days,
- Primary ventilation flow rate is 500 cfm,
- Annulus ventilation flow rate is zero cfm, and
- Inlet air temperature for the primary ventilation system is 82°F (28°C).

Case 6 was analyzed for DST AZ-102, rather than DST AZ-101.

In this section, Case 6 was modeled with HADCRT 1.3. To the extent that the GOTH_SNF code has been validated, the comparison made here with DST AZ-102 validates that the code and models are appropriate for thermal analysis of transients during retrieval. It is then a matter of verifying that the inputs for DST AZ-101 are correct. A first step is to verify that the inputs for DST AZ-101 are correct in the safe storage scenario. This is done by showing that safe storage conditions can be reproduced (Sections 3.0 and 5.1), comparing code results against hand calculations (Section 5.2), and actual DST temperature data for ventilation flow rate transients (Section 7.2). Once the verification is established for the safe storage scenario, DST AZ-101 retrieval scenario inputs for waste properties and heat load can be compared to safe storage values.

GOTH_SNF results for Case 6 are shown in Figure 7-1. The figure shows important temperatures for mixer pump operation in DST AZ-102. Between time zero and 34 days, the GOTH_SNF code is modeling safe storage, steady-state conditions. Mixing occurs between 34 and 37 days, as evidenced by the temperatures converging to a single mixed value. Mixing

Figure 7-1: Critical Waste Temperatures (Case 6) [Crea, et al., 2000].



continues to 70 days, at which time the mixer pumps are shut off and ventilation is lost. Times beyond 70 days will not be considered here.

Nomenclature for Figure 7-1 is as follows: "T1" is the convective layer temperature; "T2" is the maximum waste temperature; "T3" is the instantaneous mixed-waste temperature; and "T4" is the mixed-waste, steady-state temperature with mixer pumps operating. For the period between 0 and 34 days, these values are T1 = 128°F (53°C), T2 = 206°F (97°C), and T4 = 195°F (90.6°C). HADCRT does not calculate T3 directly and this temperature is not considered as part of the comparison.

HADCRT input for DST AZ-102 runs will not be discussed in any detail here. The HADCRT heat sink nodalization is very similar to that used for DST AZ-101 and described in Sections 4 and 9, except that waste properties reflect DST AZ-102. Input files are listed in Sections 8.6 and 8.7.

Calculations are broken down into two phases: steady-state safe storage, as shown in Figure 7-1 by the duration between 0 and 34 days; and the mixer pump operation, which is shown in the figure by the duration between 37 days and 70 days. The steady-state phase is considered first.

An initial calculation was made using the regions and junctions shown in Figure 2-1 and the heat sink nodalization in Figure 2-2, but with DST AZ-102 waste properties (see Section 8.6). Initial temperatures were set to the expected steady-state values shown in Figure 7-1 to minimize run time. Resulting temperatures are as follows: T1 = 52.5°C and T2 = 99°C. Note that T4 is irrelevant for the first phase of calculations, and that for mixer pump operation, there is only one waste temperature. Plotted HADCRT temperatures would be straight lines and are not presented. At 58 days, code output for the NCL temperature distribution (°C) is as follows:

```
HS#  9  (convt to   52.561)   53.023   57.943   62.584   66.944   71.025
            74.827   78.349   81.593   84.558   87.244   89.652   91.782
            93.634   95.209   96.505   97.525   98.267   98.732   98.920
            98.831 (    insulated    )
```

This output shows the boundary condition at the top, "(convt to 52.561)", which is just the convective layer temperature. The other boundary condition "(insulated)" shows that the non-convective layer is part of a composite heat sink and is conjoined with the liner.

A calculation for indefinite mixer pump operation was also made. See Section 8.7 for input. HADCRT results are shown here as Figure 7-2 and can be compared to Figure 7-1. HADCRT does not have a mixing model, so the initial mixed waste temperature was an input. Figure 7-2 is in good agreement with Figure 7-1 for the interval between 37 and 70 days. HADCRT predicts a steady-state temperature of 91°C at roughly 30 days after the start of mixing. The headspace temperature predicted by HADCRT is 84°C, or 183°F, which is also in good agreement with the peak value shown in Figure 7-1 for "Dome Air".

These calculations taken together verify that HADCRT is an appropriate tool for DST thermal and source term analysis, and that the nodalization shown by Figures 2-1 and 2-2 is sufficient.

7.2 Validation and Verification Against DST AZ-101 Waste Temperature Data

DST AZ-101 thermocouple data recorded during operational transients that took place between mid-May, 2001 and September 2001 provide excellent data to validate/verify both the code and inputs. This experience is not formally documented, but relevant operating logs, weather data, communications, etc., are either described in this section or included in Section 9.0. A plot of DST waste temperatures during the subject period is shown here as Figure 7-3. Clearly, the cooler temperature values represent the supernatant while the high temperature values represent non-convective layer spots. With respect to this plot, the main task is for the code to reproduce heatup rates as a function of boundary conditions, namely ventilation flow rate, and temperature differences between the supernatant and points in the non-convective layers.

Figure 7-2: HADCRT Results for DST AZ-102 Waste Temperature During Mixing.

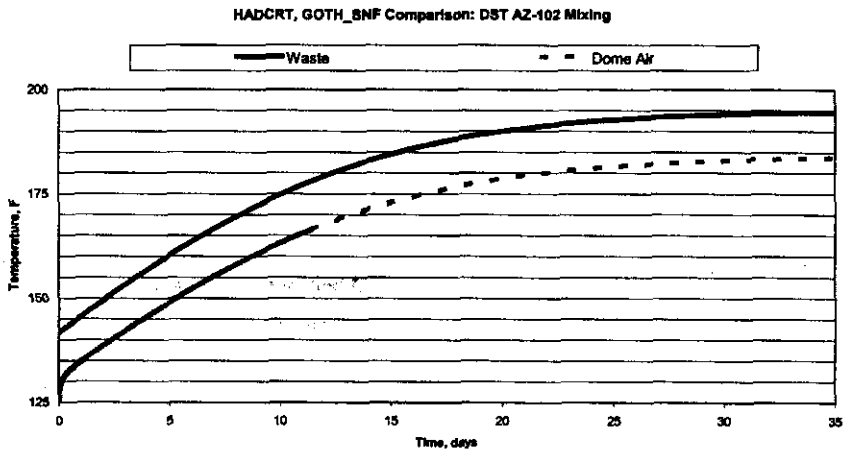
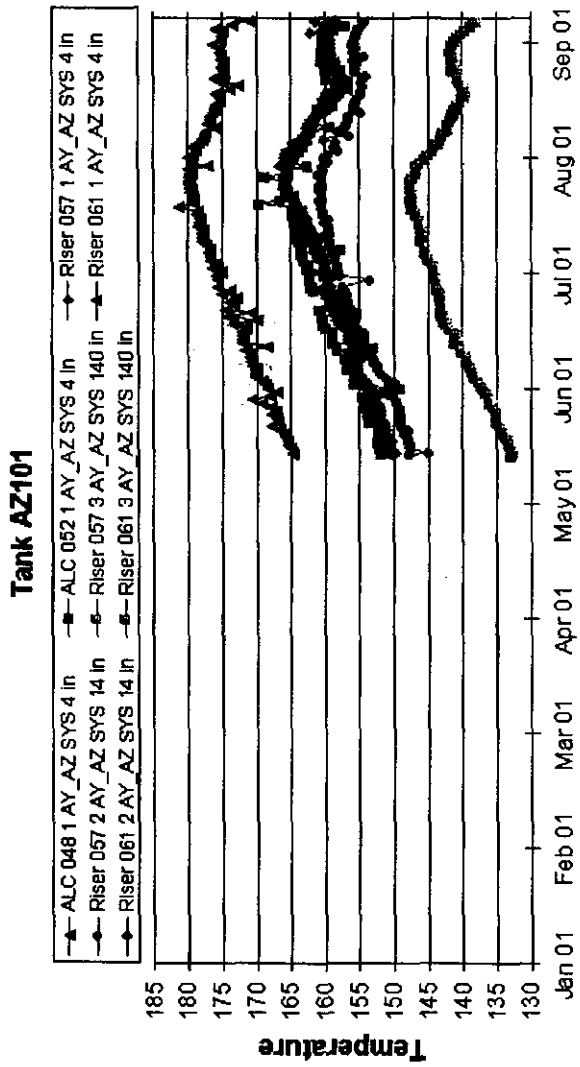


Figure 7-3: DST AZ-101 Thermocouple Data from May 17, 2001 to September 10, 2001. (Temperature is in °F.)



7.2.1 DST AZ-101 Operating History Between Mid-May 2001 and September 2001

To understand how the data can be used to validate/verify both the model and the code, we first describe DST AZ-101 operation between mid-May and mid-August. Steady-state runs (SSSS.DAT and RETSS.DAT) show large ventilation rates are needed to maintain steady-state temperatures, which means that degraded ventilation flow rates lead to temperature transients. Operating history, included here as part of the "Communications" section, can be summarized as follows:

- Between mid-May and July 16th, a recirculation fan bearing failure limited the AZ-101 ventilation flow rate to 100 cfm,
- The fan bearing was replaced on July 16th and AZ-101 flow rate increased from 100 cfm to 300 cfm, and
- From July 18th to August 20th, the AZ-101 ventilation system operated in "high heat mode" at 450 cfm.

High heat mode means that headspace gas is directed to the common exhaust system with no air returning to the tank. The HADCRT nodalization in Figure 2-1 represents the high heat mode, which has also been described as the "once-through ambient air" mode in [Crea, et al., 2000]. So the HADCRT DST nodalization is only approximate for the recirculation mode, where 80% of the air stream from the condenser is returned back to the DST.

The period after August 18th is ignored because it appears to be a repeat of the cycle between mid-May and August 18th. It is enough to validate one heatup and cooldown transient each.

Mid-May initial conditions for the waste are not particularly important, other than to note that because of mixer pump operation in May 2000, the NCL is not uniformly distributed, hence the ALC 048 plot that lies above the others. This thermocouple location is a hot spot where the NCL is relatively thick. But if we are interested in validating heatup rate, it suffices to note that the heatup rate is everywhere much the same. All the temperature histories in Figure 7-3 have the same slope; each looks much like a translation, up or down, of the other.

7.2.2 HADCRT Input Files for Validation/Verification vs. DST AZ-101 Recorded Waste Temperatures

Two validation runs are made. The first is termed SSDEGV and covers the period between mid-May and July 18th, where ventilation is degraded to 100 cfm. The second run (SSDEGV2) is a restart of the first and covers the period from July 19th to August 19th, where ventilation flow rate is 450 cfm in the high heat mode. Strictly speaking, the ventilation flow rate is 300 cfm on July 16th and 17th, but this detail is neglected. Because thermal time constants for DST transients are expressed in weeks or months, a change in boundary conditions that lasts only two days is unimportant.

SSDEGV is a restart of the steady-state, safe storage run (SSSS.DAT) at 115 days, with three changes: (1) total heat load is 61 kW – a best-estimate (refer to Section 9.0 for updated heat loads), (2) the ventilation flow rate is 100 cfm, and (3) site weather data is used for the ambient boundary condition. These changes are appropriate for a best-estimate validation, rather than a conservative source term analysis. The easiest way to describe SSDEGV.DAT is as a difference listing with respect to SSLV.DAT – the loss of ventilation scenario starting from safe storage, steady-state conditions. This is shown in Section 8.0. To create SSDEGV.DAT, waste properties (decay heat in the liquid and volumetric heat generation in the NCL) were updated, the ventilation flow rate was changed from 0.0 to 100 cfm, and the actual average temperature during the relevant time period (22°C or 72°F) was input instead of the conservative 28°C value. End time in the input files is 230 days (a 115 day long run), although the duration is not important as long as we establish a heatup rate.

SSDEGV2.DAT is a restart of SSDEGV.DAT at 230 days, and runs to 277 days. Again the duration is not important as long as we can compare the predicted cooldown rate to the DST AZ-101 TC data. To create SSDEGV2.DAT from SSDEGV.DAT, all that is required is to: (1) change start and end times, (2) specify a restart file, and (3) change the ventilation flow rate from 100 cfm to 450 cfm. These steps are shown in Section 8.0, which contains a difference listing of SSDEGV.DAT with respect to SSDEGV2.DAT.

7.3 Results

7.3.1 Degraded Ventilation Heatup – May 17th to July 18th, 2001

Figure 7-4 shows results for the SSDEGV scenario. Validation/verification consists of comparing the slopes (heatup rates) shown in Figure 7-4 against those in Figure 7-3. Figure 7-3 shows a heatup rate of 0.12 to 0.13°C/day (0.22°F/day) during the degraded ventilation phase. Figure 7-4 shows the following temperatures: convective layer, NCL top, NCL bottom, and NCL average. Underneath each temperature history is a linear regression curve fit for slope, which is heatup rate. Heatup rates vary between 0.13 and 0.16°C/day, and represent reasonable agreement with the data.

The first few days of the heatup transient actually result in a minor temperature dip, but this is entirely predictable. The brief dip in temperature stems from a restart of SSSS results at 115 days, which were developed with inputs of 71 kW total heat load. Since the restart uses 61 kW total heat load, temperature profiles adjust over the course of several days. Because we are interested in the long-term slope, this temperature drop is not a concern. Indeed, the dip indicates correct response, given the input heat loads.

Predicted temperature profiles should match the data in Figure 7-3. Figure 7-5 shows two temperature profiles: the top curve is the NCL temperature profile at 230 days, and the bottom curve is the NCL temperature profile adjusted to match the convective layer temperature on July 18th, which is 67.8°C (146.7°F). The plots, which are in degrees Fahrenheit for ease of comparison, extend from the bottom of the NCL to a depth of 30 inches. Above 17 inches (the convective layer), the temperature is constant. Both analysis and data indicate that the temperature difference between the convective layer and any point in the NCL is always constant. Subtracting 7.3°F from the first profile results in the second temperature profile, which can then be compared directly to Figure 7-3.

Comparing Figure 7-5 to 7-3 shows that "ALC 048 1 AY_AZ SYS 4 In" temperature is about 178°F on July 18th, while the adjusted curve on Figure 7-5 shows a peak temperature of

Figure 7-4: HADCRT Results for the Degraded Ventilation Scenario.

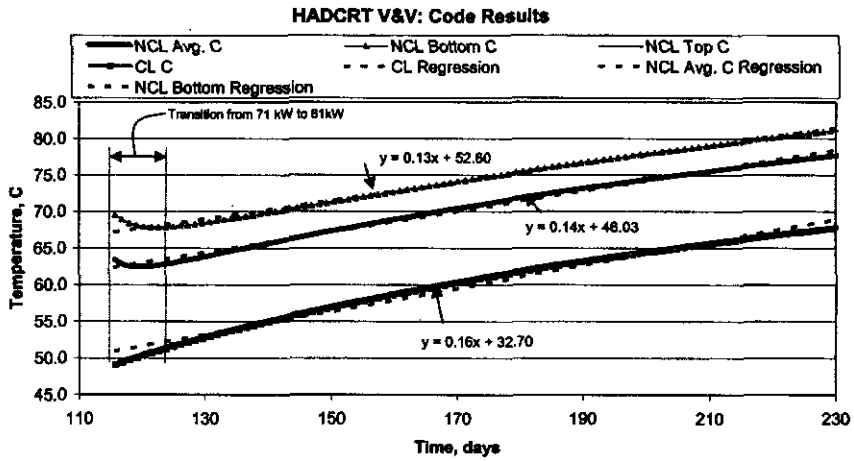
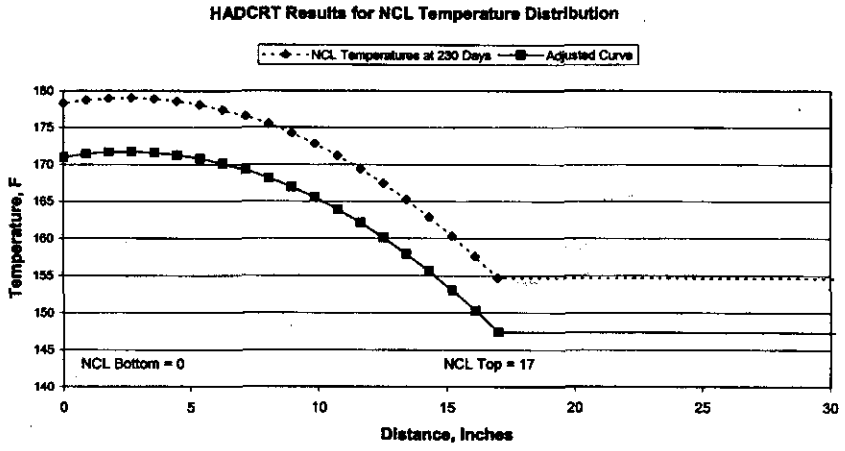


Figure 7-5: HADCRT Results for NCL Temperature Distribution.



172°F. Figure 7-5 shows the code predicts 171°F at 4 inches and 158°F at 14 inches. This is fair agreement with the data of Figure 7-3, which shows that, on July 18th, "Riser 057 2 AY_AZ SYS 14 In" temperature is 160°F and "Riser ALC 052 1 AY_AZ SYS 4 In" temperature is 165°F. HADCRT fails to predict the "hot spot" data but otherwise overstates NCL temperatures a bit. This is not unexpected, however, because no effort was made to account for a non-uniform sludge distribution.

In summary, HADCRT predictions for waste heatup rate during degraded ventilation transients are in good agreement with DST thermocouple data. Predictions for heatup rate are only slightly conservative. Predictions for the NCL temperature distribution are only fair because the waste is not a uniform slab, as modeled, and actually exhibits peaks and valleys in the aftermath of mixing operations that took place in May of 2000. This does not alter the conclusion that heatup rate can be accurately estimated using the methods and models described here. Knowing the current waste temperature distribution (initial conditions) and a degraded ventilation flow rate, the time to boiling can be accurately estimated.

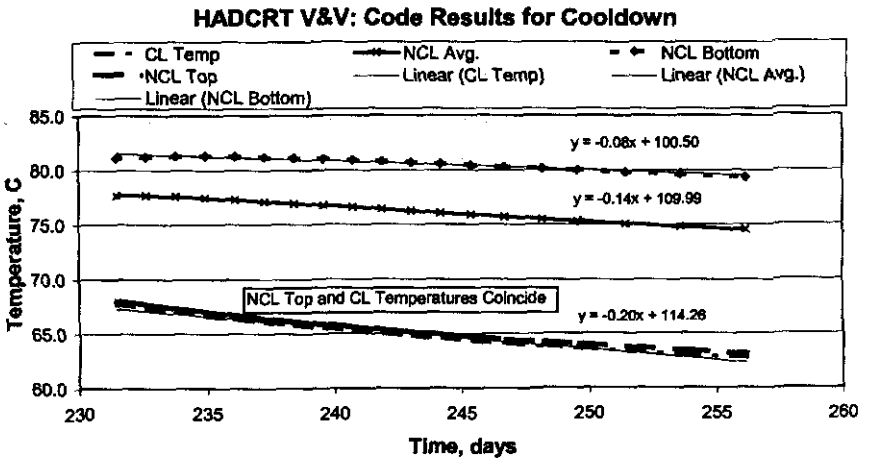
7.3.2 High Heat Mode Cooldown – July 19th to August 22nd, 2001

Figure 7-3 shows the temperatures after July 19th, waste temperatures remain roughly constant for several days and then decline until August 22nd. The reason waste temperatures do not all respond immediately is because of the thermal time constant of the sludge, which is about 9 days if one uses the properties and NCL thickness shown in the input files. In other words, it takes several days for waste temperatures to "turn around" in response to the increase in ventilation flow rate. Cooling rates were found from regression analysis of the temperature data between July 29th and August 22nd, and can be summed up as follows: (1) convective layer temperature decreases by 0.18°C/day, (2) NCL temperatures between 4" and 14" from the bottom decrease by 0.15 to 0.18°C/day, and (3) the hot spot temperature decreases 0.12°C/day.

Figure 7-6 shows code predictions for the following temperatures: (1) convective layer, (2) the NCL bottom, (3) the NCL average, and (4) the NCL top. As before, the CL and NCL top

Figure 7-6:

HADCRT Predictions for Waste Cooldown During the High Heat Mode, July 19th to August 22nd, 2001.



temperatures are very close to each other. Results of a linear regression analysis are placed above each temperature history. The absolute value of the slope is the cooldown rate.

Figure 7-6 shows reasonable predictions of cooling rates and response time for the hottest parts of the waste. The predicted cooldown rate for the convective layer (0.20°C/day) is greater than the actual one (0.18°C/day), but the cooldown rate for average NCL temperature (0.14°C/day) is in good agreement with that for NCL temperature data at 4" and 14" from the bottom (0.15 to 0.18°C/day). Note that in Figure 7-6, the NCL bottom does not begin to respond for about seven or eight days, which is expected, based on the sludge time constant. At the NCL bottom, predicted cooldown rate is 0.08°C/day. This may be regarded as a bit conservative, considering that the hot spot location cools at a rate of 0.12°C/day, but the correspondence between the hot spot data and the predicted NCL bottom temperature is not exact.

8.0 HADCRT CASE INPUT FILES

8.1 Safe Storage, Steady-State (SSSS.DAT)

```
*********************************************************************
*   Underground DST with loss of cooling
*********************************************************************
*
*-------------------------------------------------------------------
CONTROL     ! Major keyword group
*-------------------------------------------------------------------
*
*
 TITLE      ! Keyword; next line is title, title can be any length*  -
 DST AZ-101 SS Conditions; fin heat transfer
 500 scfm primary ventilation, no annulus ventilation, condenser
 END TITLE ! Anything after END is a comment
*
*
*
 TIMING     ! Keyword
   TSTART       0.     !  START TIME, >0 FOR RESTART RUN
   TLAST  10000000.!  END TIME
   DTMIN              !  MIN TIMESTEP (Seconds)
     0.0      1.0
    10.0      1.0
    100.0     5.0
    1000.0    5.0
   100000.0   5.0
   DTMAX              !  MAX TIMESTEP (Seconds)
    0.0       1.0
    5.0       1.0
    100.0     20.0
    1000.     20.0
  100000.     20.
   DTPRIN             !  PRINT INTERVAL (Seconds)
   0.0       100000.0
  1000000. 1000000.
  10000000. 1000000.
   PLTMIN             !  MIN PLOT INTERVAL (Seconds)
   0.0       0.05
   10.0      1.0
   100.0     10.0
   1000.0    100.0
   10000.0   1000.0
   100000.0 10000.0
   1000000.0 100000.0
   PLTMAX             !  MAX INTERVAL WITHOUT PLOT (Seconds)
   0.0       0.1
   10.0      10.
   100.0     100.
   1000.0 1000.0
   10000.0 10000.0
   100000.0 100000.0
   1000000.0 1000000.0
   DTRST              !  RESTART INTERVAL (Seconds)
   0.0       1.E7
   5.E6      1.E6
*
   FTPCH      0.001       !  FRACTIONAL CHANGE IN T AND P
   FAECH      0.001       !  FRACTIONAL CHANGE IN aerosol mass
   FPPLCH     0.03        !  FRACTIONAL CHANGE FOR PLOTTING
 END TIMING ! TIMING is a comment.
*
* COMPOUND LIBRARY ORDER FOR OUTPUT
*   This section allows user specification of the order
*   in which compound names are printed & placed in the
*   plot files.  This section is optional, but recommended.
*   Using this section saves computation time by limiting
*   the range of loops. This section rearranges internal
*   storage to the user-defined order, and essentially
*   defines a sub-library for this case only.
*
*   Format:
*   The section begins with the keyword COMPOUND followed
*   by the number of compounds to be used for this run.
*   Compound names are placed on succeeding lines,
*     using up to 80 columns.
*   Finish the list with the END keyword.
*   You can comment a line in the list by putting
*     the double asterisk ** in cols. 1 and 2.
*   Example (here column 1 has * for comment):
* COMPOUNDS 8
*    STEAM OXYGEN NITROGEN
*    HEXONE CARBON_DIO
*    WASTE WASTTRAC STEATRAC
* END
*
*   User caveats:
*   1. If this is invoked, it MUST PRECEDE any input section that
*   refers to compound names, such as plotting, sources, etc.
*   2. The user must name ALL compounds that are used in the
*   calculation, or else the compound will be skipped. For
```

```
*   example there may be no combustion products initially
*   present anywhere, but these must be named to be used later.
*   3. Spelling must be identical to names in GASPROP.DAT
*   Check the log file for mis-spelling warnings.
*
 COMPOUNDS 4
   STEAM OXYGEN NITROGEN WASTE
 END
*
*
 PLOT        ! Keyword for plotting section
* Plotting syntax:
*
* PRESSURE n rlist - Pressure, Pa
* GAS-T  n rlist  - Gas Temperature, K
* LIQ-T  n rlist  - Liquid Temperature, K
* LIQ-EL n rlist  - Liquid Level, m
* HS-TI  n hlist  - Heat Sink Temperature - Inner Surface, K
* HS-TO  n hlist  - Heat Sink Temperature - Outer Surface, K
* HS-TA  n hlist  - Heat Sink Temperature - Average, K
* AEROSOL n rlist - Aerosol Mass (Total), kg
* GAS-W  n jlist  - Mass Flowrate, kg/s
* GAS-WX n jlist  - CounterCurrent Mass Flowrate, kg/s
* SPECIAL-X n xlist - Special model state variable
* SPECIAL-R n xlist - Special model rate variable
* GAS-X    GASNAME n rlist  - Gas Mole Fraction
* GAS-RH   GASNAME n rlist  - Gas Relative Humidity
* GAS-MASS GASNAME n rlist - Gas Mass (Species), kg
* AER-MASS GASNAME n rlist - Aerosol Mass (Species), kg
* MASS     GASNAME n rlist - Total Mass (Species), kg
* LIQ-MASS - GASNAME n rlist - Deposited Mass (Species), kg
*
* Pressure, Gas Temperature, and total aerosol mass require a region
* list
*
* Heat Sink Temperatures need a heat sink number list
*
* Flowrates need a junction number list
*
* Gas concentration, relative humidity, individual species gas mass,
* individual species aerosol mass, total (gas+aerosol) individual
* species mass, and individual species deposited liquid mass require
* a region and gas name
*
*  special state & rate variables are:
*  1=  Waste surface entrainment during a burn
*  2=  Tank surface entrainment during a burn
*  3=  Waste surface entrainment during blowdown
*  4=  Unused, reserved for tank surface entrainment during blowdown
*  5=  Total entrainment
*
  PRESSURE     4  1  2  3  4     ! Pressure
  GAS-T        4  1  2  3  4     ! Gas Temps
  LIQ-T        2    1   4          ! L temps
  LIQ-EL       2    1   4          ! L elevations
  GAS-X  NITROGEN   1   1         ! N2 Concentration
  GAS-X  OXYGEN     1   1         ! O2 concentration
  GAS-X  STEAM      1   1         ! H2O concentration
  GAS-W        4    1   2   3   4  ! Gas flow rates
  HS-TA        7    3 4 5 6 7 8 9
  WCOND-PL  STEAM   1   1          ! Condensation rate of steam on pool
  WCOND-HSO STEAM   2   1   18     ! Condensation rate of steam on hs-1
  WCOND-HSI STEAM   4   2   3   4  18 ! Condensation rate of steam on hs-2
& 3
  QGAS-HSO     8   1   3   4   5   6  7  8  13    ! gas-to-hs hx
  QGAS-HSI     7   2   3   4   5  13 15 16    ! gas-to-hs hx
  QGAS-POOL    1   1      ! gas-to-pool hx
  QLIQ-HSI     4   4   5   6   7    ! liquid-to-hs hx
  QLIQ-HSO     1   9                ! liquid-to-hs hx
 END PLOT  ! PLOT is a comment
*
PRINT
      HS 18 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
END
*
 ACTIVE MODELS ! Keyword; MODELS is a comment; 1 = on, 0 = off
  IJUNC   1    ! Junction flow model
  ICCFLW  0   ! Counter-current flow model
  IHSINK  1    ! Heat sinks
  IHXPOL  1    ! gas-pool heat/mass transfer
  ICNDS   1    ! Condensation
  IASED   1    ! Aerosol Sedimentation
  IALEAK  1   ! Aerosol Leakage
  IFOG    1    ! Fog formation
  ISRC    1    ! User-defined sources
  IQDECAY 1    ! Decay power
  IMCO    0    ! MCO models
  ISENS   0    ! Sensitivity runs
  ILXFER  1   ! Liquid transfers
  IDCRT   0    ! DCRT Runs
 END ACTIVE MODELS ! ACTIVE MODELS  is a comment
*
*
 MODEL PARAMETERS
  AGAMMA   2.5   ! Shape factor for nonsphericity for coagulation
  ACHI     1.0   ! Shape factor for nonsphericity for stokes'law
  AFEO     1.0   ! Collision efficiency: 1.0 Fuchs, 0.33 Prupacher-Klett
  ENT_BOIL 2.E-7  ! Boiling entrainment coefficient
  SURF_LIQ 0.07   ! Liquid surface tension; water is default
 END MODEL PARAMETERS
*
C-----------------------------------------------------------------------
C      DECAY POWER
C
 DECAY
    WASTE   0.0407
```

```
 END
*
C-----------------------------------------------------------------------
C       SOURCE GROUP:  GROUPS REPEATED FOR INPUT # OF REGIONS
C         END OF GROUP DESIGNATED BY 'REGION' OR 'END' KEYWORDS
C       ENTER: TIME, TEMP, FLOWRATES, POWER
C       SYNTAX EXAMPLE:
SOURCES 1                          ! -- KEYWORD AND # SOURCE GROUPS
 REGION  1  GASES 1  PHASE 3        !-- REGION #, # COMPOUNDS, PHASE #
    STEAM              !-- GAS NAMES MUST BE ON NEXT LINE
  0      26.7   0.0 0.00E5 ! MIXER PUMP POWER
  1.0E9 26.7   0.0 0.00E5 ! MIXER PUMP POWER
 END REGION                     !-- ENDS A REGION SOURCE
END SOURCES

* PHASE INDEX: 1=GAS, 2=AERO, 3=LIQUID
*
*
*
END CONTROL    ! End of CONTROL keyword group
*
*
*-----------------------------------------------------------------------
*     OPERATIONS
*-----------------------------------------------------------------------
*
 OPERATIONS
*
*     OPERATIONS         ! Keyword to begin this section
*
*     Keyword groups go here as described below.  Active groups are:
*     TRANSFER
*
*     END OPERATIONS     ! End is a comment here
*
*     WASTE TRANSFER SYNTAX:  SAME AS REGION & JUNCTION SYNTAX, COLUMNS
*     TRANSFER ilist     Keyword TRANSFER followed by list of indices
*                        each index is a transfer index #
*       KEYWORD  rlist   Keyword name (see list below) and column values
*                        corresponding to ilist above
*      END                End this section
*     Use 5 transfer columns per set maximum, then repeat the group
*     Maximum of 30 defined transfers
*
*     Waste is transferred from region IXR1 to IXR2 at constant
*        volumetric flowrate WV_XFER or at a pulsed flowrate
*        during the active duty cycle time DUTY_ON, followed by
*        the idle cycle duration DUTY_OFF.
*     Transfers start at time T_START and end at time T_END.
*     Rational level controls also exist for transfers.
*     Transfer begins when donor region level exceeds
*        the high level ZL1_HI.  Default begins transfer if the
*        donor level exceeds region top minus 1 cm.
*     Transfer ends when donor region level falls below
*        the low level ZL1_LO.  Default ends at 1 cm elevation.
*     Transfer ends when receiver region level exceeds
*        the high level ZL2_HI.  Default ends transfer if the
*        receiver level exceeds region top minus 1 cm.
*     The program will abort due to errors in PTREG1 or PTREG2
*        if a region becomes "solid", and transfers or
*        sources into a full region are the cause.  Remedy by
*        better control over intended transfers.
*     Waste can be cascaded in a series of tanks via a series
*        of transfers initiated on level.
*     Waste can flow in both directions controlled by level,
*        using a pair of transfers, one in each direction.
*
*     WASTE TRANSFER KEYWORD DEFINITIONS
*
*     IXR1        "FROM" REGION
*     IXR2        "TO" REGION
*     IDUTY       1= USE DUTY CYCLES, 0= CONSTANT FLOW
*     IR1_HI      1= BEGIN ON HIGH LEVEL IN IXR1, 0= IGNORE
*     WV_XFER     NOMINAL VOLUMETRIC FLOWRATE AT ZERO DP WHEN ACTIVE
*     T_START     TIME TO START XFER FLOW
*     T_END       TIME TO END XFER FLOW
*     DUTY_ON     DUTY CYCLE TIME FOR TRANSFER FLOW IF PERIODIC
*     DUTY_OFF    DUTY CYCLE TIME FOR NO (OFF) TRANSFER FLOW IF PERIODIC
*                 TOGETHER THESE CYCLE TIMES DEFINE A COMPLETE CYCLE
*     ZL1_HI      HIGH LEVEL IN "FROM" REGION THAT BEGINS XFER:
*                  ZLR(IXR1) > ZL1_HI. DEFAULT: 1 CM FROM TOP
*     ZL2_HI      HIGH LEVEL IN "TO" REGION THAT ENDS XFER:
*                  ZLR(IXR2) < ZL2_HI. DEFAULT: 1 CM FROM TOP
*     ZL1_LO      LOW LEVEL IN "FROM" REGION THAT ENDS XFER:
*                  ZLR(IXR1) < ZL1_LO. DEFAULT: 1 CM FROM BOTTOM

 TRANSFER          1
     IXR1          4
     IXR2          1
     IDUTY         0
     IR1_HI        1
     WV_XFER      1.E6
     T_START      0.0
     T_END        1.0E10
     DUTY_ON      100.
     DUTY_OFF     100.
     ZL1_HI      10.0
     ZL2_HI      7.47
     ZL1_LO      1.00
 END TRANSFER

END OPERATIIONS
*-----------------------------------------------------------------------
VOLUMES    4       ! total number of control volumes
*-----------------------------------------------------------------------
* No more than 5 columns (regions) at a time
```

```
* Units:
* VOLUME m^3, SED_AREA m^2, ELEVATION m, TEMP_GAS K, PRESSURE  Pa
*
*              TANK            ANNULUS     Ambient    Condenser
 REGIONS        1                2           3          4
  VOLUME      5338.            623.78      1.E10      1000.
  SED_AREA     411.             0.0        0.0        0.0
  ELEVATION    0.429            0.0        15.        16.
  TEMP_GAS     45.             28.0        28.        10.0
  PRESSURE     101350.         101350.     101350.    101350.
  ZTOP        12.99            11.0       1.E6        1000.
  Z_LIQ        7.47            0.01       0.00        990.0
  TEMP_LIQ     49.0            28.0       28.0        10.0
 END REGIONS  ! REGIONS is a comment
*
* Gas composition of each region; specify mole fraction of each gas
* No more than five columns at a time
*
*             TANK        ANNULUS   AMBIENT     CONDENSER
 GASES         1            2         3           4
  STEAM       0.100        0.1       0.0023      0.0100
  OXYGEN      0.189        0.189     0.2077      0.2000
  NITROGEN    0.711        0.711     0.7900      0.7900
 END GASES           ! GASES is a comment
*
*            TANK     ANNULUS   AMBIENT   CONDENSER
LIQUIDS       1          2         3         4
  STEAM      0.790   1.0       1.0       1.0
  WASTE      0.210    0.0       0.0       0.0
END LIQS          ! LIQS is a comment
*
* Aerosol concentration of each region (kg/m^3)
* No more than five columns at a time
*
*AEROSOLS       1         2         3         4        5
* WASTE       0.000     0.0       0.0       0.0      0.0
*END AEROSOLS ! AEROSOLS is a comment
*   OFFSET_TIMETG
*   EXTRAPOLATION_TIMETG
*   TIMETG  REGION # TIME1, TIME2...TIMELAST
*   TGFIX   REGION # TEMP1, TEMP2... TEMPLAST   TEMPS ARE IN C!!!
*   LINEAR INTERPOLATION BETWEEN VALUES
*
*   SIMILAR SYNTAX FOR PRESSURE:
*   OFFSET_TIMETG
*   EXTRAPOLATION_TIMEPG
*   TIMEP  REGION #  TIME1, TIME2...
*   PRFIX  REGION #  PRES1, PRES2...PRESSURES ARE IN PA!!!
*
*  OFFSET_TIMETG=  OFFSET TIME; ENTER LOOKUP TABLE WITH
*                  TIME+OFFSET_TIMETG
*  EXTRAPOLATION_TIMETG= LAST TO USE LAST VALUE IN THE TABLE,
*                      = EXTRAP TO EXTRAPOLATE FROM LAST TWO POINTS,
*                      = PERIOD TO WRAP AROUND.
*  OFFSET_TIMETG          0.
*  EXTRAPOLATION_TIMETG      LAST
*TIMETG 4  0.0     1.E10
*TGFIX  4 15.0     15.0
*
* CONTROL  BOUNDARY P,
*  OFFSET_TIMEPG          0.
*  EXTRAPOLATION_TIMEPG      EXTRAP
*TIMEP 4  0.0        1.E10
*PRFIX  4  0.9840E5 0.9840E5
END
* Major keyword-----------------------------------------------------------
HEAT_SINKS      18 !Total number of heat sinks
*------------------------------------------------------------------------
* No more than 5 columns at a time,
* Repeat the following structure,
* SINKS
* .
* .
* .
* END
*
* Syntax:
* IGEOM  1 for plane, 0 or 2 for cylinder
* IORIHS 0 for vertical, 1 for horizontal
* RHO    Density (kg/m^3)
* KHS    Thermal Conductivity (W/m/K)
* CPHS   Specific Heat (J/kg/K)
* QV      Volumetric Heat Generation (W/m^3)
* XRI     Inner Radius (m)
* XRO     Outer Radius (m); for plane wall, thickness = XRO-XRI
* AHS     One-sided heat sink area (m^2)
* TIINIT  Initial inside surface temperature (C)
* TOINIT  Initial outside surface temperature (C)
* IMSLAB  Number of slabs; 3 is minimum
* IREGI   Region index for inner surface or 0 (insulated)
*         or -1 for constant temperature
* TIHS    Region surface temperature when IREGI = -1  (C)
* IREGO   Region index for outer surface or 0 (insulated)
*         or -1 for constant temperature
* TOHS    Region surface temperature when IREGO = -1  (C)
* XLHS    Characteristic length for natural convection (m)
* EHSI    Emissivity of inner surface
* EHSO    Emissivity of outer surface
*
*
SINKS        1          2          3          4          5
*          tank       tank top   tank wall  tank wall  tank wall
*         ceiling      soil       first     second      third
 IGEOM       1          1          2          2          2
 IORIHS      1          1          0          0          0
 IMATHS      1          2          1          1          1
```

```
 XRI        0.0000      0.0         11.438      11.438      11.438
 XRO        0.0100      4.0         11.448      11.448      11.448
 AHS        411.0     411.0       358.0       143.891     143.891
 TIINIT       45.00     20.0        49.0        49.0        49.0
 TOINIT       45.00     45.0        49.0        49.0        49.0
 IMSLAB        3        20           3           3           3
 IREGI         0         3           1           1           1
 TIHS         0.0       0.0         0.0         0.0         0.0
 IREGO         1         0           2           2           2
 TOHS         0.0       0.0         0.0         0.0         0.0
 XLHS        22.88     22.88       5.0         2.0         2.0
 XZHS         0.0       0.0        2.50         1.0         1.0
 ZBHS        12.99     13.00       8.75        7.0         5.0
 ZTHS        13.00     15.1433    12.98        8.75        7.0
END
*
SINKS         6          7           8           9          10
*        tank wall   tank wall   tank wall  non-convective  tank
*          fourth      fifth       sixth       layer       floor
 IGEOM        2          2           2           1           1
 IORIHS       0          0           0           2           2
 IMATHS       1          1           1           3           1
 XRI        11.438     11.438      11.438       0.0         0.0
 XRO        11.448     11.448      11.448       0.43        0.01
 AHS       143.891    143.891      71.946     411.0       411.0
 TIINIT       54.00      54.0        54.0       64.0        54.0
 TOINIT       54.00      54.0        54.0       64.0        54.0
 IMSLAB        3          3           3          20           3
 IREGI         1          1           1           0           0
 TIHS         0.0        0.0         0.0         0.0         0.0
 IREGO         2          2           2           1           0
 TOHS         0.0        0.0         0.0         0.0         0.0
 XLHS        2.00       2.00        1.0        22.88       22.88
 XZHS         1.0        1.0       0.025        11.0         0.0
 ZBHS         3.0        1.0         0.0         0.0       -0.01
 ZTHS         5.0        3.0         1.0        0.43         0.0
END
*
SINKS        11         12          13          14          15
*       tank bottom  tank bottom  annulus top  annulus wall  annulus wall
*         concrete     soil         soil        soil        concrete
 IGEOM        1          1           1           0           0
 IORIHS       2          2           1           0           0
 IMATHS       4          2           2           2           4
 XRI        0.0        0.0         0.0       12.707      12.225
 XRO        0.4572    30.0         4.0      112.707      12.707
 AHS        411.0     411.0       411.0      1223.82     861.59
 TIINIT     49.00      12.0        20.0       49.0        49.0
 TOINIT     49.00      49.0        49.0       25.0        45.0
 IMSLAB     20         20          20         20          20
 IREGI       0         -1           3          0           2
 TIHS       0.0       12.0         0.0        0.0         0.0
 IREGO       0          0           2          0           0
 TOHS        0.0        0.0         0.0       20.0         0.0
 XLHS        0.0        0.0       0.762        0.0        11.0
 XZHS        0.0        0.0         4.0        0.0         0.0
 ZBHS      -0.4826   -10.4826      10.99        0.0         0.0
 ZTHS      -0.0100    -0.4826      15.0       11.0        11.0
END
*
SINKS        16          17          18
*       annulus bottom  annulus bottom  condenser
*         concrete        soil
 IGEOM        1           1           1
 IORIHS       2           2           1
 IMATHS       4           2           5
 XRI        0.0         0.0         0.0
 XRO       0.4572      10.0         0.01
 AHS       56.707      56.707      1000.
 TIINIT     25.00       20.0        10.0
 TOINIT     45.00       45.0        10.0
 IMSLAB     20          20           3
 IREGI       0          -1          -1
 TIHS       0.0        20.0        10.0
 IREGO       2           0           4
 TOHS       0.0         0.0        10.0
 XLHS      0.762        0.0      1000.0
 XZHS       0.0         0.0         0.0
 ZBHS     -0.4572     -10.4826     1015.0
 ZTHS       0.0        -0.4826     1016.0
END
*
*    name      index    rho     khs     cp      qv     ehs1    ehso
MATERIAL
     STSTEEL     1     8000.    16.     500.    0.     0.75    0.75
     SOIL        2     1500.    1.0    1840.   0.      0.75    0.75
     SLUDGE      3     1640.    0.9    2255.   231.0   0.75    0.75
     CONCRETE    4     2200.    0.6    880.    0.      0.75    0.75
     TUBE        5    10000.0  1000.0 10000.   0.0     0.5     0.5
END
*
COND_NETWORK 3,4,5,6,7,8
SANDWICH  9  1000.  10   1000.  11  1000. 12
SANDWICH  1  1000.  2
SANDWICH  14 1000.  15
SANDWICH  16 1000.  17
*
*
* USER CAN CONTROL HEAT SINK BOUNDARY TEMPERATURE
* SYNTAX:
*          OFFSET_TIMEHS
*          EXTRAPOLATION_TIMEHS
*          TIMTHS IHS ISD TIME1, TIME2...
*          THSFIX IHS ISD TEMP1, TEMP2..
* IHS = HEAT SINK NO.; ISD = SIDE NO. (1 OR 2) FOR IHS
* CONTROL HEAT SINK BOUNDARY T
```

```
* OFFSET_TIMEHS          0.
*EXTRAPOLATION_TIMEHS     EXTRAP
* TIMTHS 15 2 0.0      1.E6
* THSFIX 15 2 85.0     85.0
* TIMTHS 30 2 0.0      1.E6
* THSFIX 30 2 85.0     85.0
* TIMTHS 41 2 0.0      1.E6
* THSFIX 41 2 85.0     85.0
* TIMTHS 42 1 0.0      1.E6
* THSFIX 42 1 85.0     85.0
* TIMTHS 43 2 0.0      1.E6
* THSFIX 43 2 85.0     85.0
*
*
END HEAT_SINKS ! HEAT_SINKS is a comment
*-----------------------------------------------------------------------
JUNCTIONS   5 ! 4 Junctions
*-----------------------------------------------------------------------
*
* Syntax:
*  IJTYP   Junction Type: 1 = Normal, 2 = HEPA, 3 = Cover
*  IR1     Upstream Region
*  IR2     Downstream Region
*  AJN     Area (m^2)
*  ABYP    Bypass area for HEPA junction (m^2)
*  PHEPA   HEPA Filter Failure Pressure (Pa)
*  ACOV    Cover Area (m^2)
*  MCOV    Cover Weight (kg)
*  Z1JN    Elevation wrt floor of IR1 opening (m)
*  Z2JN    "          "  "    "   IR2   "    "
*  CJN     Loss coefficient multiplies 0.5*rho*v^2
*  IHORIZ  Orientation: 1 = horizontal, 0 = vertical
*  XWJN    Characteristic width, m
*  XHJN    Characteristic height, m
*  XLJN    Characteristic length, m
*  DFJN    Decontamination Factor
*  N90     No. of 90 bends
*
*              INLET                      ANNULUS     ANNULUS  condenser
*              LEAKAGE       OUTLET       INLET       OUTLET   outlet
     PATHS       1            2            3           4        5
        IJTYP    1            1            1           1        1
        IR1      3            1            3           2        4
        IR2      1            4            2           3        3
        IHORIZ   1            0          0           0        0
        XWJN     0.1000     0.1000       0.1524      0.1524    0.01
        XHJN     0.1000     0.1000       0.1524      0.1524    0.01
        XLJN     1000.        20.    5.0         5.0       10.0
        AJN      0.03000    0.03000      0.07297     0.07297   0.030
        Z1JN     1.0          12.0       1.00        12.00     10.0
        Z2JN     12.0         1.0        12.00       1.00      10.0
        CJN      5.           5.0        2.0          2.0      5.0
        DFJN     1.0          1.0        1.0         1.0       1.0
```

```
        N90      0            0            0           0        0.0
        KFILTER  1000.      10000.     1000.0      1000.0    15000.
        IFAN     0            0          0           0          1
        WVFAN    0.0          0.0      0.0         0.0        0.46
     END PATHS  ! PATHS is a comment.
*
*
END JUNCTIONS   ! JUNCTIONS is a comment.
```

8.2 Comparison of SSSS.DAT (indicated by "<") against SSLV.DAT (Loss of Ventilation Scenario, indicated by ">")

```
12c12
<  500 scfm primary ventilation, no annulus ventilation, condenser
---
>  restart w/ no scfm primary ventilation, no annulus ventilation,
condenser
18,19c18,19
<    TSTART      0.     !  START TIME, >0 FOR RESTART RUN
<    TLAST  10000000.!  END TIME
---
>    TSTART 10001000.     !  START TIME, >0 FOR RESTART RUN
>    TLAST  50000000.!  END TIME
23,24c23,24
<     100.0    5.0
<     1000.0   5.0
---
>     100.0    1.0
>     1000.0   1.0
29,30c29,30
<     100.0    20.0
<     1000.    20.0
---
>     100.0    5.0
>     1000.    5.0
54c54
<    5.E6      1.E6
---
>    3.E6      1.E7
149a150,152
>   HS-TI        1   9
>   HS-TO        1   9
>   AER-MASS WASTE 4 1 2 3 4
283c286
<      IXR2          1
---
>      IXR2          3
```

```
357,358c360,361
< *TIMETG 4  0.0    1.E10
< *TGFIX  4 15.0    15.0
---
> * TIMETG 4  0.0    1.E10
> * TGFIX  4 15.0    15.0
363,364c366,367
< *TIMEP 4  0.0       1.E10
< *PRFIX  4  0.9840E5 0.9840E5
---
> * TIMEP 4  0.0       1.E10
> * PRFIX  4  1.0135E5 1.0135E5
432,433c435,436
<  TIINIT        54.00      54.0        54.0        64.0        54.0
<  TOINIT        54.00      54.0        54.0        64.0        54.0
---
>  TIINIT        54.00      54.0        54.0        54.0        54.0
>  TOINIT        54.00      54.0        54.0        54.0        54.0
440c443
<  XZHS          1.0        1.0         0.025       11.0        0.0
---
>  XZHS          1.0        1.0         0.025       0.1         0.0
568,569c571,572
<          IFAN    0          0          0          0          1
<          WVFAN   0.0        0.0    0.0       0.0        0.46
---
>          IFAN    0          0          0          0          0
>          WVFAN   0.0        0.0    0.0       0.0        0.00
```

8.3 Retrieval Steady-State Input File (RETSS.DAT)

```
*****************************************************************
*   Underground DST with loss of cooling
*****************************************************************
*
*---------------------------------------------------------------
CONTROL     ! Major keyword group
*---------------------------------------------------------------
*
*
 TITLE      ! Keyword; next line is title, title can be any length*  -
 DST AZ-101 Run to mixer pump SS Conditions; fin heat transfer
 500 scfm primary ventilation, no annulus ventilation, condenser
 END TITLE ! Anything after END is a comment
*
*
*
```

```
TIMING    ! Keyword
  TSTART       0.     !  START TIME, >0 FOR RESTART RUN
  TLAST  10000000.!  END TIME
  DTMIN                !  MIN TIMESTEP (Seconds)
    0.0      1.0
   10.0      1.0
   100.0     1.0
   1000.0    1.0
  100000.0   1.0
  DTMAX                !  MAX TIMESTEP (Seconds)
   0.0       1.0
   5.0       1.0
   100.0     5.0
   1000.     5.0
 100000.     5.
  DTPRIN               !  PRINT INTERVAL (Seconds)
  0.0       100000.0
 1000000. 1000000.
 10000000. 1000000.
  PLTMIN               !  MIN PLOT INTERVAL (Seconds)
  0.0       0.05
  10.0      1.0
  100.0     10.0
  1000.0    100.0
  10000.0   1000.0
  100000.0 10000.0
  1000000.0 100000.0
  PLTMAX               !  MAX INTERVAL WITHOUT PLOT (Seconds)
  0.0       0.1
  10.0      10.
  100.0    100.
  1000.0 1000.0
  10000.0 10000.0
  100000.0 100000.0
  1000000.0 1000000.0
  DTRST                !  RESTART INTERVAL (Seconds)
  0.0       1.4e6
  3.E6      1.E7
*
  FTPCH      0.001        !  FRACTIONAL CHANGE IN T AND P
  FAECH      0.001        !  FRACTIONAL CHANGE IN aerosol mass
  FPPLCH     0.03         !  FRACTIONAL CHANGE FOR PLOTTING
END TIMING ! TIMING is a comment.
*
* COMPOUND LIBRARY ORDER FOR OUTPUT
*   This section allows user specification of the order
*   in which compound names are printed & placed in the
*   plot files.  This section is optional, but recommended.
*   Using this section saves computation time by limiting
*   the range of loops. This section rearranges internal
*   storage to the user-defined order, and essentially
*   defines a sub-library for this case only.
*
```

```
*   Format:
*   The section begins with the keyword COMPOUND followed
*   by the number of compounds to be used for this run.
*   Compound names are placed on succeeding lines,
*     using up to 80 columns.
*   Finish the list with the END keyword.
*   You can comment a line in the list by putting
*     the double asterisk ** in cols. 1 and 2.
*   Example (here column 1 has * for comment):
* COMPOUNDS 8
*    STEAM OXYGEN NITROGEN
*    HEXONE CARBON_DIO
*    WASTE WASTTRAC STEATRAC
* END
*
*   User caveats:
*   1. If this is invoked, it MUST PRECEDE any input section that
*   refers to compound names, such as plotting, sources, etc.
*   2. The user must name ALL compounds that are used in the
*   calculation, or else the compound will be skipped. For
*   example there may be no combustion products initially
*   present anywhere, but these must be named to be used later.
*   3. Spelling must be identical to names in GASPROP.DAT
*   Check the log file for mis-spelling warnings.
*
 COMPOUNDS 4
   STEAM OXYGEN NITROGEN WASTE
 END
*
*
 PLOT        ! Keyword for plotting section
* Plotting syntax:
*
* PRESSURE n rlist - Pressure, Pa
* GAS-T  n rlist  - Gas Temperature, K
* LIQ-T  n rlist  - Liquid Temperature, K
* LIQ-EL n rlist  - Liquid Level, m
* HS-TI  n hlist  - Heat Sink Temperature - Inner Surface, K
* HS-TO  n hlist  - Heat Sink Temperature - Outer Surface, K
* HS-TA  n hlist  - Heat Sink Temperature - Average, K
* AEROSOL n rlist - Aerosol Mass (Total), kg
* GAS-W  n jlist  - Mass Flowrate, kg/s
* GAS-WX n jlist  - CounterCurrent Mass Flowrate, kg/s
* SPECIAL-X n xlist - Special model state variable
* SPECIAL-R n xlist - Special model rate variable
* GAS-X    GASNAME n rlist  - Gas Mole Fraction
* GAS-RH   GASNAME n rlist  - Gas Relative Humidity
* GAS-MASS GASNAME n rlist - Gas Mass (Species), kg
* AER-MASS GASNAME n rlist - Aerosol Mass (Species), kg
* MASS     GASNAME n rlist - Total Mass (Species), kg
* LIQ-MASS - GASNAME n rlist - Deposited Mass (Species), kg
*
* Pressure, Gas Temperature, and total aerosol mass require a region
* list
*
* Heat Sink Temperatures need a heat sink number list
*
* Flowrates need a junction number list
*
* Gas concentration, relative humidity, individual species gas mass,
* individual species aerosol mass, total (gas+aerosol) individual
* species mass, and individual species deposited liquid mass require
* a region and gas name
*
*  special state & rate variables are:
*  1=  Waste surface entrainment during a burn
*  2=  Tank surface entrainment during a burn
*  3=  Waste surface entrainment during blowdown
*  4=  Unused, reserved for tank surface entrainment during blowdown
*  5=  Total entrainment
*
  PRESSURE     4  1  2  3  4     ! Pressure
  GAS-T        4  1  2  3  4      ! Gas Temps
  LIQ-T        2    1   4          ! L temps
  LIQ-EL       2    1   4          ! L elevations
  GAS-X  NITROGEN   1   1         ! N2 Concentration
  GAS-X  OXYGEN     1   1         ! O2 concentration
  GAS-X  STEAM      1   1         ! H2O concentration
  GAS-W        4    1   2   3   4  ! Gas flow rates
  HS-TA        7    3 4 5 6 7 8 9
  WCOND-PL  STEAM   1   1          ! Condensation rate of steam on pool
  WCOND-HSO STEAM   2   1   18      ! Condensation rate of steam on hs-1
  WCOND-HSI STEAM   4   2   3   4  18 ! Condensation rate of steam on hs-2
& 3
  QGAS-HSO     8   1   3   4   5   6  7  8  13     ! gas-to-hs hx
  QGAS-HSI     7   2   3   4   5  13 15 16     ! gas-to-hs hx
  QGAS-POOL    1   1       ! gas-to-pool hx
  QLIQ-HSI     4   4   5   6   7     ! liquid-to-hs hx
  QLIQ-HSO     1   9                 ! liquid-to-hs hx
 END PLOT  ! PLOT is a comment
*
PRINT
      HS 18 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
END
*
 ACTIVE MODELS ! Keyword; MODELS is a comment; 1 = on, 0 = off
  IJUNC   1    ! Junction flow model
  ICCFLW  0   ! Counter-current flow model
  IHSINK  1    ! Heat sinks
  IHXPOL  1    ! gas-pool heat/mass transfer
  ICNDS   1    ! Condensation
  IASED   1    ! Aerosol Sedimentation
  IALEAK  1   ! Aerosol Leakage
  IFOG    1    ! Fog formation
  ISRC    1    ! User-defined sources
  IQDECAY 1    ! Decay power
```

```
  INCO    0     ! MCO models
  ISENS   0     ! Sensitivity runs
  ILXFER  1    ! Liquid transfers
  IDCRT   0     ! DCRT Runs
 END ACTIVE MODELS ! ACTIVE MODELS  is a comment
*
*
 MODEL PARAMETERS
  AGAMMA   2.5   ! Shape factor for nonsphericity for coagulation
  ACHI     1.0   ! Shape factor for nonsphericity for stokes'law
  APEO     1.0   ! Collision efficiency: 1.0 Fuchs, 0.33 Prupacher-Klett
  ENT_BOIL 2.E-7  ! Boiling entrainment coefficient
  SURF_LIQ 0.07   ! Liquid surface tension; water is default
 END MODEL PARAMETERS
*
C-----------------------------------------------------------------------
C      DECAY POWER
C
 DECAY
    WASTE   0.07588
 END
*
C-----------------------------------------------------------------------
C      SOURCE GROUP:  GROUPS REPEATED FOR INPUT # OF REGIONS
C        END OF GROUP DESIGNATED BY 'REGION' OR 'END' KEYWORDS
C      ENTER: TIME, TEMP, FLOWRATES, POWER
C      SYNTAX EXAMPLE:
SOURCES 1                          ! -- KEYWORD AND # SOURCE GROUPS
 REGION  1  GASES 1  PHASE 3        !-- REGION #, # COMPOUNDS, PHASE #
    STEAM              !-- GAS NAMES MUST BE ON NEXT LINE
  0      26.7   0.0 4.39E5 ! MIXER PUMP POWER
  1.0E9 26.7   0.0 4.39E5 ! MIXER PUMP POWER
 END REGION                     !-- ENDS A REGION SOURCE
END SOURCES

* PHASE INDEX: 1=GAS, 2=AERO, 3=LIQUID
*
*
*
END CONTROL    ! End of CONTROL keyword group
*
*
*-----------------------------------------------------------------------
*     OPERATIONS
*-----------------------------------------------------------------------
*
 OPERATIONS
*
*     OPERATIONS         ! Keyword to begin this section
*
*     Keyword groups go here as described below.  Active groups are:
*     TRANSFER
*
*     END OPERATIONS    ! End is a comment here
*
*     WASTE TRANSFER SYNTAX:  SAME AS REGION & JUNCTION SYNTAX, COLUMNS
*     TRANSFER ilist    Keyword TRANSFER followed by list of indices
*                       each index is a transfer index #
*       KEYWORD  rlist  Keyword name (see list below) and column values
*                       corresponding to ilist above
*      END               End this section
*     Use 5 transfer columns per set maximum, then repeat the group
*     Maximum of 30 defined transfers
*
*     Waste is transferred from region IXR1 to IXR2 at constant
*        volumetric flowrate WV_XFER or at a pulsed flowrate
*        during the active duty cycle time DUTY_ON, followed by
*        the idle cycle duration DUTY_OFF.
*     Transfers start at time T_START and end at time T_END.
*     Rational level controls also exist for transfers.
*     Transfer begins when donor region level exceeds
*        the high level ZL1_HI.  Default begins transfer if the
*        donor level exceeds region top minus 1 cm.
*     Transfer ends when donor region level falls below
*        the low level ZL1_LO.  Default ends at 1 cm elevation.
*     Transfer ends when receiver region level exceeds
*        the high level ZL2_HI.  Default ends transfer if the
*        receiver level exceeds region top minus 1 cm.
*     The program will abort due to errors in PTREG1 or PTREG2
*        if a region becomes "solid", and transfers or
*        sources into a full region are the cause.  Remedy by
*        better control over intended transfers.
*     Waste can be cascaded in a series of tanks via a series
*        of transfers initiated on level.
*     Waste can flow in both directions controlled by level,
*        using a pair of transfers, one in each direction.
*
*     WASTE TRANSFER KEYWORD DEFINITIONS
*
*     IXR1        "FROM" REGION
*     IXR2        "TO" REGION
*     IDUTY       1= USE DUTY CYCLES, 0= CONSTANT FLOW
*     IR1_HI      1= BEGIN ON HIGH LEVEL IN IXR1, 0= IGNORE
*     WV_XFER     NOMINAL VOLUMETRIC FLOWRATE AT ZERO DP WHEN ACTIVE
*     T_START     TIME TO START XFER FLOW
*     T_END       TIME TO END XFER FLOW
*     DUTY_ON     DUTY CYCLE TIME FOR TRANSFER FLOW IF PERIODIC
*     DUTY_OFF    DUTY CYCLE TIME FOR NO (OFF) TRANSFER FLOW IF PERIODIC
*                 TOGETHER THESE CYCLE TIMES DEFINE A COMPLETE CYCLE
*     ZL1_HI      HIGH LEVEL IN "FROM" REGION THAT BEGINS XFER:
*                  ZLR(IXR1) > ZL1_HI. DEFAULT: 1 CM FROM TOP
*     ZL2_HI      HIGH LEVEL IN "TO" REGION THAT ENDS XFER:
*                  ZLR(IXR2) < ZL2_HI. DEFAULT: 1 CM FROM TOP
*     ZL1_LO      LOW LEVEL IN "FROM" REGION THAT ENDS XFER:
*                  ZLR(IXR1) < ZL1_LO. DEFAULT: 1 CM FROM BOTTOM
```

```
 TRANSFER          1
     IXR1          4
     IXR2          1
     IDUTY         0
     IR1_HI        1
     WV_XFER      1.E6
     T_START      0.0
     T_END        1.0E10
     DUTY_ON      100.
     DUTY_OFF     100.
     ZL1_HI      10.0
     ZL2_HI      7.90
     ZL1_LO      1.00
 END TRANSFER

END OPERATIIONS
*-----------------------------------------------------------------------
VOLUMES    4       ! total number of control volumes
*-----------------------------------------------------------------------
* No more than 5 columns (regions) at a time
* Units:
* VOLUME m^3, SED_AREA m^2, ELEVATION m, TEMP_GAS K, PRESSURE  Pa
*
*              TANK            ANNULUS     Ambient   Condenser
 REGIONS        1                2           3         4
  VOLUME      5338.            623.78      1.E10     1000.
  SED_AREA     411.             0.0         0.0      0.0
  ELEVATION    0.0              0.0        15.     16.
  TEMP_GAS     54.             28.0        28.       10.0
  PRESSURE     101350.        101350.      101350.   101350.
  ZTOP        12.99             11.0        1.E6    1000.
  Z_LIQ        7.90          0.01       0.00     990.0
  TEMP_LIQ     61.0            28.0      28.0       10.0
 END REGIONS  ! REGIONS is a comment
*
* Gas composition of each region; specify mole fraction of each gas
* No more than five columns at a time
*
*             TANK        ANNULUS   AMBIENT     CONDENSER
 GASES         1           2         3           4
  STEAM       0.100        0.1      0.0023      0.0100
  OXYGEN      0.189       0.189     0.2077      0.2000
  NITROGEN    0.711       0.711     0.7900      0.7900
 END GASES          ! GASES is a comment
*
*             TANK      ANNULUS   AMBIENT   CONDENSER
LIQUIDS       1          2         3         4
  STEAM      0.760   1.0       1.0       1.0
  WASTE      0.240    0.0      0.0       0.0
END LIQS          ! LIQS is a comment
*
* Aerosol concentration of each region (kg/m^3)
* No more than five columns at a time
*
*AEROSOLS       1         2         3         4        5
* WASTE        0.000     0.0       0.0       0.0      0.0
*END AEROSOLS ! AEROSOLS is a comment
*   OFFSET_TIMETG
*   EXTRAPOLATION_TIMETG
*   TIMETG  REGION # TIME1, TIME2...TIMELAST
*   TGFIX   REGION # TEMP1, TEMP2... TEMPLAST   TEMPS ARE IN C!!!
*   LINEAR INTERPOLATION BETWEEN VALUES
*
*   SIMILAR SYNTAX FOR PRESSURE:
*   OFFSET_TIMETG
*   EXTRAPOLATION_TIMEPG
*   TIMEP  REGION #  TIME1, TIME2...
*   PRFIX  REGION #  PRES1, PRES2...PRESSURES ARE IN PA!!!
*
*  OFFSET_TIMETG=  OFFSET TIME; ENTER LOOKUP TABLE WITH
*                  TIME+OFFSET_TIMETG
*  EXTRAPOLATION_TIMETG= LAST TO USE LAST VALUE IN THE TABLE,
*                      = EXTRAP TO EXTRAPOLATE FROM LAST TWO POINTS,
*                      = PERIOD TO WRAP AROUND.
*  OFFSET_TIMETG          0.
*  EXTRAPOLATION_TIMETG      LAST
* TIMETG 4  0.0    1.E10
* TGFIX  4 15.0    15.0
*
* CONTROL  BOUNDARY P,
*  OFFSET_TIMEPG          0.
*  EXTRAPOLATION_TIMEPG     EXTRAP
* TIMEP 4  0.0        1.E10
* PRFIX  4  1.0135E5 1.0135E5
END
* Major keyword-------------------------------------------------------
HEAT_SINKS     18 !Total number of heat sinks
*-----------------------------------------------------------------------
* No more than 5 columns at a time,
* Repeat the following structure,
* SINKS
* .
* .
* .
* END
*
* Syntax:
* IGEOM  1 for plane, 0 or 2 for cylinder
* IORIHS 0 for vertical, 1 for horizontal
* RHO    Density (kg/m^3)
* KHS    Thermal Conductivity (W/m/K)
* CPHS   Specific Heat (J/kg/K)
* QV      Volumetric Heat Generation (W/m^3)
* XRI     Inner Radius (m)
* XRO     Outer Radius (m); for plane wall, thickness = XRO-XRI
* AHS     One-sided heat sink area (m^2)
```

```
* TIINIT  Initial inside surface temperature (C)
* TOINIT  Initial outside surface temperature (C)
* IMSLAB  Number of slabs; 3 is minimum
* IREGI   Region index for inner surface or 0 (insulated)
*          or -1 for constant temperature
* TIHS    Region surface temperature when IREGI = -1  (C)
* IREGO   Region index for outer surface or 0 (insulated)
*          or -1 for constant temperature
* TOHS    Region surface temperature when IREGO = -1  (C)
* XLHS    Characteristic length for natural convection (m)
* EHSI    Emissivity of inner surface
* EHSO    Emissivity of outer surface
*
*
SINKS        1            2            3            4            5
*          tank       tank top     tank wall    tank wall    tank wall
*         ceiling       soil        first        second       third
 IGEOM       1            1            2            2            2
 IORIHS      1            1            0            0            0
 IMATHS      1            2            1            1            1
 XRI       0.0000        0.0        11.438       11.438       11.438
 XRO       0.0100        4.0        11.448       11.448       11.448
 AHS       411.0       411.0       358.0        143.891      143.891
 TIINIT      54.00       20.0        49.0         54.0         54.0
 TOINIT      54.00       45.0        49.0         54.0         54.0
 IMSLAB       3          20           3            3            3
 IREGI        0           3           1            1            1
 TIHS       0.0          0.0         0.0          0.0          0.0
 IREGO        1           0           2            2            2
 TOHS       0.0          0.0         0.0          0.0          0.0
 XLHS      22.88        22.88        5.0          2.0          2.0
 XZHS       0.0          0.0        2.50          1.0          1.0
 ZBHS      12.99        13.00        8.75         7.0          5.0
 ZTHS      13.00       15.1433      12.98         8.75         7.0
END
*
SINKS        6            7            8            9           10
*          tank wall    tank wall    tank wall  non-convective  tank
*          fourth       fifth        sixth        layer        floor
 IGEOM       2            2            2            1            1
 IORIHS      0            0            0            2            2
 IMATHS      1            1            1            3            1
 XRI       11.438       11.438       11.438        0.0          0.0
 XRO       11.448       11.448       11.448        0.01         0.01
 AHS      143.891      143.891       71.946      411.0        411.0
 TIINIT      54.00        54.0         54.0        83.0         83.0
 TOINIT      54.00        54.0         54.0        45.0         83.0
 IMSLAB       3            3            3          20            3
 IREGI        1            1            1           0            0
 TIHS       0.0          0.0          0.0         0.0          0.0
 IREGO        2            2            2           1            0
 TOHS       0.0          0.0          0.0         0.0          0.0
 XLHS       2.00         2.00         1.0        22.88        22.88
 XZHS       1.0          1.0         0.025        0.1          0.0
 ZBHS       3.0          1.0         0.0          0.0         -0.01
 ZTHS       5.0          3.0         1.0          0.01         0.0
END
*
SINKS       11           12           13           14           15
*        tank bottom  tank bottom  annulus top  annulus wall  annulus wall
*          concrete      soil         soil         soil        concrete
 IGEOM       1            1            1            0            0
 IORIHS      2            2            1            0            0
 IMATHS      4            2            2            2            4
 XRI       0.0          0.0          0.0         12.707       12.225
 XRO       0.4572      30.0          4.0        112.707       12.707
 AHS       411.0       411.0        411.0       1223.82       861.59
 TIINIT    57.00        12.0         20.0         49.0         49.0
 TOINIT    57.00        83.0         45.0         25.0         45.0
 IMSLAB      20           20           20           20           20
 IREGI        0           -1            3            0            2
 TIHS       0.0         12.0          0.0          0.0          0.0
 IREGO        0            0            2            0            0
 TOHS       0.0          0.0          0.0         20.0          0.0
 XLHS       0.0          0.0         0.762         0.0         11.0
 XZHS       0.0          0.0          4.0          0.0          0.0
 ZBHS      -0.4826     -10.4826      10.99         0.0          0.0
 ZTHS      -0.0100      -0.4826      15.0         11.0         11.0
END
*
SINKS       16           17           18
*        annulus bottom  annulus bottom  condenser
*          concrete        soil
 IGEOM       1            1            1
 IORIHS      2            2            1
 IMATHS      4            2            5
 XRI       0.0          0.0          0.0
 XRO       0.4572      10.0          0.01
 AHS       56.707      56.707       1000.
 TIINIT    25.00        20.0         10.0
 TOINIT    45.00        45.0         10.0
 IMSLAB      20           20           3
 IREGI        0           -1           -1
 TIHS       0.0         20.0         10.0
 IREGO        2            0            4
 TOHS       0.0          0.0         10.0
 XLHS      0.762         0.0        1000.0
 XZHS       0.0          0.0          0.0
 ZBHS      -0.4572     -10.4826      1015.0
 ZTHS       0.0         -0.4826      1016.0
END
*
*    name      index    rho     khs     cp     qv     ehsi    ehso
MATERIAL
     STSTEEL     1    8000.    16.    500.    0.    0.75    0.75
     SOIL        2    1500.    1.0   1840.    0.    0.75    0.75
```

```
    SLUDGE      3     1559.    0.9  2807.    0.0   0.75      0.75
    CONCRETE    4     2200.    0.6   880.    0.    0.75      0.75
    TUBE        5    10000.0  1000.0 10000.  0.0   0.5       0.5
END
*
COND_NETWORK 3,4,5,6,7,8
SANDWICH  9  1000.  10   1000.  11  1000. 12
SANDWICH  1  1000.  2
SANDWICH  14 1000.  15
SANDWICH  16 1000.  17
*
*
* USER CAN CONTROL HEAT SINK BOUNDARY TEMPERATURE
* SYNTAX:
*         OFFSET_TIMEHS
*         EXTRAPOLATION_TIMEHS
*         TIMTHS IHS ISD TIME1, TIME2...
*         THSFIX IHS ISD TEMP1, TEMP2..
* IHS = HEAT SINK NO.; ISD = SIDE NO. (1 OR 2) FOR IHS
* CONTROL HEAT SINK BOUNDARY T
* OFFSET_TIMEHS          0.
*EXTRAPOLATION_TIMEHS      EXTRAP
* TIMTHS 15 2 0.0      1.E6
* THSFIX 15 2 85.0     85.0
* TIMTHS 30 2 0.0      1.E6
* THSFIX 30 2 85.0     85.0
* TIMTHS 41 2 0.0      1.E6
* THSFIX 41 2 85.0     85.0
* TIMTHS 42 1 0.0      1.E6
* THSFIX 42 1 85.0     85.0
* TIMTHS 43 2 0.0      1.E6
* THSFIX 43 2 85.0     85.0
*
*
END HEAT_SINKS ! HEAT_SINKS is a comment
*-----------------------------------------------------------------------
JUNCTIONS   5 ! 4 Junctions
*-----------------------------------------------------------------------
*
* Syntax:
*  IJTYP   Junction Type: 1 = Normal, 2 = HEPA, 3 = Cover
*  IR1     Upstream Region
*  IR2     Downstream Region
*  AJN     Area (m^2)
*  ABYP    Bypass area for HEPA junction (m^2)
*  PHEPA   HEPA Filter Failure Pressure (Pa)
*  ACOV    Cover Area (m^2)
*  MCOV    Cover Weight (kg)
*  Z1JN    Elevation wrt floor of IR1 opening (m)
*  Z2JN    "      "   "    "   IR2    "    "
*  CJN     Loss coefficient multiplies 0.5*rho*v^2
*  IHORIZ  Orientation: 1 = horizontal, 0 = vertical
*  XWJN    Characteristic width, m
*  XHJN    Characteristic height, m
*  XLJN    Characteristic length, m
*  DFJN    Decontamination Factor
*  N90     No. of 90 bends
*
*            INLET                          ANNULUS     ANNULUS  condenser
*            LEAKAGE       OUTLET           INLET       OUTLET   outlet
     PATHS      1            2                3           4        5
        IJTYP   1            1                1           1        1
        IR1     3            1                3           2        4
        IR2     1            4                2           3        3
        IHORIZ  1            0          0            0          0
        XWJN    0.1000     0.1000         0.1524      0.1524     0.01
        XHJN    0.1000     0.1000         0.1524      0.1524     0.01
        XLJN    1000.        20.     5.0          5.0       10.0
        AJN     0.03000    0.03000        0.07297     0.07297    0.030
        Z1JN    1.0          12.0         1.00        12.00      10.0
        Z2JN    12.0         1.0          12.00       1.00       10.0
        CJN     5.           5.0          2.0          2.0      5.0
        DFJN    1.0          1.0          1.0         1.0       1.0
        N90     0            0            0            0        0.0
*       APIPE1  0.07297      0.03         0.09121     0.09121
*       DPIPE1  0.3048       0.10         0.1524      0.1524
*       LPIPE1  0.0          0.0          0.0         0.0
*       EPIPE1  0.001        0.001        0.001       0.001
*       KLOCAL1 0.3          0.00         0.0         0.0
*       APIPE2  1.E10        0.03         0.0921      0.03
*       DPIPE2  0.3048       0.10         0.1524      0.10
*       LPIPE2  0.0          10.0         0.0         10.0
*       EPIPE2  0.001        0.001        0.001       0.001
*       KLOCAL2 0.0          0.0          0.0         0.0
        KFILTER 1000.      10000.       1000.0      1000.0     15000.
        IFAN    0            0            0           0          1
        WVFAN   0.0          0.0      0.0         0.0        0.23
     END PATHS  ! PATHS is a comment.
*
*
END JUNCTIONS   ! JUNCTIONS is a comment.
```

8.4 Comparison of Retrieval Steady-State Input File (RETSS .DAT, designated by ">") against RETLV.DAT, Loss of Ventilation Scenario Input File

```
12c12
<  lose scfm primary ventilation, no annulus ventilation, lose condenser
---
```

```
> 500 scfm primary ventilation, no annulus ventilation, condenser
18c18
<    TSTART  1500000.    !  START TIME, >0 FOR RESTART RUN
---
>    TSTART      0.     !  START TIME, >0 FOR RESTART RUN
34c34
<   2000000. 1000000.
---
>   1000000. 1000000.
53c53
<    0.0        1e5
---
>    0.0        1.4e6
148,149d147
<   AER-MASS WASTE    4 1 2 3 4
<   LIQ-MASS WASTE    1 1
281a280
>
284c283
<       IXR2          3
---
>       IXR2          1
292c291
<       ZL1_HI      991.0
---
>       ZL1_HI      10.0
294c293
<       ZL1_LO      899.0
---
>       ZL1_LO      1.00
579,580c578,579
<          IFAN     0          0          0          0          0
<          WVFAN    0.0        0.0     0.0        0.0        0.00
---
>          IFAN     0          0          0          0          1
>          WVFAN    0.0        0.0     0.0        0.0        0.23
```

8.5 Comparison of Retrieval Loss of Ventilation Scenario (RETLV .DAT, designated by "<") against RETLVR.DAT, Recovery Input File

```
11,12c11,13
<  DST AZ-101 Run to mixer pump SS Conditions; fin heat transfer
<  lose scfm primary ventilation, no annulus ventilation, lose condenser
---
>  DST AZ-101  fin heat transfer
```

```
>  recover 500 scfm primary ventilation after boiling,
>  no annulus ventilation, condenser
18,19c19,20
<    TSTART  1500000.    !  START TIME, >0 FOR RESTART RUN
<    TLAST  10000000.!  END TIME
---
>    TSTART  2301000. !  START TIME, >0 FOR RESTART RUN
>    TLAST   4000000. !  END TIME
22,25c23,24
<      10.0     1.0
<      100.0    1.0
<      1000.0   1.0
<    100000.0   1.0
---
>    2.3E6      0.1
>    2.4E6      1.0
27,31c26,28
<      0.0      1.0
<      5.0      1.0
<      100.0    5.0
<      1000.    5.0
<    100000.    5.
---
>      0.0      5.0
>    2.3E6      1.0
>    2.4E6      5.0
34c31
<   2000000. 1000000.
---
>   3000000. 1000000.
42a40
>    2.3E6    5000.0
50a49
>    2.3E6    10000.0
53c52
<    0.0        1e5
---
>    0.0        1.4e6
148,149d146
<   AER-MASS WASTE    4 1 2 3 4
<   LIQ-MASS WASTE    1 1
151a149,150
>   AER-MASS WASTE    4 1 2 3 4
>   LIQ-MASS WASTE    1 1
281a281
>
284c284
<       IXR2          3
---
>       IXR2          1
287,289c287,289
<       WV_XFER      1.E6
<       T_START      0.0
```

```
<       T_END        1.0E10
---
>       WV_XFER      0.0002
>       T_START      2.31e6
>       T_END        10.4E6
292c292
<       ZL1_HI       991.0
---
>       ZL1_HI       10.0
294c294
<       ZL1_LO       899.0
---
>       ZL1_LO       1.00
579,580c579,580
<          IFAN      0          0          0          0          0
<          WVFAN     0.0        0.0     0.0       0.0        0.00
---
>          IFAN      0          0          0          0          1
>          WVFAN     0.0        0.0     0.0       0.0        0.230
```

8.6 Input File SSAZ102.DAT: DST AZ-102 Safe Storage, Steady-State

```
*********************************************************************
*   Underground DST with loss of cooling
*********************************************************************
*
*-------------------------------------------------------------------
CONTROL     ! Major keyword group
*-------------------------------------------------------------------
*
*
 TITLE      ! Keyword; next line is title, title can be any length*  -
 DST AZ-102  SS Conditions; fin heat transfer
 500 scfm primary ventilation, no annulus ventilation, condenser
 END TITLE ! Anything after END is a comment
*
*
*
 TIMING     ! Keyword
   TSTART       0.     !  START TIME, >0 FOR RESTART RUN
   TLAST  5000000.!  END TIME
   DTMIN              !  MIN TIMESTEP (Seconds)
     0.0      1.0
    10.0      1.0
    100.0     1.0
    1000.0    1.0
    100000.0  10.0
    DTMAX             !  MAX TIMESTEP (Seconds)
     0.0      1.0
     5.0      1.0
     100.0    5.0
     1000.    5.0
   100000.    20.
    DTPRIN            !  PRINT INTERVAL (Seconds)
    0.0      100000.0
   1000000. 1000000.
   10000000. 1000000.
    PLTMIN            !  MIN PLOT INTERVAL (Seconds)
    0.0      0.05
    10.0     1.0
    100.0    10.0
    1000.0   100.0
    10000.0  1000.0
    100000.0 10000.0
    1000000.0 100000.0
    PLTMAX            !  MAX INTERVAL WITHOUT PLOT (Seconds)
    0.0      0.1
    10.0     10.
    100.0    100.
    1000.0 1000.0
    10000.0 10000.0
    100000.0 100000.0
    1000000.0 1000000.0
    DTRST             !  RESTART INTERVAL (Seconds)
    0.0       1e6
    3.E6      1.E7
*
    FTPCH      0.001       !  FRACTIONAL CHANGE IN T AND P
    FAECH      0.001       !  FRACTIONAL CHANGE IN aerosol mass
    FPPLCH     0.03        !  FRACTIONAL CHANGE FOR PLOTTING
 END TIMING ! TIMING is a comment.
*
* COMPOUND LIBRARY ORDER FOR OUTPUT
*   This section allows user specification of the order
*   in which compound names are printed & placed in the
*   plot files.  This section is optional, but recommended.
*   Using this section saves computation time by limiting
*   the range of loops. This section rearranges internal
*   storage to the user-defined order, and essentially
*   defines a sub-library for this case only.
*
*   Format:
*   The section begins with the keyword COMPOUND followed
*   by the number of compounds to be used for this run.
*   Compound names are placed on succeeding lines,
*     using up to 80 columns.
*   Finish the list with the END keyword.
*   You can comment a line in the list by putting
*     the double asterisk ** in cols. 1 and 2.
```

```
*   Example (here column 1 has * for comment):
* COMPOUNDS 8
*    STEAM OXYGEN NITROGEN
*    HEXONE CARBON_DIO
*    WASTE WASTTRAC STEATRAC
* END
*
*   User caveats:
*   1. If this is invoked, it MUST PRECEDE any input section that
*   refers to compound names, such as plotting, sources, etc.
*   2. The user must name ALL compounds that are used in the
*   calculation, or else the compound will be skipped. For
*   example there may be no combustion products initially
*   present anywhere, but these must be named to be used later.
*   3. Spelling must be identical to names in GASPROP.DAT
*   Check the log file for mis-spelling warnings.
*
 COMPOUNDS 4
   STEAM OXYGEN NITROGEN WASTE
 END
*
*
 PLOT        ! Keyword for plotting section
* Plotting syntax:
*
* PRESSURE n rlist - Pressure, Pa
* GAS-T  n rlist  - Gas Temperature, K
* LIQ-T  n rlist  - Liquid Temperature, K
* LIQ-EL n rlist  - Liquid Level, m
* HS-TI  n hlist  - Heat Sink Temperature - Inner Surface, K
* HS-TO  n hlist  - Heat Sink Temperature - Outer Surface, K
* HS-TA  n hlist  - Heat Sink Temperature - Average, K
* AEROSOL n rlist - Aerosol Mass (Total), kg
* GAS-W  n jlist  - Mass Flowrate, kg/s
* GAS-WX n jlist  - CounterCurrent Mass Flowrate, kg/s
* SPECIAL-X n xlist - Special model state variable
* SPECIAL-R n xlist - Special model rate variable
* GAS-X    GASNAME n rlist  - Gas Mole Fraction
* GAS-RH   GASNAME n rlist  - Gas Relative Humidity
* GAS-MASS GASNAME n rlist - Gas Mass (Species), kg
* AER-MASS GASNAME n rlist - Aerosol Mass (Species), kg
* MASS     GASNAME n rlist - Total Mass (Species), kg
* LIQ-MASS - GASNAME n rlist - Deposited Mass (Species), kg
*
* Pressure, Gas Temperature, and total aerosol mass require a region
* list
*
* Heat Sink Temperatures need a heat sink number list
*
* Flowrates need a junction number list
*
* Gas concentration, relative humidity, individual species gas mass,
* individual species aerosol mass, total (gas+aerosol) individual
* species mass, and individual species deposited liquid mass require
* a region and gas name
*
*  special state & rate variables are:
*  1=  Waste surface entrainment during a burn
*  2=  Tank surface entrainment during a burn
*  3=  Waste surface entrainment during blowdown
*  4=  Unused, reserved for tank surface entrainment during blowdown
*  5=  Total entrainment
*
  PRESSURE     4  1  2  3  4     ! Pressure
  GAS-T        4  1  2  3  4     ! Gas Temps
  LIQ-T        2    1   4         ! L temps
  LIQ-EL       2    1   4         ! L elevations
  GAS-X  NITROGEN   1   1        ! N2 Concentration
  GAS-X  OXYGEN     1   1        ! O2 concentration
  GAS-X  STEAM      1   1        ! H2O concentration
  GAS-W        4    1   2   3   4  ! Gas flow rates
  HS-TA        7    3 4 5 6 7 8 9
  WCOND-PL  STEAM   1   1          ! Condensation rate of steam on pool
  WCOND-HSO STEAM   2   1   18     ! Condensation rate of steam on hs-1
  WCOND-HSI STEAM   4   2   3   4  18 ! Condensation rate of steam on hs-2
& 3
  QGAS-HSO     8   1   3   4   5   6  7  8  13    ! gas-to-hs hx
  QGAS-HSI     7   2   3   4   5  13 15 16    ! gas-to-hs hx
  QGAS-POOL    1   1       ! gas-to-pool hx
  QLIQ-HSI     4   4   5   6   7    ! liquid-to-hs hx
  QLIQ-HSO     1   9                ! liquid-to-hs hx
 END PLOT  ! PLOT is a comment
*
PRINT
     HS 18 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
END
*
 ACTIVE MODELS ! Keyword; MODELS is a comment; 1 = on, 0 = off
  IJUNC   1    ! Junction flow model
  ICCFLW  0   ! Counter-current flow model
  IHSINK  1    ! Heat sinks
  IHXPOL  1    ! gas-pool heat/mass transfer
  ICNDS   1    ! Condensation
  IASED   1    ! Aerosol Sedimentation
  IALEAK  1   ! Aerosol Leakage
  IFOG    1    ! Fog formation
  ISRC    1    ! User-defined sources
  IQDECAY 1    ! Decay power
  IMCO    0    ! MCO models
  ISENS   0    ! Sensitivity runs
  ILXFER  1   ! Liquid transfers
  IDCRT   0    ! DCRT Runs
 END ACTIVE MODELS ! ACTIVE MODELS  is a comment
*
*
 MODEL PARAMETERS
```

```
  AGAMMA   2.5   ! Shape factor for nonsphericity for coagulation
  ACHI     1.0   ! Shape factor for nonsphericity for stokes'law
  AFEO     1.0   ! Collision efficiency: 1.0 Fuchs, 0.33 Prupacher-Klett
 END MODEL PARAMETERS
*
C-----------------------------------------------------------------------
C      DECAY POWER
C
 DECAY
    WASTE   0.026
 END
*
C-----------------------------------------------------------------------
C      SOURCE GROUP:  GROUPS REPEATED FOR INPUT # OF REGIONS
C        END OF GROUP DESIGNATED BY 'REGION' OR 'END' KEYWORDS
C      ENTER: TIME, TEMP, FLOWRATES, POWER
C      SYNTAX EXAMPLE:
SOURCES 1                          ! -- KEYWORD AND # SOURCE GROUPS
 REGION  1  GASES 1  PHASE 3        !-- REGION #, # COMPOUNDS, PHASE #
    STEAM              !-- GAS NAMES MUST BE ON NEXT LINE
  0     26.7   0.0 0.00E5 ! MIXER PUMP POWER
  1.0E9 26.7   0.0 0.00E5 ! MIXER PUMP POWER
 END REGION                  !-- ENDS A REGION SOURCE
END SOURCES

* PHASE INDEX: 1=GAS, 2=AERO, 3=LIQUID
*
*
*
END CONTROL    ! End of CONTROL keyword group
*
*
*-----------------------------------------------------------------------
*     OPERATIONS
*-----------------------------------------------------------------------
*
 OPERATIONS
*
*     OPERATIONS          ! Keyword to begin this section
*
*     Keyword groups go here as described below.  Active groups are:
*     TRANSFER
*
*     END OPERATIONS      ! End is a comment here
*
*     WASTE TRANSFER SYNTAX:  SAME AS REGION & JUNCTION SYNTAX, COLUMNS
*     TRANSFER ilist     Keyword TRANSFER followed by list of indices
*                        each index is a transfer index #
*       KEYWORD  rlist   Keyword name (see list below) and column values
*                        corresponding to ilist above
*      END                End this section
*     Use 5 transfer columns per set maximum, then repeat the group
*     Maximum of 30 defined transfers
*
*     Waste is transferred from region IXR1 to IXR2 at constant
*        volumetric flowrate WV_XFER or at a pulsed flowrate
*        during the active duty cycle time DUTY_ON, followed by
*        the idle cycle duration DUTY_OFF.
*     Transfers start at time T_START and end at time T_END.
*     Rational level controls also exist for transfers.
*     Transfer begins when donor region level exceeds
*        the high level ZL1_HI.  Default begins transfer if the
*        donor level exceeds region top minus 1 cm.
*     Transfer ends when donor region level falls below
*        the low level ZL1_LO.  Default ends at 1 cm elevation.
*     Transfer ends when receiver region level exceeds
*        the high level ZL2_HI.  Default ends transfer if the
*        receiver level exceeds region top minus 1 cm.
*     The program will abort due to errors in PTREG1 or PTREG2
*        if a region becomes "solid", and transfers or
*        sources into a full region are the cause.  Remedy by
*        better control over intended transfers.
*     Waste can be cascaded in a series of tanks via a series
*        of transfers initiated on level.
*     Waste can flow in both directions controlled by level,
*        using a pair of transfers, one in each direction.
*
*     WASTE TRANSFER KEYWORD DEFINITIONS
*
*     IXR1        "FROM" REGION
*     IXR2        "TO" REGION
*     IDUTY       1= USE DUTY CYCLES, 0= CONSTANT FLOW
*     IR1_HI      1= BEGIN ON HIGH LEVEL IN IXR1, 0= IGNORE
*     WV_XFER     NOMINAL VOLUMETRIC FLOWRATE AT ZERO DP WHEN ACTIVE
*     T_START     TIME TO START XFER FLOW
*     T_END       TIME TO END XFER FLOW
*     DUTY_ON     DUTY CYCLE TIME FOR TRANSFER FLOW IF PERIODIC
*     DUTY_OFF    DUTY CYCLE TIME FOR NO (OFF) TRANSFER FLOW IF PERIODIC
*                 TOGETHER THESE CYCLE TIMES DEFINE A COMPLETE CYCLE
*     ZL1_HI      HIGH LEVEL IN "FROM" REGION THAT BEGINS XFER:
*                  ZLR(IXR1) > ZL1_HI. DEFAULT: 1 CM FROM TOP
*     ZL2_HI      HIGH LEVEL IN "TO" REGION THAT ENDS XFER:
*                  ZLR(IXR2) < ZL2_HI. DEFAULT: 1 CM FROM TOP
*     ZL1_LO      LOW LEVEL IN "FROM" REGION THAT ENDS XFER:
*                  ZLR(IXR1) < ZL1_LO. DEFAULT: 1 CM FROM BOTTOM

 TRANSFER          1
     IXR1          4
     IXR2          1
     IDUTY         0
     IR1_HI        1
     WV_XFER       1.E6
     T_START       0.0
     T_END         1.0E10
     DUTY_ON       100.
     DUTY_OFF      100.
```

```
     ZL1_HI      10.0
     ZL2_HI      8.75
     ZL1_LO      1.00
 END TRANSFER

END OPERATIIONS
*-----------------------------------------------------------------------
VOLUMES    4       ! total number of control volumes
*-----------------------------------------------------------------------
* No more than 5 columns (regions) at a time
* Units:
* VOLUME m^3, SED_AREA m^2, ELEVATION m, TEMP_GAS K, PRESSURE  Pa
*
*                TANK            ANNULUS     Ambient   Condenser
 REGIONS          1                2           3          4
  VOLUME       5338.            623.78      1.E10      1000.
  SED_AREA      411.             0.0        0.0        0.0
  ELEVATION     0.0              0.0        15.       16.
  TEMP_GAS      46.             28.0        28.        10.0
  PRESSURE      101350.        101350.      101350.    101350.
  ZTOP         12.99              11.0       1.E6      1000.
  Z_LIQ         8.75             0.01       0.00      990.0
  TEMP_LIQ      54.0             28.0      28.0       10.0
 END REGIONS  ! REGIONS is a comment
*
* Gas composition of each region; specify mole fraction of each gas
* No more than five columns at a time
*
*               TANK         ANNULUS    AMBIENT      CONDENSER
 GASES           1            2          3            4
  STEAM         0.100        0.1       0.0023       0.0100
  OXYGEN        0.189        0.189     0.2077       0.2000
  NITROGEN      0.711        0.711     0.7900       0.7900
 END GASES            ! GASES is a comment
*
*               TANK      ANNULUS    AMBIENT    CONDENSER
LIQUIDS         1          2          3          4
  STEAM         0.816      1.0        1.0        1.0
  WASTE         0.184       0.0       0.0        0.0
END LIQS            ! LIQS is a comment
*
* Aerosol concentration of each region (kg/m^3)
* No more than five columns at a time
*
*AEROSOLS        1          2          3          4        5
* WASTE         0.000      0.0        0.0        0.0      0.0
*END AEROSOLS ! AEROSOLS is a comment
*   OFFSET_TIMETG
*   EXTRAPOLATION_TIMETG
*   TIMETG  REGION # TIME1, TIME2...TIMELAST
*   TGFIX   REGION # TEMP1, TEMP2... TEMPLAST    TEMPS ARE IN C!!!
*   LINEAR INTERPOLATION BETWEEN VALUES
*
*   SIMILAR SYNTAX FOR PRESSURE:
*   OFFSET_TIMETG
*   EXTRAPOLATION_TIMEPG
*   TIMEP  REGION #  TIME1, TIME2...
*   PRFIX  REGION #  PRES1, PRES2...PRESSURES ARE IN PA!!!
*
*  OFFSET_TIMETG=  OFFSET TIME; ENTER LOOKUP TABLE WITH
*                  TIME+OFFSET_TIMETG
*  EXTRAPOLATION_TIMETG= LAST TO USE LAST VALUE IN THE TABLE,
*                        = EXTRAP TO EXTRAPOLATE FROM LAST TWO POINTS,
*                        = PERIOD TO WRAP AROUND.
*  OFFSET_TIMETG           0.
*  EXTRAPOLATION_TIMETG      LAST
* TIMETG 4  0.0     1.E10
* TGFIX  4 10.0     10.0
*
* CONTROL  BOUNDARY P,
*  OFFSET_TIMEPG           0.
*  EXTRAPOLATION_TIMEPG      EXTRAP
* TIMEP 4  0.0        1.E10
* PRFIX  4  1.0135E5 1.0135E5
END
* Major keyword-------------------------------------------------------
HEAT_SINKS      18 !Total number of heat sinks
*-----------------------------------------------------------------------
* No more than 5 columns at a time,
* Repeat the following structure,
* SINKS
* .
* .
* .
* END
*
* Syntax:
* IGEOM  1 for plane, 0 or 2 for cylinder
* IORIHS 0 for vertical, 1 for horizontal
* RHO    Density (kg/m^3)
* KHS    Thermal Conductivity (W/m/K)
* CPHS   Specific Heat (J/kg/K)
* QV      Volumetric Heat Generation (W/m^3)
* XRI     Inner Radius (m)
* XRO     Outer Radius (m); for plane wall, thickness = XRO-XRI
* AHS     One-sided heat sink area (m^2)
* TIINIT  Initial inside surface temperature (C)
* TOINIT  Initial outside surface temperature (C)
* IMSLAB  Number of slabs; 3 is minimum
* IREGI   Region index for inner surface or 0 (insulated)
*         or -1 for constant temperature
* TIHS    Region surface temperature when IREGI = -1  (C)
* IREGO   Region index for outer surface or 0 (insulated)
*         or -1 for constant temperature
* TOHS    Region surface temperature when IREGO = -1  (C)
* XLHS    Characteristic length for natural convection (m)
```

```
* EHSI    Emissivity of inner surface
* EHSO    Emissivity of outer surface
*
*
SINKS        1          2          3          4          5
*          tank       tank top   tank wall  tank wall  tank wall
*         ceiling      soil       first      second     third
 IGEOM       1          1          2          2          2
 IORIHS      1          1          0          0          0
 IMATHS      1          2          1          1          1
 XRI       0.0000      0.0       11.438     11.438     11.438
 XRO       0.0100      4.0       11.448     11.448     11.448
 AHS       411.0     411.0      358.0      143.891    143.891
 TIINIT      54.00     20.0       49.0       54.0       54.0
 TOINIT      54.00     45.0       49.0       54.0       54.0
 IMSLAB       3         20         3          3          3
 IREGI        0          3         1          1          1
 TIHS        0.0        0.0       0.0        0.0        0.0
 IREGO        1          0         2          2          2
 TOHS        0.0        0.0       0.0        0.0        0.0
 XLHS       22.88      22.88      5.0        2.0        2.0
 XZHS        0.0        0.0       2.50       1.0        1.0
 ZBHS       12.99      13.00      8.75       7.0        5.0
 ZTHS       13.00     15.1433    12.98      8.75       7.0
END
*
SINKS        6          7          8          9         10
*         tank wall  tank wall  tank wall  non-convective  tank
*          fourth     fifth      sixth       layer      floor
 IGEOM       2          2          2          1          1
 IORIHS      0          0          0          2          2
 IMATHS      1          1          1          3          1
 XRI       11.438     11.438     11.438      0.0        0.0
 XRO       11.448     11.448     11.448      0.96       0.01
 AHS      143.891    143.891     71.946     411.0      411.0
 TIINIT      54.00      54.0       54.0       96.0       96.0
 TOINIT      54.00      54.0       54.0       54.0       96.0
 IMSLAB       3          3          3         20          3
 IREGI        1          1          1          0          0
 TIHS        0.0        0.0       0.0        0.0        0.0
 IREGO        2          2          2          1          0
 TOHS        0.0        0.0       0.0        0.0        0.0
 XLHS       2.00       2.00       1.0       22.88      22.88
 XZHS       1.0        1.0       0.025      0.10       0.0
 ZBHS       3.0        1.0       0.0        0.0       -0.01
 ZTHS       5.0        3.0       1.0        0.01       0.0
END
*
SINKS       11         12         13         14         15
*         tank bottom tank bottom annulus top annulus wall annulus wall
*          concrete   soil       soil       soil       concrete
 IGEOM       1          1          1          0          0
 IORIHS      2          2          1          0          0
 IMATHS      4          2          2          2          4
 XRI        0.0        0.0       0.0       12.707     12.225
 XRO       0.4572     30.0       4.0      112.707     12.707
 AHS       411.0      411.0     411.0     1223.82     861.59
 TIINIT    96.00      12.0      20.0       49.0       49.0
 TOINIT    96.00      96.0      45.0       25.0       45.0
 IMSLAB    20         20        20         20         20
 IREGI      0         -1         3          0          2
 TIHS      0.0       12.0       0.0        0.0        0.0
 IREGO      0          0         2          0          0
 TOHS      0.0        0.0       0.0       20.0        0.0
 XLHS      0.0        0.0       0.762      0.0       11.0
 XZHS      0.0        0.0       4.0        0.0        0.0
 ZBHS     -0.4826   -10.4826   10.99      0.0        0.0
 ZTHS     -0.0100    -0.4826   15.0       11.0       11.0
END
*
SINKS       16                 17                 18
*        annulus bottom    annulus bottom     condenser
*          concrete           soil
 IGEOM       1                  1                  1
 IORIHS      2                  2                  1
 IMATHS      4                  2                  5
 XRI        0.0                0.0                0.0
 XRO       0.4572             10.0                0.01
 AHS       56.707             56.707             1000.
 TIINIT    25.00              20.0               10.0
 TOINIT    45.00              45.0               10.0
 IMSLAB    20                 20                 3
 IREGI      0                 -1                 -1
 TIHS      0.0                20.0               10.0
 IREGO      2                  0                  4
 TOHS      0.0                0.0                10.0
 XLHS      0.762              0.0                1000.0
 XZHS      0.0                0.0                0.0
 ZBHS     -0.4572            -10.4826            1015.0
 ZTHS      0.0               -0.4826             1016.0
END
*
*    name      index    rho     khs     cp      qv     ehs1     ehso
MATERIAL
    STSTEEL     1    8000.    16.    500.    0.     0.75     0.75
    SOIL        2     1500.    1.0   1840.   0.     0.75     0.75
    SLUDGE      3     1559.    0.9   2807.   99.0   0.75     0.75
    CONCRETE    4     2200.    0.6    880.   0.     0.75     0.75
    TUBE        5    10000.0  1000.0 10000.  0.0    0.5      0.5
END
*
COND_NETWORK 3,4,5,6,7,8
SANDWICH  9  1000.  10   1000.  11  1000. 12
SANDWICH  1  1000.  2
SANDWICH  14 1000.  15
SANDWICH  16 1000.  17
```

```
*
*
* USER CAN CONTROL HEAT SINK BOUNDARY TEMPERATURE
* SYNTAX:
*          OFFSET_TIMEHS
*          EXTRAPOLATION_TIMEHS
*          TIMTHS IHS ISD TIME1, TIME2...
*          THSFIX IHS ISD TEMP1, TEMP2..
* IHS = HEAT SINK NO.; ISD = SIDE NO. (1 OR 2) FOR IHS
* CONTROL HEAT SINK BOUNDARY T
* OFFSET_TIMEHS          0.
*EXTRAPOLATION_TIMEHS     EXTRAP
* TIMTHS 15 2 0.0     1.E6
* THSFIX 15 2 85.0    85.0
* TIMTHS 30 2 0.0     1.E6
* THSFIX 30 2 85.0    85.0
* TIMTHS 41 2 0.0     1.E6
* THSFIX 41 2 85.0    85.0
* TIMTHS 42 1 0.0     1.E6
* THSFIX 42 1 85.0    85.0
* TIMTHS 43 2 0.0     1.E6
* THSFIX 43 2 85.0    85.0
*
*
END HEAT_SINKS ! HEAT_SINKS is a comment
*-----------------------------------------------------------------------
JUNCTIONS   5 ! 4 Junctions
*-----------------------------------------------------------------------
*
* Syntax:
*  IJTYP   Junction Type: 1 = Normal, 2 = HEPA, 3 = Cover
*  IR1     Upstream Region
*  IR2     Downstream Region
*  AJN     Area (m^2)
*  ABYP    Bypass area for HEPA junction (m^2)
*  PHEPA   HEPA Filter Failure Pressure (Pa)
*  ACOV    Cover Area (m^2)
*  MCOV    Cover Weight (kg)
*  Z1JN    Elevation wrt floor of IR1 opening (m)
*  Z2JN    "      "   "   "   IR2   "    "
*  CJN     Loss coefficient multiplies 0.5*rho*v^2
*  IHORIZ  Orientation: 1 = horizontal, 0 = vertical
*  XWJN    Characteristic width, m
*  XHJN    Characteristic height, m
*  XLJN    Characteristic length, m
*  DFJN    Decontamination Factor
*  N90     No. of 90 bends
*
*            INLET                      ANNULUS    ANNULUS  condenser
*            LEAKAGE       OUTLET       INLET      OUTLET   outlet
     PATHS      1            2            3          4        5
       IJTYP    1            1            1          1        1
       IR1      3            1            3          2        4
       IR2      1            4            2          3        3
       IHORIZ   1            0            0          0        0
       XWJN     0.1000       0.1000       0.1524     0.1524   0.01
       XHJN     0.1000       0.1000       0.1524     0.1524   0.01
       XLJN     1000.        20.    5.0          5.0      10.0
       AJN      0.03000      0.20000      0.07297    0.07297  0.0729
       Z1JN     1.0          12.0         1.00       12.00    10.0
       Z2JN     12.0         1.0          12.00      1.00     10.0
       CJN      5.           5.0          2.0        2.0      5.0
       DFJN     1.0          1.0          1.0        1.0      1.0
       N90      0            0            0          0        0.0
*      APIPE1   0.07297      0.03         0.09121    0.09121
*      DPIPE1   0.3048       0.10         0.1524     0.1524
*      LPIPE1   0.0          0.0          0.0        0.0
*      EPIPE1   0.001        0.001        0.001      0.001
*      KLOCAL1  0.3          0.00         0.0        0.0
*      APIPE2   1.E10        0.03         0.0921     0.03
*      DPIPE2   0.3048       0.10         0.1524     0.10
*      LPIPE2   0.0          10.0         0.0        10.0
*      EPIPE2   0.001        0.001        0.001      0.001
*      KLOCAL2  0.0          0.0          0.0        0.0
       KFILTER  1000.        0.     1000.0     1000.0     1000.
       IFAN     0            0            0          0          1
       WVFAN    0.0          0.0    0.0        0.0        0.23
     END PATHS  ! PATHS is a comment.
*
*
END JUNCTIONS   ! JUNCTIONS is a comment.
```

8.7 Input File Comparison: SSAZ102.DAT vs. MIXSS.DAT, Input File for Mixer Pump Operation in DST AZ-102

```
11c11
<  DST AZ-102 Run to mixer pump SS Conditions; fin heat transfer
---
>  DST AZ-102  SS Conditions; fin heat transfer
25c25
<    100000.0  1.0
---
>    100000.0  10.0
31c31
<   100000.    5.
---
>   100000.    20.
192c192
<     WASTE   0.07668
---
```

```
>     WASTE   0.026
203,204c203,204
<   0      26.7   0.0 4.39E5 ! MIXER PUMP POWER
<   1.0E9 26.7   0.0 4.39E5 ! MIXER PUMP POWER
---
>   0      26.7   0.0 0.00E5 ! MIXER PUMP POWER
>   1.0E9 26.7   0.0 0.00E5 ! MIXER PUMP POWER
307c307
<   TEMP_GAS     54.             28.0         28.       10.0
---
>   TEMP_GAS     46.             28.0         28.       10.0
311c311
<   TEMP_LIQ     61.0             28.0     28.0      10.0
---
>   TEMP_LIQ     54.0             28.0     28.0      10.0
428c428
<  XRO        11.448     11.448         11.448        0.01          0.01
---
>  XRO        11.448     11.448         11.448        0.96          0.01
430,431c430,431
<  TIINIT        54.00      54.0         54.0        83.0         83.0
<  TOINIT        54.00      54.0         54.0        45.0          83.0
---
>  TIINIT        54.00      54.0         54.0        96.0         96.0
>  TOINIT        54.00      54.0         54.0        54.0          96.0
438c438
<  XZHS           1.0         1.0         0.025        0.1          0.0
---
>  XZHS           1.0         1.0         0.025        0.10         0.0
452,453c452,453
<  TIINIT     57.00      12.0           20.0        49.0           49.0
<  TOINIT     57.00      83.0           45.0        25.0           45.0
---
>  TIINIT     96.00      12.0           20.0        49.0           49.0
>  TOINIT     96.00      96.0           45.0        25.0           45.0
491c491
<     SLUDGE      3     1559.    0.9  2807.    0.0   0.75     0.75
---
>     SLUDGE      3     1559.    0.9  2807.    99.0   0.75     0.75
```

9.0 COMMUNICATIONS

9.1 Preliminary Scenario Descriptions

From: Grant_W_Ryan@RL.gov
Sent: Friday, March 23, 2001 9:09 AM
To: malinovic@fauske.com; plys@fauske.com
Cc: J_M_Mike_Grigsby@rl.gov; Robert_J_Bob_Cash@rl.gov;
Grant_W_Ryan@rl.gov
Subject: Detailed Task Descriptions for Revised Tank Bump Analyses

Importance: High

Marty and Boro,

Included below are detailed descriptions of the tasks related to revising the tank bump analysis to address Waste Feed Delivery operations and activities. After reviewing the task descriptions included below, I would appreciate it if you would let me know how long (i.e., somewhat specific dates) when draft results would be available. To support our August submittal date we need firm results by mid to late April (or earlier if possible).

Please let me know as soon as possible if you need additional information to be able to complete these tasks.

The Fauske Analysis Scope

The following items need to be analyzed for inclusion in a revision to RPP-6213, Hanford Waste Tank Bump Accident and Consequence Analysis:

1. Consequence analysis of boiling waste. Consider the unmitigated scenario where mixer pumps are allowed to run for extended periods of time after a loss of ventilation (primary tank and annulus). Initial thoughts are that this scenario will not produce consequences exceeding those of a safe storage tank bump. Documentation can be structured as an appendix to RPP-6213. Specific scenarios to be analyzed are:

   Unmitigated Scenario #1:

   Mixer pumps are operating, ventilation is operating, temperature of waste is at 194 F (everything is within current AB controls)). Ventilation fails, pumps keep operating, waste heats up to boiling, HEPAs saturate and fail (take no credit for HEPA filtration), headspace aerosols are released with steam.

   Associated assumptions:

* Assume, if necessary, that the ventilation flow rate from affected tank is 500 cfm (1/2 of total system capacity).

Unmitigated Scenario #2:

Extended mixer pump operation heats waste to boiling while ventilation system is operating with no HEPA filters in place.

Assumptions from above would apply, as appropriate.

[This scenario would estimate the maximum consequences that could be expected from the aerosols generated from boiling waste and expelled to the atmosphere by the active ventilation system. Additional information on the system related to ductwork size, shape, lengths, etc., can be determined later if necessary. I expect that the stack height will result in consequences not requiring additional refinement.]

Unmitigated Scenario #3:

Extended mixer pump operation heats waste to near boiling while ventilation system is operating and mixer pumps are stopped to recover from increased waste temperature (T > 195 F). Ventilation system fails at this point and the waste begins to boil. Several days are required to restore ventilation (~7 days as assumed in the safe storage tank bump), allowing aerosols to escape from the tank because the headspace is pressurized from the boiling waste. The ventilation system is repaired and restarted to recover waste temperature, however, no HEPA filters are in place and the increased aerosol loading in the headspace is exhausted (1) for a set period of time; or (2) until the waste is no longer boiling (and creating aerosols).

Assumptions from above would apply, as appropriate.

[This scenario would estimate the maximum consequences that could be expected from a combination of boiling waste/no ventilation and boiling waste/active ventilation. We may be able to truncate this analysis to just address the boiling waste/no ventilation option depending on the results of Scenario #2.]

Release Duration for All Identified Scenarios

The release duration is still to be determined. For all scenarios, do a release vs. time for more than 24 hours. We will then finalize the duration, as appropriate, after reviewing the calculations.

2. Consideration of a range of initial waste conditions (i.e., fully mixed to partially settled) upon loss of primary tank and annulus ventilation. The fully settled case is already addressed in the safe storage tank bump analysis. The intent is to determine the "worst" case waste configuration and (a) confirm that the consequences resulting from this waste configuration are still bounded by the safe storage (fully settled) end state; (b) determine a new heat-up rate equation; and (c) determine if the current surveillance frequency in LCO 3.3.2 remains adequate or would need to be adjusted.

3. New appendix in RPP-6213 to directly address the Verification and Validation of the computer code(s) used to assess the phenomena and consequences of the tank bump accident (e.g., HADCRT). This item is

being included to address an upcoming letter to the Contractor regarding the V&V of codes used for accident analysis purposes.

4. Technical justification that the frequency of a tank bump during Waste Feed Delivery activities and operations is not qualitatively higher than the frequency of the event during safe storage (currently established to be "unlikely").

Grant W. Ryan
Phone: (509) 376-5114
Fax: (509) 376-5396
Pager: 85-5913

From: Grant_W_Ryan@RL.gov
Sent: Monday, May 14, 2001 7:43 AM
To: Malinovic@Fauske.com
Cc: J_M_Mike_Grigsby@rl.gov; Grant_W_Ryan@rl.gov; Plys@Fauske.com
Subject: Tank Heat-up Analyses

Importance: High

Boro,

I've talked with Mike this morning and we think that if we can get the following pieces of information on the tank heat-up cases we can start to button this up:

1. Re-establish the heat-up rate for Tank 241-AZ-101 assuming no ventilation and no mixer pumps operating.
2. Establish the heat-up rate for Tank 241-AZ-101 with mixer pumps operating and no ventilation system operating.
3. Determine the waste release rate (e.g., kg/hr) from the Number (1).
4. Determine the waste release rate from Number (2). From your previous correspondence, I believe this is approximated to be ~2 kg/day.

We have decided not pursue any additional analyses for Scenario #3.

Grant W. Ryan
Phone: (509) 376-5114
Fax: (509) 376-5396
Pager: 85-5913

9.2 Heatup Calculation for AZ-101 Updated Heat Load

Calculation of Heat Load (Q) from CHG Letter 7KN00-00-JGF-062 (for Tank 241-AZ-101)

Radionuclide	Waste Inventory - 1/1/94	Decay Heat (W/Ci)	Heat Load (W)
Sr-90	5.65E+06	0.00669	37,799
Cs-137	7.05E+06	0.00472	33,276
Am-241	2.66E+04	0.0328	872

		Sum	71,947

Updated calculation of Heat Load (Q) for Tank 241-AZ-101

Radionuclide	Waste Inventory -1/31/01	Decay Heat (W/Ci)	Heat Load (W)
Sr-90	4.77E+06	0.00669	31,930
Cs-137	5.99E+06	0.00472	28,279
Am-241	2.63E+04	0.0328	863
		Sum	61,072

	Half-life (yr)
Sr-90 =	29.1
Cs-137 =	30.17
Am-241 =	432.7

Decay time (1/1/94 to 1/31/01) = 7.083 yr

Heat-up rate (Equation from Fauske memo)
dT/dt = 0.0067 Q - 0.0774 C/day

dT/dt = 0.33 C/day (using revised heat load value)
[redacted] F/day (using revised heat load value)

9.3 Heatup Calculation for AZ-101 Original Heat Load

Calculation of Heat Load (Q) from CHG Letter 7KN00-00-JGF-062 (for Tank 241-AZ-101)

Radionuclide	Waste Inventory - 1/1/94	Decay Heat (W/Ci)	Heat Load (W)
Sr-90	5.65E+06	0.00669	37,799
Cs-137	7.05E+06	0.00472	33,276
Am-241	2.66E+04	0.0328	872
		Sum	71,947

Updated calculation of Heat Load (Q) for Tank 241-AZ-101

Radionuclide	Waste Inventory -1/31/01	Decay Heat (W/Ci)	Heat Load (W)
Sr-90	4.77E+06	0.00669	31,930
Cs-137	5.99E+06	0.00472	28,279
Am-241	2.63E+04	0.0328	863
		Sum	61,072

	Half-life (yr)
Sr-90 =	29.1
Cs-137 =	30.17
Am-241 =	432.7

Decay time (1/1/94 to 1/31/01) = 7.083 yr

Heat-up rate (Equation from Fauske memo)
dT/dt = 0.0067 Q - 0.0774 C/day

dT/dt = 0.40 C/day (using revised heat load value)
[redacted] F/day (using revised heat load value)

9.4 Inputs for Validation / Verification

From: Grant_W_Ryan@RL.gov
Sent: Wednesday, September 19, 2001 11:46 AM
To: malinovic@fauske.com
Subject: FW: 200E temperatures

Boro,

Here are more temperature data files (for August and September 2001). Do you need additional ventilation system data?

Grant W. Ryan
Phone: (509) 376-5114
Fax: (509) 376-5396
Pager: 85-5913

-----Original Message-----
From: Burk, Kenneth W [mailto:ken.burk@pnl.gov]
<mailto:[mailto:ken.burk@pnl.gov]>
Sent: Wednesday, September 19, 2001 9:35 AM
To: Ryan, Grant W
Subject: RE: 200E temperatures

Ryan,
The files are attached.
ken
<<rqt06.aug>> <<rqt06.sep>>

-----Original Message-----
From: Ryan, Grant W
Sent: Wednesday, September 19, 2001 9:19 AM
To: Burk, Kenneth W
Subject: RE: 200E temperatures
Importance: High

Ken,

Could you send me similar temperature data files for August and September 2001?

Thanks.

Grant W. Ryan
Phone: (509) 376-5114
Fax: (509) 376-5396
Pager: 85-5913

-----Original Message-----

From: Burk, Kenneth W [mailto:ken.burk@pnl.gov]
<mailto:[mailto:ken.burk@pnl.gov]>
Sent: Wednesday, September 05, 2001 12:24 PM
To: Ryan, Grant W
Subject: 200E temperatures

Grant,
This is a load of data, but it was easier for me to give you the 15-minute averages, which includes wind data that you probably don't want. Missing data and/or erroneous data will be obvious. Temperatures are in degrees F. If you have any questions just let me know. These are ASCII text, comma delimited files.

<< File: rqt06.may >> << File: rqt06.jun >> << File: rqt06.jul >>

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
Ken Burk
email: <mailto:ken.burk@pnl.gov> ken.burk@pnl.gov
<http://hms.rl.gov> http://hms.rl.gov On Site
<http://etd.pnl.gov:2080/HMS> http://etd.pnl.gov:2080/HMS Off Site
(509)373-3215
Hanford Meteorological Station (HMS)
Battelle - PNNL S3-91
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

From: Grant_W_Ryan@RL.gov
Sent: Wednesday, September 05, 2001 2:52 PM
To: Malinovic
Subject: FW: 200E temperatures

Boro,

Here is the weather data that you have been waiting for. Please let me know if you need additional info.

Grant W. Ryan
Phone: (509) 376-5114
Fax: (509) 376-5396
Pager: 85-5913

-----Original Message-----
From: Burk, Kenneth W [mailto:ken.burk@pnl.gov]
<mailto:[mailto:ken.burk@pnl.gov]>
Sent: Wednesday, September 05, 2001 12:24 PM
To: Ryan, Grant W
Subject: 200E temperatures

Grant,
This is a load of data, but it was easier for me to give you the 15-minute averages, which includes wind data that you probably don't want. Missing data and/or erroneous data will be obvious. Temperatures are in degrees F. If you have any questions just let me know. These are ASCII text, comma delimited files.

<<rqt06.may>> <<rqt06.jun>> <<rqt06.jul>>

Ken Burk
email: <mailto:ken.burk@pnl.gov> ken.burk@pnl.gov
<http://hms.rl.gov> http://hms.rl.gov On Site
<http://etd.pnl.gov:2080/HMS> http://etd.pnl.gov:2080/HMS Off Site
(509)373-3215
Hanford Meteorological Station (HMS)
Battelle - PNNL S3-91

From: Grant_W_Ryan@RL.gov
Sent: Wednesday, July 25, 2001 6:43 PM
To: malinovic@fauske.com
Cc: Grant_W_Ryan@rl.gov; J_M_Mike_Grigsby@rl.gov
Subject: Temperature Data for Tank 241-AZ-101

Importance: High

Boro,

Included in the attached Excel files (zipped) is the temperature data that I have been able to gather for Tank 241-AZ-101 from the time period of July 1, 1999 to July 25, 2001. Also included in the Word file is a key to show you where the thermocouple is located (i.e., riser number and vertical position in the tank, as measured from the bottom of the tank). I am also faxing you a copy of the plan view of the tank showing the riser penetrations. As an aid, I have circled the risers with active thermocouples.

Also included in the Excel files in temperature data for the thermocouples that have been embedded into the concrete surrounding the tank. I do not have a detailed map of where these are located in the tank. I didn't think that this would be important for what we are trying to do now.

I am still working to get the exhaust flow rate data and air temperature to the inlet of the condenser. I expect to have that tomorrow.

Please let me know if you need more info.

<<Riser and TC Data Key.doc>> <<AZ-101 Temperature Data.zip>>

Grant W. Ryan
Phone: (509) 376-5114
Fax: (509) 376-5396
Pager: 85-5913

From: Grant_W_Ryan@RL.gov
Sent: Monday, August 27, 2001 3:15 PM
To: malinovic@fauske.com
Cc: Grant_W_Ryan@rl.gov
Subject: More data for thermal analyses

Importance: High

Boro,

Here is a summary timeline of events:

April 23, 2001 - Recirculation fan bearing failure in 702-AZ ventilation system (for AZ-101).
- Ventilation flow for AZ-101 maintained at ~100 cfm. Temperature increase noted.
July 16, 2001 - Recirculation fan bearing repaired and ventilation flow increased from 100 cfm to
~300 cfm for Tank 241-AZ-101.
July 18, 2001 - Ventilation system switched to high heat mode for Tank 241-AZ-101.

Here is a description of the ventilation system modes:

Primary Tank Ventilation System. The primary tank ventilation system for the tanks in the 241-AZ/AZ Tank Farms incorporates individually controlled air inlets, independent cooling systems (i.e., Recirculation Ventilation Cooling Systems), and a common ventilation exhaust to maintain headspace confinement in the AWF tanks. A functional overview of the 241-AZ-702 ventilation system is found in Figure 2-xx.

The primary tank ventilation off gas from each tank is exhausted through a flow control valve, processed through a condenser, high-efficiency mist eliminator (HEME), heater, and then filtered through two HEPA filters and a high-efficiency gas adsorber (HEGA) filter before being released to the environment through a stack. The filter/fan train is redundant to maintain negative tank pressures during anticipated maintenance shutdowns or component failure.

The system has three operating modes which are manually established: 1) recirculation (Figure 2-xx), 2) bypass (Figure 2-xx), and 3) high heat (Figure 2-xx). The alignment of the ventilation system on any one tank is independent of the alignment of the ventilation system on the other tanks in the 241-AY/AZ Tank Farms:

1. Each tank's recirculation mode directs tank headspace gases through their respective Recirculation Ventilation Cooling System with, typically, 80% of the airstream returned back into the tank and 20% to the common exhaust system. The common exhaust system draws enough air to maintain a negative pressure in all of the tanks, relative to atmospheric pressure, with the majority of the flow back to the tank. The air flow through the recirculation loop is fixed by equipment design, however each tank's exhaust flow rate is actively-controlled and held constant.

2. The bypass mode directs tank headspace gases directly to the common exhaust system, bypassing the Recirculation Ventilation Cooling System.

3. The high heat mode directs tank headspace gases through the Recirculation Ventilation Cooling System then into the common exhaust system with no air returning to the tank. When any tank is in the high heat mode, the common exhaust fan flow is increased in order to increase evaporative cooling of the tank operating in high heat mode. Exhaust flow is routed through the Recirculation Ventilation Cooling system to help remove moisture.

Grant W. Ryan
Phone: (509) 376-5114
Fax: (509) 376-5396
Pager: 85-5913

10.0 REFERENCES

Crea, B. A., Sathyanarayana, K., and Ogden, D., 2000, "Parametric Analyses of Heat Removal from High-Level Waste Tanks," RPP-5637, Rev. 0, CH2M Hill Hanford Group, Inc., Richland, WA, February.

Epstein, M., 2001, "Aerosol Generation During Select Normal and Off-Normal Waste Treatment Plant Processes Operability and Safety Evaluation, Tasks 3 and 4," FAI/01-07, Fauske & Associates, Inc., Burr Ridge, IL, January.

Epstein, M., Malinovic, B., Plys, M. G., Hauser, G. M., and Bratzel, D. R., 2000, "Hanford Waste Tank Bump Accident and Consequence Analysis," RPP-6213, Rev. 0, CH2M Hill Hanford Group, Inc., Richland, WA, June.

Epstein, M., Malinovic, B., Plys, M. G., and Bratzel, D. R., 2000A, "Tank Bump Accident Potential and Consequences During Waste Retrieval," RPP-6654, Rev. 0, CH2M Hill Hanford Group, Inc., Richland, WA, September.

FAI, 1994, "Evaporative Losses from Hanford Single Shell Tanks," FAI/94-95, Fauske & Associates, Inc., Burr Ridge, IL, September.

Plys, M. G., Malinovic, B., Epstein, M., and Lee, S. J., 2001, "Fuel Cycle Facility Source Term Model HADCRT 1.3: User's Manual," FAI/01-68, Fauske & Associates, Inc., Burr Ridge, IL, September.

Fauske & Associates, Inc. (FAI)

DATE: March 13, 2003

TO: Janet Davis (CH2MHill Hanford Group), James Williams (Flour Federal Services)

FROM: Boro Malinovic

SUBJECT: **DST Boiling Source Term with HADCRT 1.4**

Purpose and Conclusions

Using the latest version of the HADCRT code (Version 1.4b), this memorandum repeats the safe storage loss of ventilation calculations first performed in "Consequences of Select Boiling Waste Scenarios for Waste Feed Delivery, Rev. 1" (FAI/01-42, October 2001). New results are essentially the same as the old, which means that the safe storage loss of ventilation results obtained in FAI/01-42, Rev. 1, are still bounding for current safe storage conditions.

Method and Results

Table 5-1 from FAI/01-42, Rev. 1, is shown here for convenience. We concern ourselves only with runs SSSS (Safe Storage, Steady-State) and SSLV (Safe Storage, Loss of Ventilation), as the other runs (RETSS, RETLV, and RETLVR) involve mixer pump scenarios for waste feed delivery.

Table 5-1: Summary of HADCRT Run Scenarios (from FAI/01-42, Rev. 1).

Run Name	Input File Name	Description	Results
Safe Storage Scenarios			
Steady-State (SSSS)	SSSS.DAT	Run to approximate steady-state (115 days) temperature profile for safe storage conditions.	Steady-state temperature profiles in waste, structural materials, and soil.

16W070 West 83rd Street | Burr Ridge, Illinois 60527 | E-Mail: malinovic@fauske.com
Phone: (630) 323-8750 | Telefax: (630) 986-5481

Table 5-1: Summary of HADCRT Run Scenarios (from FAI/01-42, Rev. 1).

Run Name	Input File Name	Description	Results
Safe Storage Scenarios			
Loss of Ventilation (SSLV)	SSLV.DAT	Restart of SSSS.DAT at 115 days with loss of ventilation; run to 550 days.	Waste temperature profile after loss of ventilation, time to boiling, aerosol generation, and source term due to boiling.
Retrieval Scenarios (Mixer Pumps Operate Indefinitely)			
Steady-State (RETSS)	RETSS.DAT	Run to approximate steady-state (115 days) temperature profile for mixer pump opera-tion, with 500 cfm primary ventilation and no annulus ventilation.	Waste temperature during mixing, mixed-waste steady-state temperature equals 95°C.
Loss of Ventilation (RETLV)	RETLV.DAT	Restart of RETSS.DAT at 16 days with loss of ventilation; run for another 98 days or until supernatant inventory is substantially depleted.	Waste temperature profile after loss of ventilation, time to boiling, aerosol generation, and source term due to boiling.
Recovery (RETLVR)	RETLVR.DAT	Restart of RETLV.DAT at 26.5 days with ventilation re-covery, recovery of ventila-tion after boiling.	Waste temperature profile after recovery, aerosol genera-tion, and source term due to boiling.

These runs were repeated using HADCRT 1.4b and slight modification to the original input files. The only significant modification needed to make the runs with the current code is to remove the surface tension input from the old input files; this input is now part of the gas properties file. For the sake of comparison, a new gas properties file was created so that the current surface tension properties match the old ones. Other input file modifications include trivial changes for time step and added plot variables, and for the sake of numerical stability, introduction of a small oxygen source to the headspace. Input files are contained in Appendix C.

The purpose of run SSSS is just to establish steady-state conditions from which to begin boiling source term analysis. Appendix A shows that at 10 million seconds (116 days), the new run produces practically the same results as the old one does.

Run SSLV.DAT is a restart of SSSS.DAT, and takes the scenario from steady-state conditions to boiling and aerosol generation. Figure 1 shows the results reported in FAI/01-42, Rev. 1. Note that the "restart" occurs at 116 days and boiling starts at about 350 days. Aerosol generation takes place from 350 day to the end of the run at 550 days. Recall that the FAI/01-42, Rev. 1, results were obtained assuming DST 241-AZ-101 carried a total heat load of 71 kW, as compared to the current value of 60.4 kW. Figure 2 shows HADCRT 1.4b results for

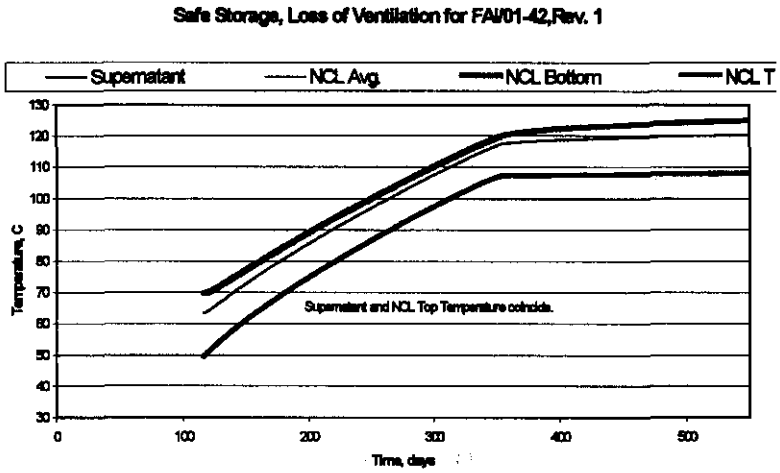


Figure 1: Waste Temperatures from FAI/01-42, Rev 1., SSLV Scenario

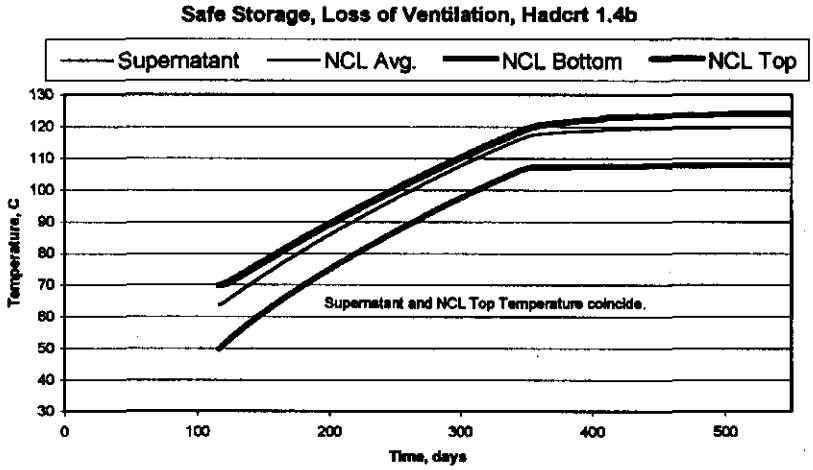


Figure 2: HADCRT 1.4b Results for Waste Temperatures in the SSLV Scenario

SSLV.DAT waste temperatures and demonstrates that the latest code version practically duplicates the old results. In these figures, NCL Bottom has the highest temperature, NCL Top coincides with supernatant temperature, and NCL Avg. is somewhere between the NCL Top and NCL Bottom temperatures.

For both new and old code results, Appendix B shows conditions at 50 million seconds (578 days), which is long after boiling starts. The results are very close and further justify the continued use of FAI/01-42, Rev. 1. HADCRT 1.4b predicts 12.44 kg of waste released over 200 days, for an average of 0.06 kg waste per day, with 20.35 kg deposited. The original work reports 12.41 kg waste released and 20.29 kg waste deposited.

Validation

For the heatup-phase between 116 and 350 days, the HADCRT model has been thoroughly validated in FAI/01-42, Rev. 1. The validation includes a comparison of HADCRT results against temperature data for a degraded ventilation transient that took place in DST 241-AZ-101 during the summer of 2001. The HADCRT code used at the time (HADCRT 1.3, Beta 13) produced excellent agreement with waste temperature data. Because we use the same model for the HADCRT 1.4b runs and obtain very similar results to those in FAI/01-42, Rev. 1, the HADCRT 1.4b runs are validated.

The actual DST 241-AZ-101 temperature recordings are shown here as Figure 3. In this figure, temperature (in degrees F) is plotted at various waste locations during the primary ventilation transient. Transient history can be summarized as follows:

- Between mid-May and July 16th, a recirculation fan bearing failure limited the 241-AZ-101 ventilation flow rate to 100 cfm,
- The fan bearing was replaced on July 16th and AZ-101 flow rate increased from 100 cfm to 300 cfm, and
- From July 18th to August 20th, the 241-AZ-101 ventilation system operated in "high heat mode" at 450 cfm.

HADCRT results are shown here in Figure 4 for the heatup-phase from May to mid-June:

Figure 3 shows a heatup rate of 0.12 to 0.13°C/day (0.22°F/day) during the degraded ventilation phase. Figure 4 shows the following temperatures: convective layer, NCL top, NCL bottom, and NCL average. Underneath each temperature history is a linear regression curve fit for slope, which is heatup rate. Heatup rates vary between 0.13 and 0.16°C/day, and represent reasonable agreement with the data.

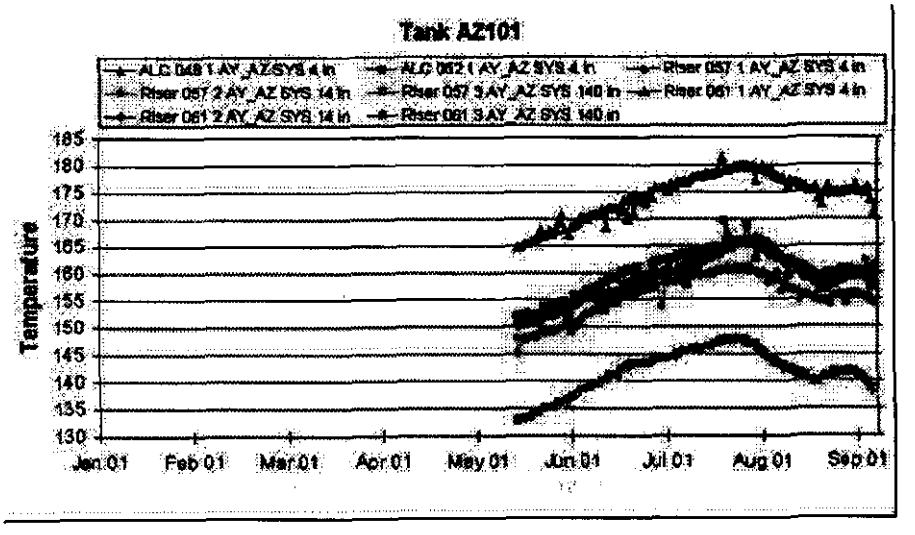


Figure 3: DST-AZ-101 Waste temperature data during the summer of 2001 loss of ventilation transient.

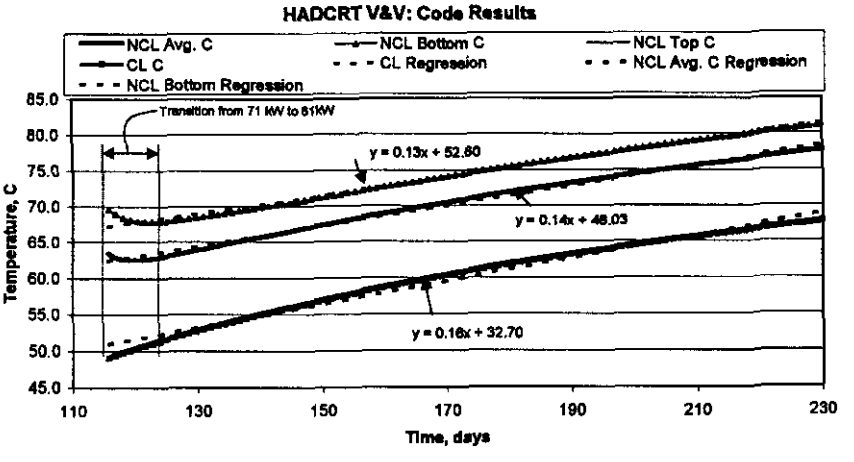


Figure 4: HADCRT (Version 1.3, Beta 12) results for Waste temperature data during the summer of 2001 loss of ventilation transient; taken from FAI/01-42.

For the boiling-phase, it is easy to confirm that the HADCRT 1.4b results match a priori expectations. Consider boiling rate first. For the 71 kW 241-AZ-101 model, supernatant heat load is 30 kW and NCL heat load is 41 kW. Boiling rate must therefore be somewhere between 0.014 kg/s (30 kW divided by 2.2 MJ/kg) and 0.032 kg/s. Appendix B shows that in either the new run, evaporation rate is 0.025 kg/s and is in good agreement with the expectation. At fifty million seconds, the evaporation rate is roughly equal to the outflows through junctions one and two. Note that by convention, a negative flow rate in junction one is out the tank.

Although the boiling aerosol generation model is validated in the HADCRT 1.4 User's Manual (Plys, et al., 2002), consider some simple calculations here. Maximum superficial velocity for boiling in the DST is given by the following:

$$j = \frac{0.032\ \text{kg/s}}{0.6\ \text{kg/m}^3 \times 411\ \text{m}^2} = 0.01\ \text{cm/s}$$

where 411 m^2 is the DST floor area. As explained in the user's manual, this superficial velocity is much less than the transition superficial velocity for the air-water system (5 cm/s), which means that the entrainment coefficient for boiling aerosol generation is 2.0E-7. Aerosol generation due to boiling is then

$$W_a = \frac{2.0\text{E-}7 \times 0.025\ \text{kg/s} \times 1000\ \text{kg/m}^3}{0.6\ \text{kg/m}^3} = 8.3\text{E-}6\ \text{kg/s} = 0.7\ \text{kg/day}$$

Now this aerosol generation rate includes both water and dissolved solids or "waste" as it is termed in the HADCRT input. The mass fraction of waste is 21% by weight, so that an upper bound on waste aerosol generation would be 0.15 kg/day (21% of 0.7 kg/day). Calculated release are somewhere between 0.03 and 0.06 kg/day, which suggests a very reasonable leak path factor of three or four.

Now consider the leakage time constant:

$$\lambda = \frac{\text{Volumetric Flowrate}}{\text{Headspace Volume}} = \frac{0.025/0.6\ \text{m}^3/\text{s}}{2000\ \text{m}^3} = 2.1\text{E-}5\ 1/\text{s} = 1.8\ 1/\text{day}$$

This demonstrates that in the course of the day, 1.8 headspace volumes are turned over and that leakage should remove much of the waste aerosol generated if filters are not credited.

Leak path factor and releases are determined by a race between leakage and deposition. Characteristic time constant for leakage is then about half a day (1/1.8 days). Characteristic time constant for aerosol deposition is known to vary between several hours and to a day, depending on concentration and particle properties. Therefore, it makes sense to observe some releases with most of the airborne waste retained in the DST. At 50 million seconds, 12.4 kg of waste are released, but 20 kg are deposited.

Reference

Plys, M. G., B. Malinovic, M. Epstein, and S. J. Lee, 2002, *Fuel Cycle Facility Source Term Model HADCRT 1.4: User's Manual*, FAI/02-50, Fauske & Associates, Inc., Burr Ridge, Illinois, July.

Appendix A:

Comparison of HADCRT 1.4b Results for SSSS.DAT with Results Reported for FAI/01-42, Rev. 1

A.1 HADCRT 1.4b Tabular Output Header for SSSS.DAT and Snapshot at 10 Million Seconds

```
                                  -----------
                                  HADCRT 1.4b
                                  -----------

 Time & Date of Run:      19:54:19.69      03/10/03

 Base Input:    C:\HANSF MCO\BOILST\02/27/2003.04:17P  24,629  SSSS.DAT

 Gas Property: C:\HANSF MCO\BOILST\03/10/2003.11:36A  17,397  GASPROP1.DAT

 DST AZ-101 SS CONDITIONS; FIN HEAT TRANSFER
 500 SCFM PRIMARY VENTILATION, NO ANNULUS VENTILATION, CONDENSER

.
.
.
Region properties:                                Time=  10000000.000 seconds
                                                          2777.778 hours
 Timestep =    5.0000     Average =    4.9998

 Region # ->          1           2           3           4
 Press., Pa     1.00430E+05 1.01501E+05 1.01345E+05 9.45161E+04
 Temp., C         4.547E+01   4.798E+01   2.798E+01   1.639E+01
      , K         3.186E+02   3.211E+02   3.011E+02   2.895E+02
 Spec. Heat Cv    7.492E+02   7.670E+02   7.187E+02   7.238E+02
 Ratio Cp/Cv      1.395E+00   1.391E+00   1.402E+00   1.402E+00
 k, W/m-C         2.652E-02   2.644E-02   2.568E-02   2.472E-02
 rho, kg/m^3      1.067E+00   1.055E+00   1.167E+00   1.125E+00
 mu, Pa-s         1.908E-05   1.907E-05   1.843E-05   1.784E-05
 Tliq, C          4.924E+01   4.751E+01   2.500E+01   1.006E+01
 Mliq, kg         3.591E+06   5.611E+02   0.000E+00   8.695E+05
 Zliq, m          7.470E+00   1.001E-02   0.000E+00   8.709E+02
 Cvliq            3.512E+03   4.179E+03   0.000E+00   4.208E+03

 Mole fractions of gas ...
 STEAM            6.474E-02   1.018E-01   2.314E-03   1.808E-02
 OXYGEN           1.947E-01   1.886E-01   2.077E-01   2.044E-01
 NITROGEN         7.406E-01   7.097E-01   7.900E-01   7.775E-01
```

A.2 Tabular Output Header for SSSS.DAT and Snapshot at 10 Million Seconds, as Reported in FAI/01-42, Rev. 1

```
                    -----------------
                     HADCRT Rev. 1.3
                         beta 12
                    -----------------

Time & Date of Run:     15:23:12.63     09/09/01

Base Input:   C:\RYAN\RUNS\SSSS.DAT  24712  07/28/01  4:04P

Gas Property: C:\RYAN\RUNS\GASPROP.DAT  13309  07/26/01  6:17P

DST AZ-101 SS CONDITIONS; FIN HEAT TRANSFER
500 SCFM PRIMARY VENTILATION, NO ANNULUS VENTILATION, CONDENSER
.
.
Region properties:                                Time=  10000000.000 seconds
                                                              2777.778 hours
 Timestep =   5.0000     Average =   4.9998

 Region # ->          1          2          3          4
 Press., Pa       1.004E+05  1.015E+05  1.013E+05  9.452E+04
 Temp., C         4.525E+01  4.774E+01  2.798E+01  1.643E+01
      , K         3.184E+02  3.209E+02  3.011E+02  2.896E+02
 Spec. Heat Cv    7.493E+02  7.635E+02  7.187E+02  7.238E+02
 Ratio Cp/Cv      1.395E+00  1.392E+00  1.402E+00  1.402E+00
 k, W/m-C         2.650E-02  2.648E-02  2.568E-02  2.472E-02
 rho, kg/m^3      1.068E+00  1.059E+00  1.167E+00  1.125E+00
 mu, Pa-s         1.907E-05  1.909E-05  1.843E-05  1.784E-05
 Tliq, C          4.898E+01  4.729E+01  2.500E+01  1.007E+01
 Mliq, kg         3.591E+06  5.636E+02  0.000E+00  8.689E+05
 Zliq, m          7.470E+00  1.005E-02  0.000E+00  8.703E+02
 Cvliq            3.512E+03  4.179E+03  0.000E+00  4.208E+03

 Mole fractions of gas ...
 STEAM            6.517E-02  9.456E-02  2.314E-03  1.811E-02
 OXYGEN           1.946E-01  1.900E-01  2.077E-01  2.044E-01
 NITROGEN         7.402E-01  7.154E-01  7.900E-01  7.775E-01
```

Appendix B:

Comparison of HADCRT 1.4b Results for SSLV.DAT with Results Reported for FAI/01-42, Rev. 1

B.1 HADCRT 1.4b Tabular Output Header for SSLVR.DAT and Snapshot at 50 Million Seconds

Region properties: Time= 50000000.000 seconds
13888.889 hours

Timestep = 20.7578 Average = 29.5462

Region # ->	1	2	3	4
Press., Pa	1.01490E+05	1.01489E+05	1.01359E+05	1.01355E+05
Temp., C	1.053E+02	1.049E+02	2.800E+01	1.080E+01
, K	3.784E+02	3.781E+02	3.012E+02	2.839E+02
Spec. Heat Cv	1.498E+03	8.228E+02	7.187E+02	7.207E+02
Ratio Cp/Cv	1.295E+00	1.378E+00	1.402E+00	1.403E+00
k, W/m-C	2.490E-02	2.997E-02	2.568E-02	2.434E-02
rho, kg/m^3	5.885E-01	8.640E-01	1.167E+00	1.233E+00
mu, Pa-s	1.270E-05	2.127E-05	1.843E-05	1.758E-05
Tliq, C	1.078E+02	9.363E+01	2.800E+01	1.057E+01
Mliq, kg	3.200E+06	9.995E-06	8.133E+05	4.775E+03
Zliq, m	6.616E+00	1.808E-10	8.184E-02	4.783E+00
Cvliq	3.471E+03	4.214E+03	4.185E+03	4.206E+03
Mole fractions of gas ...				
STEAM	1.000E+00	1.931E-01	2.377E-03	1.289E-02
OXYGEN	2.704E-05	1.680E-01	2.077E-01	2.064E-01
NITROGEN	1.088E-17	6.389E-01	7.899E-01	7.807E-01
Gas masses ...				
STEAM	1.541E+03	7.003E+01	1.732E+07	9.913E+00
OXYGEN	7.410E-02	1.083E+02	2.691E+09	2.823E+02
NITROGEN	2.609E-14	3.606E+02	8.960E+09	9.347E+02
TOTAL	1.542E+03	5.390E+02	1.167E+10	1.227E+03
Relative humidities ...				
STEAM	8.317E+01	1.623E+01	6.339E+00	1.002E+02
Aerosol masses ...				
STEAM	-6.848E-18	-2.194E-13	1.917E-03	1.035E+03
WASTE	5.996E-02	0.000E+00	1.244E+01	6.968E-02
TOTAL	5.996E-02	-2.194E-13	1.245E+01	1.035E+03
Diam,micron	6.629E-01	5.093E-01	3.429E-01	8.508E+00
Log SD	1.732E+00	1.475E+00	1.475E+00	2.547E+00
Dep Mass kg	2.035E+01	0.000E+00	0.000E+00	0.000E+00
Liquid masses ...				
STEAM	2.446E+06	9.995E-06	8.133E+05	4.775E+03
WASTE	7.542E+05	0.000E+00	8.804E-01	1.818E-01
TOTAL	3.200E+06	9.995E-06	8.133E+05	4.775E+03

Rates of change of gas and aerosol ...

STEAM	g	-6.153E-04	-1.274E-07	2.274E-02	-2.759E-05
STEAM	a	0.000E+00	0.000E+00	1.156E-04	1.615E-04
OXYGEN	g	-1.873E-07	-1.972E-07	3.982E-05	-3.844E-05
NITROGEN	g	-4.179E-19	-6.562E-07	1.282E-04	-1.276E-04
WASTE	a	2.580E-07	0.000E+00	8.908E-07	1.750E-09

Junction Flowrates: Time= 50000000.000 seconds
13888.889 hours

Path # ->	1	2	3	4	5
W: kg/s	-2.266E-02	2.043E-03	-4.904E-07	4.904E-07	1.675E-04

B.2 Tabular Output Header for SSLV.DAT and Snapshot at 50 Million Seconds, as Reported in FAI/01-42, Rev. 1

```
-----------------
 HADCRT Rev. 1.3
     beta 12
-----------------

Time & Date of Run:     19:34:08.81     09/09/01

Base Input:   C:\RYAN\RUNS\SSLV.DAT  24843  09/08/01  2:57P

Gas Property: C:\RYAN\RUNS\GASPROP.DAT  13309  07/26/01  6:17P

DST AZ-101 SS CONDITIONS; FIN HEAT TRANSFER
RESTART W/ NO SCFM PRIMARY VENTILATION, NO ANNULUS VENTILATION, CONDENSER

Restart From: C:\RYAN\RUNS\SSLV.RER  310736  09/09/01  7:34P
.
.
.
Region properties:                          Time=  49999984.000 seconds
                                                      13888.884 hours
Timestep =  20.0000     Average =  12.8653
```

Region # ->	1	2	3	4
Press., Pa	1.015E+05	1.015E+05	1.014E+05	1.014E+05
Temp., C	1.053E+02	1.049E+02	2.801E+01	1.079E+01
, K	3.784E+02	3.780E+02	3.012E+02	2.839E+02
Spec. Heat Cv	1.498E+03	1.039E+03	7.187E+02	7.208E+02
Ratio Cp/Cv	1.295E+00	1.343E+00	1.402E+00	1.403E+00
k, W/m-C	2.490E-02	2.780E-02	2.568E-02	2.434E-02
rho, kg/m^3	5.885E-01	7.465E-01	1.167E+00	1.233E+00
mu, Pa-s	1.269E-05	1.868E-05	1.843E-05	1.758E-05
Tliq, C	1.078E+02	1.049E+02	2.801E+01	1.055E+01
Mliq, kg	3.201E+06	2.700E+02	8.118E+05	4.747E+03
Zliq, m	6.618E+00	4.902E-03	8.169E-02	4.755E+00
Cvliq	3.471E+03	4.229E+03	4.185E+03	4.207E+03

Mole fractions of gas ...

STEAM	1.000E+00	5.360E-01	2.377E-03	1.287E-02
OXYGEN	9.505E-19	9.709E-02	2.077E-01	2.055E-01
NITROGEN	3.615E-18	3.669E-01	7.899E-01	7.816E-01

```
Gas masses ...
STEAM          1.541E+03   1.950E+02   1.732E+07   9.901E+00
OXYGEN         2.604E-15   6.278E+01   2.691E+09   2.811E+02
NITROGEN       8.670E-15   2.077E+02   8.960E+09   9.359E+02
TOTAL          1.541E+03   4.654E+02   1.167E+10   1.227E+03

Relative humidities ...
STEAM          8.324E+01   4.507E+01   6.339E+00   1.001E+02

Aerosol masses ...
STEAM         -6.905E-18  -5.421E-18   0.000E+00   1.015E+03
WASTE          5.992E-02   0.000E+00   1.241E+01   6.889E-02
TOTAL          5.992E-02  -5.421E-18   1.241E+01   1.015E+03
Diam,micron    6.628E-01   1.000E+00   1.000E+00   1.000E+00
Log SD         1.732E+00   2.000E+00   2.000E+00   2.000E+00
Dep Mass kg    2.029E+01   0.000E+00   0.000E+00   0.000E+00

Liquid masses ...
STEAM          2.447E+06   2.700E+02   8.118E+05   4.747E+03
WASTE          7.542E+05   0.000E+00   8.802E-01   1.808E-01
TOTAL          3.201E+06   2.700E+02   8.118E+05   4.747E+03

Rates of change of gas and aerosol ...
STEAM     g    1.733E-07   1.356E-06   3.177E-02   7.778E-06
STEAM     a    0.000E+00   0.000E+00   0.000E+00  -3.163E-06
OXYGEN    g   -3.502E-20   7.768E-06  -8.447E-06   6.796E-07
NITROGEN  g   -1.166E-19   2.586E-05  -2.813E-05   2.263E-06
WASTE     a   -5.078E-09   0.000E+00   7.379E-07   6.452E-10

Junction Flowrates:                          Time=  49999984.000 seconds
                                                       13888.884 hours

Path # ->       1           2           3           4           5

W: kg/s   -1.898E-02   1.756E-03   1.684E-05  -1.684E-05  -2.947E-06
Wcc: kg/s  0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00
```

Appendix C:

Input and Gas Properties Files

C.1 SSSS.DAT: Base Input File for Steady-State Conditions

```
*********************************************************************
*   Underground DST with loss of cooling
*********************************************************************
*
*-------------------------------------------------------------------
CONTROL    ! Major keyword group
*-------------------------------------------------------------------
*
*
 TITLE     ! Keyword; next line is title, title can be any length*  -
 DST AZ-101 SS Conditions; fin heat transfer
 500 scfm primary ventilation, no annulus ventilation, condenser
 END TITLE ! Anything after END is a comment
*
*
*
 TIMING    ! Keyword
   TSTART      0.     !  START TIME, >0 FOR RESTART RUN
   TLAST  10000000.!  END TIME
   DTMIN              !  MIN TIMESTEP (Seconds)
     0.0      1.0
    10.0      1.0
    100.0     5.0
    1000.0    5.0
   100000.0  5.0
   DTMAX              !  MAX TIMESTEP (Seconds)
    0.0       1.0
    5.0       1.0
    100.0     20.0
    1000.     20.0
  100000.     20.
   DTPRIN             !  PRINT INTERVAL (Seconds)
   0.0       100000.0
  1000000. 1000000.
  10000000. 1000000.
   PLTMIN             !  MIN PLOT INTERVAL (Seconds)
   0.0       1000.0
   10000.0  1000.0
   100000.0 10000.0
   1000000.0 100000.0
   PLTMAX             !  MAX INTERVAL WITHOUT PLOT (Seconds)
   0.0    1000.0
   1000.0 1000.0
   10000.0 10000.0
   100000.0 100000.0
   1000000.0 1000000.0
   DTRST              !  RESTART INTERVAL (Seconds)
   0.0       1.E7
   5.E6      1.E6
*
   FTPCH      0.001        !  FRACTIONAL CHANGE IN T AND P
   FAECH      0.001        !  FRACTIONAL CHANGE IN aerosol mass
   FPPLCH     0.03          !  FRACTIONAL CHANGE FOR PLOTTING
 END TIMING ! TIMING is a comment.
```

```
*
* COMPOUND LIBRARY ORDER FOR OUTPUT
*   This section allows user specification of the order
*   in which compound names are printed & placed in the
*   plot files.  This section is optional, but recommended.
*   Using this section saves computation time by limiting
*   the range of loops. This section rearranges internal
*   storage to the user-defined order, and essentially
*   defines a sub-library for this case only.
*
*   Format:
*   The section begins with the keyword COMPOUND followed
*   by the number of compounds to be used for this run.
*   Compound names are placed on succeeding lines,
*     using up to 80 columns.
*   Finish the list with the END keyword.
*   You can comment a line in the list by putting
*     the double asterisk ** in cols. 1 and 2.
*   Example (here column 1 has * for comment):
* COMPOUNDS 8
*    STEAM OXYGEN NITROGEN
*    HEXONE CARBON_DIO
*    WASTE WASTTRAC STEATRAC
* END
*
*   User caveats:
*   1. If this is invoked, it MUST PRECEDE any input section that
*   refers to compound names, such as plotting, sources, etc.
*   2. The user must name ALL compounds that are used in the
*   calculation, or else the compound will be skipped. For
*   example there may be no combustion products initially
*   present anywhere, but these must be named to be used later.
*   3. Spelling must be identical to names in GASPROP.DAT
*   Check the log file for mis-spelling warnings.
*
 COMPOUNDS 4
   STEAM OXYGEN NITROGEN WASTE
 END
*
*
 PLOT        ! Keyword for plotting section
* Plotting syntax:
*
* PRESSURE n rlist - Pressure, Pa
* GAS-T  n rlist  - Gas Temperature, K
* LIQ-T  n rlist  - Liquid Temperature, K
* LIQ-EL n rlist  - Liquid Level, m
* HS-TI  n hlist  - Heat Sink Temperature - Inner Surface, K
* HS-TO  n hlist  - Heat Sink Temperature - Outer Surface, K
* HS-TA  n hlist  - Heat Sink Temperature - Average, K
* AEROSOL n rlist - Aerosol Mass (Total), kg
* GAS-W  n jlist  - Mass Flowrate, kg/s
* GAS-WX n jlist  - CounterCurrent Mass Flowrate, kg/s
* SPECIAL-X n xlist - Special model state variable
* SPECIAL-R n xlist - Special model rate variable
* GAS-X    GASNAME n rlist  - Gas Mole Fraction
* GAS-RH   GASNAME n rlist  - Gas Relative Humidity
* GAS-MASS GASNAME n rlist - Gas Mass (Species), kg
* AER-MASS GASNAME n rlist - Aerosol Mass (Species), kg
* MASS     GASNAME n rlist - Total Mass (Species), kg
* LIQ-MASS - GASNAME n rlist - Deposited Mass (Species), kg
*
* Pressure, Gas Temperature, and total aerosol mass require a region
* list
```

```
*
* Heat Sink Temperatures need a heat sink number list
*
* Flowrates need a junction number list
*
* Gas concentration, relative humidity, individual species gas mass,
* individual species aerosol mass, total (gas+aerosol) individual
* species mass, and individual species deposited liquid mass require
* a region and gas name
*
*  special state & rate variables are:
*  1=  Waste surface entrainment during a burn
*  2=  Tank surface entrainment during a burn
*  3=  Waste surface entrainment during blowdown
*  4=  Unused, reserved for tank surface entrainment during blowdown
*  5=  Total entrainment
*
  PRESSURE      4  1  2  3  4     ! Pressure
  GAS-T         4  1  2  3  4      ! Gas Temps
  LIQ-T         2     1   4          ! L temps
  LIQ-EL        2     1   4          ! L elevations
  GAS-X  NITROGEN    1   1         ! N2 Concentration
  GAS-X  OXYGEN      1   1         ! O2 concentration
  GAS-X  STEAM       1   1         ! H2O concentration
  GAS-W         4    1   2   3   4  ! Gas flow rates
  HS-TA         7    3 4 5 6 7 8 9
  WCOND-PL  STEAM    1   1          ! Condensation rate of steam on pool
  WCOND-HSO STEAM    2   1   18      ! Condensation rate of steam on hs-1
  WCOND-HSI STEAM    4   2   3   4  18 ! Condensation rate of steam on hs-2 & 3
  QGAS-HSO      8   1   3   4   5   6  7  8  13     ! gas-to-hs hx
  QGAS-HSI      7   2   3   4   5  13 15 16     ! gas-to-hs hx
  QGAS-POOL     1   1       ! gas-to-pool hx
  QLIQ-HSI      4   4   5   6   7     ! liquid-to-hs hx
  QLIQ-HSO      1   9                 ! liquid-to-hs hx
 END PLOT  ! PLOT is a comment
*
PRINT
      HS 18 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
END
*
 ACTIVE MODELS ! Keyword; MODELS is a comment; 1 = on, 0 = off
  IJUNC   1    ! Junction flow model
  ICCFLW  0   ! Counter-current flow model
  IHSINK  1    ! Heat sinks
  IHXPOL  1    ! gas-pool heat/mass transfer
  ICNDS   1    ! Condensation
  IASED   1    ! Aerosol Sedimentation
  IALEAK  1   ! Aerosol Leakage
  IFOG    1    ! Fog formation
  ISRC    1    ! User-defined sources
  IQDECAY 1    ! Decay power
  IMCO    0    ! MCO models
  ISENS   0    ! Sensitivity runs
  ILXFER  1   ! Liquid transfers
  IDCRT   0    ! DCRT Runs
  IPLTYP  2    ! =1, normal mp wrap-around  =2, spreadsheet no wrap-around
  END ACTIVE MODELS ! ACTIVE MODELS  is a comment
*
*
 MODEL PARAMETERS
  AGAMMA   2.5   ! Shape factor for nonsphericity for coagulation
  ACHI     1.0   ! Shape factor for nonsphericity for stokes'law
  AFEO     1.0   ! Collision efficiency: 1.0 Fuchs, 0.33 Prupacher-Klett
  ENT_BOIL 2.E-7  ! Boiling entrainment coefficient
```

```
*  SURF_LIQ 0.07   ! Liquid surface tension; water is default
 END MODEL PARAMETERS
*
C-----------------------------------------------------------------------
C      DECAY POWER
C
 DECAY
    WASTE   0.0407
 END
*
C-----------------------------------------------------------------------
C      SOURCE GROUP:  GROUPS REPEATED FOR INPUT # OF REGIONS
C        END OF GROUP DESIGNATED BY 'REGION' OR 'END' KEYWORDS
C      ENTER: TIME, TEMP, FLOWRATES, POWER
C      SYNTAX EXAMPLE:
SOURCES 1                          ! -- KEYWORD AND # SOURCE GROUPS
 REGION  1  GASES 1  PHASE 3        !-- REGION #, # COMPOUNDS, PHASE #
    STEAM              !-- GAS NAMES MUST BE ON NEXT LINE
  0     26.7   0.0 0.00E5 ! MIXER PUMP POWER
  1.0E9 26.7   0.0 0.00E5 ! MIXER PUMP POWER
 END REGION                   !-- ENDS A REGION SOURCE
END SOURCES

* PHASE INDEX: 1=GAS, 2=AERO, 3=LIQUID
*
*
*
END CONTROL    ! End of CONTROL keyword group
*
*
*-----------------------------------------------------------------------
*     OPERATIONS
*-----------------------------------------------------------------------
*
 OPERATIONS
*
*     OPERATIONS         ! Keyword to begin this section
*
*     Keyword groups go here as described below.  Active groups are:
*     TRANSFER
*
*     END OPERATIONS     ! End is a comment here
*
*     WASTE TRANSFER SYNTAX:  SAME AS REGION & JUNCTION SYNTAX, COLUMNS
*     TRANSFER ilist     Keyword TRANSFER followed by list of indices
*                        each index is a transfer index #
*       KEYWORD  rlist   Keyword name (see list below) and column values
*                        corresponding to ilist above
*      END                End this section
*     Use 5 transfer columns per set maximum, then repeat the group
*     Maximum of 30 defined transfers
*
*     Waste is transferred from region IXR1 to IXR2 at constant
*        volumetric flowrate WV_XFER or at a pulsed flowrate
*        during the active duty cycle time DUTY_ON, followed by
*        the idle cycle duration DUTY_OFF.
*     Transfers start at time T_START and end at time T_END.
*     Rational level controls also exist for transfers.
*     Transfer begins when donor region level exceeds
*        the high level ZL1_HI.  Default begins transfer if the
*        donor level exceeds region top minus 1 cm.
*     Transfer ends when donor region level falls below
*        the low level ZL1_LO.  Default ends at 1 cm elevation.
*     Transfer ends when receiver region level exceeds
```

```
*        the high level ZL2_HI.  Default ends transfer if the
*        receiver level exceeds region top minus 1 cm.
*     The program will abort due to errors in PTREG1 or PTREG2
*        if a region becomes "solid", and transfers or
*        sources into a full region are the cause.  Remedy by
*        better control over intended transfers.
*     Waste can be cascaded in a series of tanks via a series
*        of transfers initiated on level.
*     Waste can flow in both directions controlled by level,
*        using a pair of transfers, one in each direction.
*
*     WASTE TRANSFER KEYWORD DEFINITIONS
*
*     IXR1         "FROM" REGION
*     IXR2         "TO" REGION
*     IDUTY        1= USE DUTY CYCLES, 0= CONSTANT FLOW
*     IR1_HI       1= BEGIN ON HIGH LEVEL IN IXR1, 0= IGNORE
*     WV_XFER      NOMINAL VOLUMETRIC FLOWRATE AT ZERO DP WHEN ACTIVE
*     T_START      TIME TO START XFER FLOW
*     T_END        TIME TO END XFER FLOW
*     DUTY_ON      DUTY CYCLE TIME FOR TRANSFER FLOW IF PERIODIC
*     DUTY_OFF     DUTY CYCLE TIME FOR NO (OFF) TRANSFER FLOW IF PERIODIC
*                  TOGETHER THESE CYCLE TIMES DEFINE A COMPLETE CYCLE
*     ZL1_HI       HIGH LEVEL IN "FROM" REGION THAT BEGINS XFER:
*                   ZLR(IXR1) > ZL1_HI. DEFAULT: 1 CM FROM TOP
*     ZL2_HI       HIGH LEVEL IN "TO" REGION THAT ENDS XFER:
*                   ZLR(IXR2) < ZL2_HI. DEFAULT: 1 CM FROM TOP
*     ZL1_LO       LOW LEVEL IN "FROM" REGION THAT ENDS XFER:
*                   ZLR(IXR1) < ZL1_LO. DEFAULT: 1 CM FROM BOTTOM

 TRANSFER          1
     IXR1          4
     IXR2          1
     IDUTY         0
     IR1_HI        1
     WV_XFER      1.E6
     T_START      0.0
     T_END        1.0E10
     DUTY_ON      100.
     DUTY_OFF     100.
     ZL1_HI      10.0
     ZL2_HI      7.47
     ZL1_LO      1.00
 END TRANSFER

END OPERATIIONS
*-----------------------------------------------------------------------
VOLUMES    4       ! total number of control volumes
*-----------------------------------------------------------------------
* No more than 5 columns (regions) at a time
* Units:
* VOLUME m^3, SED_AREA m^2, ELEVATION m, TEMP_GAS K, PRESSURE  Pa
*
*              TANK            ANNULUS      Ambient    Condenser
 REGIONS        1                2            3          4
  VOLUME      5338.            623.78       1.E10      1000.
  SED_AREA     411.             0.0         0.0        0.0
  ELEVATION   0.429              0.0         15.        16.
  TEMP_GAS     45.             28.0         28.        10.0
  PRESSURE    101350.         101350.       101350.    101350.
  ZTOP        12.99            11.0         1.E6       1000.
  Z_LIQ        7.47            0.01         0.00       990.0
  TEMP_LIQ     49.0            28.0         28.0       10.0
 END REGIONS  ! REGIONS is a comment
```

```
*
* Gas composition of each region; specify mole fraction of each gas
* No more than five columns at a time
*
*              TANK        ANNULUS   AMBIENT     CONDENSER
 GASES          1            2         3            4
  STEAM        0.100        0.1       0.0023      0.0100
  OXYGEN       0.189        0.189     0.2077      0.2000
  NITROGEN     0.711        0.711     0.7900      0.7900
 END GASES           ! GASES is a comment
*
*              TANK     ANNULUS   AMBIENT   CONDENSER
LIQUIDS         1         2         3         4
  STEAM        0.790   1.0       1.0       1.0
  WASTE        0.210    0.0      0.0       0.0
END LIQS           ! LIQS is a comment
*
* Aerosol concentration of each region (kg/m^3)
* No more than five columns at a time
*
*AEROSOLS        1         2         3         4        5
* WASTE         0.000     0.0       0.0       0.0     0.0
*END AEROSOLS ! AEROSOLS is a comment
*   OFFSET_TIMETG
*   EXTRAPOLATION_TIMETG
*   TIMETG  REGION # TIME1, TIME2...TIMELAST
*   TGFIX   REGION # TEMP1, TEMP2... TEMPLAST   TEMPS ARE IN C!!!
*   LINEAR INTERPOLATION BETWEEN VALUES
*
*   SIMILAR SYNTAX FOR PRESSURE:
*   OFFSET_TIMETG
*   EXTRAPOLATION_TIMEPG
*   TIMEP  REGION #  TIME1, TIME2...
*   PRFIX  REGION #  PRES1, PRES2...PRESSURES ARE IN PA!!!
*
*  OFFSET_TIMETG=  OFFSET TIME; ENTER LOOKUP TABLE WITH
*                  TIME+OFFSET_TIMETG
*  EXTRAPOLATION_TIMETG= LAST TO USE LAST VALUE IN THE TABLE,
*                      = EXTRAP TO EXTRAPOLATE FROM LAST TWO POINTS,
*                      = PERIOD TO WRAP AROUND.
*  OFFSET_TIMETG          0.
*  EXTRAPOLATION_TIMETG     LAST
*TIMETG 4  0.0    1.E10
*TGFIX  4 15.0    15.0
*
* CONTROL  BOUNDARY P,
*  OFFSET_TIMEPG          0.
*  EXTRAPOLATION_TIMEPG     EXTRAP
*TIMEP 4  0.0       1.E10
*PRFIX  4  0.9840E5 0.9840E5
END
* Major keyword-------------------------------------------------------
HEAT_SINKS     18 !Total number of heat sinks
*--------------------------------------------------------------------
* No more than 5 columns at a time,
* Repeat the following structure,
* SINKS
* .
* .
* .
* END
*
* Syntax:
* IGEOM  1 for plane, 0 or 2 for cylinder
```

```
* IORIHS 0 for vertical, 1 for horizontal
* RHO    Density (kg/m^3)
* KHS    Thermal Conductivity (W/m/K)
* CPHS   Specific Heat (J/kg/K)
* QV      Volumetric Heat Generation (W/m^3)
* XRI     Inner Radius (m)
* XRO     Outer Radius (m); for plane wall, thickness = XRO-XRI
* AHS     One-sided heat sink area (m^2)
* TIINIT  Initial inside surface temperature (C)
* TOINIT  Initial outside surface temperature (C)
* IMSLAB  Number of slabs; 3 is minimum
* IREGI   Region index for inner surface or 0 (insulated)
*         or -1 for constant temperature
* TIHS    Region surface temperature when IREGI = -1  (C)
* IREGO   Region index for outer surface or 0 (insulated)
*         or -1 for constant temperature
* TOHS    Region surface temperature when IREGO = -1  (C)
* XLHS    Characteristic length for natural convection (m)
* EHSI    Emissivity of inner surface
* EHSO    Emissivity of outer surface
*
*
SINKS        1          2          3          4          5
*          tank       tank top   tank wall  tank wall  tank wall
*         ceiling      soil       first      second     third
 IGEOM       1          1          2          2          2
 IORIHS      1          1          0          0          0
 IMATHS      1          2          1          1          1
 XRI       0.0000     0.0        11.438     11.438     11.438
 XRO       0.0100     4.0        11.448     11.448     11.448
 AHS       411.0     411.0      358.0      143.891    143.891
 TIINIT      45.00     20.0       49.0       49.0       49.0
 TOINIT      45.00     45.0       49.0       49.0       49.0
 IMSLAB       3        20          3          3          3
 IREGI        0         3          1          1          1
 TIHS        0.0       0.0        0.0        0.0        0.0
 IREGO        1         0          2          2          2
 TOHS        0.0       0.0        0.0        0.0        0.0
 XLHS       22.88     22.88      5.0        2.0        2.0
 XZHS        0.0       0.0       2.50        1.0        1.0
 ZBHS       12.99     13.00      8.75       7.0        5.0
 ZTHS       13.00     15.1433   12.98      8.75        7.0
END
*
SINKS        6          7          8          9         10
*          tank wall  tank wall  tank wall  non-convective  tank
*           fourth     fifth      sixth      layer      floor
 IGEOM       2          2          2          1          1
 IORIHS      0          0          0          2          2
 IMATHS      1          1          1          3          1
 XRI       11.438     11.438     11.438     0.0        0.0
 XRO       11.448     11.448     11.448     0.43       0.01
 AHS       143.891    143.891    71.946     411.0      411.0
 TIINIT      54.00     54.0       54.0       64.0       54.0
 TOINIT      54.00     54.0       54.0       64.0       54.0
 IMSLAB       3         3          3         20          3

 IREGI        1         1          1          0          0
 TIHS        0.0       0.0        0.0        0.0        0.0
 IREGO        2         2          2          1          0
 TOHS        0.0       0.0        0.0        0.0        0.0
 XLHS       2.00      2.00       1.0       22.88      22.88
 XZHS       1.0       1.0       0.025       11.0       0.0
 ZBHS       3.0       1.0        0.0        0.0       -0.01
```

```
 ZTHS          5.0        3.0        1.0        0.43        0.0
END
*
SINKS        11          12          13          14          15
*        tank bottom  tank bottom  annulus top  annulus wall  annulus wall
*           concrete     soil        soil         soil        concrete
 IGEOM       1           1           1           0           0
 IORIHS      2           2           1           0           0
 IMATHS      4           2           2           2           4
 XRI         0.0         0.0         0.0        12.707      12.225
 XRO         0.4572      30.0        4.0       112.707      12.707
 AHS         411.0       411.0       411.0     1223.82      861.59
 TIINIT      49.00       12.0        20.0        49.0        49.0
 TOINIT      49.00       49.0        49.0        25.0        45.0
 IMSLAB      20          20          20          20          20
 IREGI       0           -1          3           0           2
 TIHS        0.0         12.0        0.0         0.0         0.0
 IREGO       0           0           2           0           0
 TOHS        0.0         0.0         0.0        20.0         0.0
 XLHS        0.0         0.0         0.762       0.0        11.0
 XZHS        0.0         0.0         4.0         0.0         0.0
 ZBHS       -0.4826    -10.4826     10.99       0.0         0.0
 ZTHS       -0.0100     -0.4826     15.0       11.0        11.0
END
*
SINKS        16              17              18
*        annulus bottom  annulus bottom    condenser
*           concrete          soil
 IGEOM       1               1               1
 IORIHS      2               2               1
 IMATHS      4               2               5
 XRI         0.0             0.0             0.0
 XRO         0.4572          10.0            0.01
 AHS         56.707          56.707          1000.
 TIINIT      25.00           20.0            10.0
 TOINIT      45.00           45.0            10.0
 IMSLAB      20              20              3
 IREGI       0               -1              -1
 TIHS        0.0             20.0            10.0
 IREGO       2               0               4
 TOHS        0.0             0.0             10.0
 XLHS        0.762           0.0             1000.0
 XZHS        0.0             0.0             0.0
 ZBHS       -0.4572         -10.4826         1015.0
 ZTHS        0.0            -0.4826          1016.0
END
*
*    name      index    rho     khs     cp      qv     ehsl     ehso
MATERIAL
    STSTEEL     1      8000.    16.     500.    0.     0.75     0.75
    SOIL        2      1500.    1.0    1840.   0.      0.75     0.75
    SLUDGE      3      1640.    0.9    2255.    231.0  0.75     0.75
    CONCRETE    4      2200.    0.6    880.    0.      0.75     0.75
    TUBE        5     10000.0  1000.0 10000.   0.0     0.5      0.5
END
*
COND_NETWORK 3,4,5,6,7,8
SANDWICH  9  1000.  10   1000.  11  1000. 12
SANDWICH  1  1000.  2
SANDWICH  14 1000.  15
SANDWICH  16 1000.  17
*
*
* USER CAN CONTROL HEAT SINK BOUNDARY TEMPERATURE
```

```
* SYNTAX:
*         OFFSET_TIMEHS
*         EXTRAPOLATION_TIMEHS
*         TIMTHS IHS ISD TIME1, TIME2...
*         THSFIX IHS ISD TEMP1, TEMP2..
* IHS = HEAT SINK NO.; ISD = SIDE NO. (1 OR 2) FOR IHS
* CONTROL HEAT SINK BOUNDARY T
* OFFSET_TIMEHS          0.
*EXTRAPOLATION_TIMEHS     EXTRAP
* TIMTHS 15 2 0.0     1.E6
* THSFIX 15 2 85.0    85.0
* TIMTHS 30 2 0.0     1.E6
* THSFIX 30 2 85.0    85.0
* TIMTHS 41 2 0.0     1.E6
* THSFIX 41 2 85.0    85.0
* TIMTHS 42 1 0.0     1.E6
* THSFIX 42 1 85.0    85.0
* TIMTHS 43 2 0.0     1.E6
* THSFIX 43 2 85.0    85.0
*
*
END HEAT_SINKS ! HEAT_SINKS is a comment
*-----------------------------------------------------------------------
JUNCTIONS   5 ! 4 Junctions
*-----------------------------------------------------------------------
*
* Syntax:
*  IJTYP   Junction Type: 1 = Normal, 2 = HEPA, 3 = Cover
*  IR1     Upstream Region
*  IR2     Downstream Region
*  AJN     Area (m^2)
*  ABYP    Bypass area for HEPA junction (m^2)

*  PHEPA   HEPA Filter Failure Pressure (Pa)
*  ACOV    Cover Area (m^2)
*  MCOV    Cover Weight (kg)
*  Z1JN    Elevation wrt floor of IR1 opening (m)
*  Z2JN    "          "   "    "   IR2   "     "
*  CJN     Loss coefficient multiplies 0.5*rho*v^2
*  IHORIZ  Orientation: 1 = horizontal, 0 = vertical
*  XWJN    Characteristic width, m
*  XHJN    Characteristic height, m
*  XLJN    Characteristic length, m
*  DFJN    Decontamination Factor
*  N90     No. of 90 bends
*
*            INLET                    ANNULUS     ANNULUS  condenser
*            LEAKAGE       OUTLET      INLET       OUTLET   outlet
     PATHS      1            2           3           4        5
        IJTYP   1            1           1           1        1
        IR1     3            1           3           2        4
        IR2     1            4           2           3        3
        IHORIZ  1            0           0           0        0
        XWJN    0.1000     0.1000      0.1524      0.1524    0.01
        XHJN    0.1000     0.1000      0.1524      0.1524    0.01
        XLJN    1000.        20.    5.0         5.0       10.0
        AJN     0.03000    0.03000     0.07297     0.07297   0.030
        Z1JN    1.0          12.0      1.00        12.00     10.0
        Z2JN    12.0         1.0       12.00       1.00      10.0
        CJN     5.           5.0       2.0         2.0       5.0
        DFJN    1.0          1.0       1.0         1.0       1.0
        N90     0            0         0           0         0.0
        KFILTER 1000.      10000.    1000.0      1000.0    15000.
        IFAN    0            0         0           0         1
```

```
        WVFAN    0.0         0.0     0.0       0.0        0.46
     END PATHS  ! PATHS is a comment.
*
*
END JUNCTIONS   ! JUNCTIONS is a comment.
```

C.2 Difference Listing Between SSSS.DAT and SSLV1.DAT – input file for loss of ventilation and heat up as a restart of SSSS.DAT at 116 days

```
Comparing files ssss.dat and SSLV1.DAT
***** ssss.dat
 DST AZ-101 SS Conditions; fin heat transfer
 500 scfm primary ventilation, no annulus ventilation, condenser
 END TITLE ! Anything after END is a comment
***** SSLV1.DAT
 DST AZ-101 SS Conditions; fin heat transfer
 restart w/ no scfm primary ventilation, no annulus ventilation, condenser
 END TITLE ! Anything after END is a comment
*****

***** ssss.dat
 TIMING    ! Keyword
   TSTART      0.     !  START TIME, >0 FOR RESTART RUN
   TLAST  10000000.!  END TIME
   DTMIN              !  MIN TIMESTEP (Seconds)
***** SSLV1.DAT
 TIMING    ! Keyword
   TSTART 10001000.    !  START TIME, >0 FOR RESTART RUN
   TLAST  50000000.!  END TIME
   DTMIN              !  MIN TIMESTEP (Seconds)
*****

***** ssss.dat
    10.0     1.0
    100.0    5.0
    1000.0   5.0
   100000.0  5.0
***** SSLV1.DAT
    10.0     1.0
    100.0    1.0
    1000.0   1.0
   100000.0  5.0
*****

***** ssss.dat
    5.0      1.0
    100.0    20.0
    1000.    20.0
  100000.    20.
***** SSLV1.DAT
    5.0      1.0
    100.0    5.0
    1000.    5.0
  100000.    20.
*****
```

```
***** ssss.dat
   PLTMIN            !  MIN PLOT INTERVAL (Seconds)
   0.0       1000.0
   10000.0  1000.0
***** SSLV1.DAT
   PLTMIN            !  MIN PLOT INTERVAL (Seconds)
   0.0       0.05
   10.0      1.0
   100.0     10.0
   1000.0    100.0
   10000.0  1000.0
*****

***** ssss.dat
   PLTMAX            !  MAX INTERVAL WITHOUT PLOT (Seconds)
   0.0     1000.0
   1000.0 1000.0
***** SSLV1.DAT
   PLTMAX            !  MAX INTERVAL WITHOUT PLOT (Seconds)
   0.0       0.1
   10.0      10.
   100.0    100.
   1000.0 1000.0
*****

***** ssss.dat
   0.0        1.E7
   5.E6       1.E6
*
***** SSLV1.DAT
   0.0        1.E7
   3.E6       1.E7
*
*****

***** ssss.dat
  HS-TA        7    3 4 5 6 7 8 9
  WCOND-PL  STEAM   1   1          ! Condensation rate of steam on pool
  WCOND-HSO STEAM   2   1   18      ! Condensation rate of steam on hs-1
***** SSLV1.DAT
  HS-TA        7    3 4 5 6 7 8 9
  HS-TI        1   9
  HS-TO        1   9
  AER-MASS WASTE 4 1 2 3 4
 WCOND-PL  STEAM   1   1          ! Condensation rate of steam on pool
  WCOND-HSO STEAM   2   1   18      ! Condensation rate of steam on hs-1
*****

***** ssss.dat
  IPLTYP  2    ! =1, normal mp wrap-around  =2, spreadsheet no wrap-around
  END ACTIVE MODELS ! ACTIVE MODELS  is a comment
*
***** SSLV1.DAT
  IPLTYP  2    ! =1, normal mp wrap-around  =2, spreadsheet no wrap-around
  IAEB    1    ! BOILING AEROSOL GENERATION
 END ACTIVE MODELS ! ACTIVE MODELS  is a comment
*
*****
```

```
***** ssss.dat
     IXR1          4
     IXR2          1
     IDUTY         0
***** SSLV1.DAT
     IXR1          4
     IXR2          3
     IDUTY         0
*****

***** ssss.dat
*  EXTRAPOLATION_TIMETG     LAST
*TIMETG 4  0.0    1.E10
*TGFIX  4 15.0    15.0
*
***** SSLV1.DAT
*  EXTRAPOLATION_TIMETG     LAST
* TIMETG 4  0.0    1.E10
* TGFIX  4 15.0    15.0
*
*****

***** ssss.dat
*  EXTRAPOLATION_TIMEPG     EXTRAP
*TIMEP 4  0.0       1.E10
*PRFIX  4  0.9840E5 0.9840E5
END
***** SSLV1.DAT
*  EXTRAPOLATION_TIMEPG     EXTRAP
* TIMEP 4  0.0       1.E10
* PRFIX  4  1.0135E5 1.0135E5
END
*****

***** ssss.dat
 AHS       143.891    143.891        71.946      411.0        411.0
 TIINIT        54.00      54.0         54.0        64.0        54.0
 TOINIT        54.00      54.0         54.0        64.0         54.0
 IMSLAB          3          3            3          20           3
***** SSLV1.DAT
 AHS       143.891    143.891        71.946      411.0        411.0
 TIINIT        54.00      54.0         54.0        54.0        54.0
 TOINIT        54.00      54.0         54.0        54.0         54.0
 IMSLAB          3          3            3          20           3
*****

***** ssss.dat
 XLHS          2.00        2.00        1.0        22.88        22.88
 XZHS          1.0         1.0         0.025       11.0         0.0
 ZBHS          3.0         1.0         0.0         0.0        -0.01
***** SSLV1.DAT
 XLHS          2.00        2.00        1.0        22.88        22.88
 XZHS          1.0         1.0         0.025       0.1         0.0
 ZBHS          3.0         1.0         0.0         0.0        -0.01
*****

***** ssss.dat
```

```
        KFILTER  1000.     10000.     1000.0      1000.0    15000.
        IFAN     0           0           0           0          1
        WVFAN    0.0         0.0     0.0       0.0        0.46
     END PATHS  ! PATHS is a comment.
***** SSLV1.DAT
        KFILTER  1000.     10000.     1000.0      1000.0    15000.
        IFAN     0           0           0           0          0
        WVFAN    0.0         0.0     0.0       0.0        0.00
     END PATHS  ! PATHS is a comment.
*****
```

C.3 Difference Listing Between SSLV1.DAT and SSLVR.DAT – the input file for boiling aerosol generation and restart of SSLV1.DAT at 348 days

```
Comparing files SSLV1.dat and SSLVR.DAT
***** SSLV1.dat
 TIMING    ! Keyword
   TSTART 10001000.    !  START TIME, >0 FOR RESTART RUN
   TLAST  50000000.!  END TIME
***** SSLVR.DAT
 TIMING    ! Keyword
   TSTART 30010000.    !  START TIME, >0 FOR RESTART RUN
   TLAST  50000000.!  END TIME
*****

***** SSLV1.dat
    1000.    5.0
  100000.    20.
   DTPRIN            !  PRINT INTERVAL (Seconds)
***** SSLVR.DAT
    1000.    5.0
  100000.    100.
   DTPRIN            !  PRINT INTERVAL (Seconds)
*****

***** SSLV1.dat
   FPPLCH     0.03         !  FRACTIONAL CHANGE FOR PLOTTING
 END TIMING ! TIMING is a comment.
***** SSLVR.DAT
   FPPLCH     0.03         !  FRACTIONAL CHANGE FOR PLOTTING
   RESTART_FILE SSLV1.REW
 END TIMING ! TIMING is a comment.
*****

***** SSLV1.dat
  QLIQ-HSO     1   9                ! liquid-to-hs hx
 END PLOT  ! PLOT is a comment
***** SSLVR.DAT
  QLIQ-HSO     1   9                ! liquid-to-hs hx
  GAS-WX       4   1   2   3   4
  AERO-XD      1   1
  AERO-LSD     1   1
  DEPOSIT      1   1
 END PLOT  ! PLOT is a comment
*****
```

```
***** SSLV1.dat
SOURCES 1                          ! -- KEYWORD AND # SOURCE GROUPS
 REGION  1  GASES 1  PHASE 3        !-- REGION #, # COMPOUNDS, PHASE #
    STEAM              !-- GAS NAMES MUST BE ON NEXT LINE
  0      26.7    0.0 0.00E5 ! MIXER PUMP POWER
  1.0E9 26.7    0.0 0.00E5 ! MIXER PUMP POWER
 END REGION                   !-- ENDS A REGION SOURCE
***** SSLVR.DAT
SOURCES 1                          ! -- KEYWORD AND # SOURCE GROUPS
 REGION  1  GASES 1  PHASE 1        !-- REGION #, # COMPOUNDS, PHASE #
    OXYGEN             !-- GAS NAMES MUST BE ON NEXT LINE
  0      100.0  1.e-6 0.00E5 ! MIXER PUMP POWER
  1.0E9 100.0  1.e-6 0.00E5 ! MIXER PUMP POWER
 END REGION                   !-- ENDS A REGION SOURCE
*****

***** SSLV1.dat
 XRO        0.0100        4.0          11.448        11.448        11.448
 AHS        411.0       411.0         358.0         143.891       143.891
 TIINIT        45.00       20.0          49.0          49.0          49.0
***** SSLVR.DAT
 XRO        0.0100        4.0          11.448        11.448        11.448
 AHS        411.0       411.0         358.0         143.891       143.891
 TIINIT        45.00       20.0          49.0          49.0          49.0
```

C.4 Gas Properties File

```
CHECK ON
GAS NITROGEN     2.80130E+01    0.00000E+00   GAS
CVG 1.50000E+03    947.          7.42319E+02   -1.38235E-01    4.78640E-04   -2.57728E-07    4.14112E-11
BV  1.40000E+03    0.001286      1.66786E-03   -5.33929E-01   -2.18321E+03    2.87500E+12   -1.65357E+14
PV  126.100E+00    3.3818E6      5.9826E1      -1.0976E3      -8.6689E0       4.6346E-2      1.0E0
KG  1500.E0        0.09295E0     3.5100E-04     7.652E-01      2.5767E+01     0.E0
MUG 1500.E0        5.3917E-5     7.632E-7       5.8823E-1      6.775E1        0.E0
DFG 3.798          71.4          0.E0
*
GAS OXYGEN       3.20000E+01    0.00000E+00   GAS
CVG 1.50000E+03    881.          5.32655E+02    4.41600E-01   -1.54996E-04    4.29830E-09    4.29767E-12
BV  1.40000E+03    0.000871      1.21875E-03   -4.85625E-01   -2.65000E+03    5.12500E+12   -3.59375E+14
PV  154.580E+00    5.0416E6      5.2486E1      -1.2134E3      -6.7062E0       2.9764E-2      1.0E0
KG  1500.E0        0.1013E0      4.9430E-04     7.3400E-01     7.0000E+01     0.E0
MUG 1500.E0        6.3987E-5     8.038E-7       6.0478E-1      7.03E1         0.E0
DFG 3.467          106.7         0.E0
*
GAS STEAM        1.80000E+01   -2.41820E+08   GAS+LIQ
CVG 1.57320E+03    2653.         1.33579E+03   -4.37917E-03    8.40632E-04   -4.06859E-07    6.03749E-11
BV  3.23000E+02   -0.04E0        2.295514E-3   -2.024448E+0   -8.778481E+5   -3.00507E+18    5.79857E+20
PV  647.290E+00    2.1977E7      7.25500E+01   -7.20670E+03   -7.13850E+00    4.04600E-06    2.0E0
HFG 300.E0         2.4376E6      3.184381E6     0.571707E0    -0.289795E0    -0.182469E0     0.295616E0
KG  1073.E0        0.1075E0      2.1606E-03     7.6839E-01     3.9405E+03    -4.4534E+05
MUG 370.E0         1.1946E-5     6.1839E-07     6.7779E-01     8.4723E+02    -7.3930E+04
DFG 2.52E0         775.          1.0E0
RL  300.E0         993.7E0       1047.E0       -0.05916E0     -6.3184E-04     1.25235E-06   -1.49401E-09
CVL 293.E0         4180.E0       1.5354E+04    -1.1612E+02     0.45139E0     -7.8422E-04     5.2056E-07
MUL 273.E0         1.70E-3      -5.2843E+01     3.7036E+03     5.8660E0      -5.8790E-29     1.0000E+01
KL  273.E0         0.567E0      -4.3200E-01     5.7255E-03    -8.0780E-06     1.8610E-09     0.E0
STL 373.E0         0.0700        0.0700000     0.0000E-03     0.0000E-06     0.0000E-09     0.0000E-12
*
GAS HYDROGEN     2.00000E+00    0.00000E+00   GAS
CVG 4.00000E+02    14000.        1.05682E+04   -7.64315E-01    9.89067E-04    2.00916E-07   -5.85743E-11
BV  4.98000E+02    0.E0          1.22500E-02   -1.42500E+00   -1.86500E+02    3.13500E+08   -3.77000E+09
KG  300.E0         0.1869        0.1869         0.E0           0.E0           0.E0
MUG 1.5E3          5.3917E-5     7.632E-7       5.8823E-1      6.775E1        0.E0
DFG 3.798          71.4          0.E0
*
GAS HELIUM       4.00000E+00    0.00000E+00   GAS
CVG 4.00000E+02    3118.E0       3118.E0       0.E0           0.E0           0.E0           0.E0
BV  4.98000E+02    0.E0          0.E0          0.E0           0.E0           0.E0           0.E0
KG  300.E0         0.1567        8.5900E-04     0.5930E-01    -9.5700E+01     6.0000E+03
```

```
MUG 1.5E3          5.3917E-5      7.632E-7       5.8823E-1      6.775E1        0.E0
DFG 3.798          71.4           0.E0
*
**** USE FOR AB SERIES AEROSOL TESTS
*
GAS NA2O          62.0           0.00000E+00   LIQ
RL  300.           2500.          2500.E0        0.E0           0.E0           0.E0           0.E0
CVL 300.           1.E3           1.E3           0.E0           0.E0           0.E0           0.E0
MUL 293.E0         1.E-3         -6.91E0         0.E0           0.E0           0.E0           0.E0
KL  293.E0         0.60E0         0.60E0         0.E0           0.E0           0.E0           0.E0
*
**** CSOH USED FOR AEROSOL LEAKAGE VALIDATION
*    NOTE: KG.MUG ARE FROM N2; STL PLACEHOLDER
*
GAS CSOH          149.91274     -2.59408E+08   GAS+LIQ   298.15
CVG 300.E0         276.5E0        2.12857E+02    3.33181E-01   -4.90431E-04    3.38981E-07   -8.44686E-11
BV  300.           0.0            0.0            0.0            0.0            0.0            0.0
PV  1.30619E+03    .101325E6      4.18806E+01   -1.87360E+04   -3.83793E+00    3.16319E-04   -1.00000E+00
HFG 298.E0         146.562E6      146.56E6       0.E0           0.E0           0.E0           0.E0
KG  1500.E0        0.09295E0      3.5100E-04     7.652E-01      2.5767E+01     0.E0
MUG 1500.E0        5.3917E-5      7.632E-7       5.8823E-1      6.775E1        0.E0
DFG 2.52E0         775.           1.0E0
RL  300.E0         1.E3           1.E3           0.E0           0.E0           0.E0           0.E0
CVL 300.E0         4200.E0        4200.E0        0.E0           0.E0           0.E0           0.E0
MUL 293.E0         1.E-3         -6.91E0         0.E0           0.E0           0.E0           0.E0
KL  293.E0         0.60E0         0.60E0         0.E0           0.E0           0.E0           0.E0
STL 293.E0         0.07E0         0.07E0         0.E0           0.E0           0.E0           0.E0
*
**** METHANOL USED FOR FOG VAILDATION
*    DFG VALUES ARE STEAM
*
GAS METHANOL      3.20420E+01   -2.00670E+08   GAS+LIQ   298.15
CVG 1.50000E+03    3280.          1.15417E+02    3.70061E+00   -1.54313E-03    2.61327E-07   -9.65537E-12
BV  2.56300E+02   -0.2867        -1.99738E-02    1.93496E+01   -3.34249E+06    2.40809E+19   -6.85787E+21
PV  512.58         8.0858E6       1.0993E2      -7.4713E3      -1.3988E1       1.5281E-2      1.0
HFG 175.59         1.289E6        1.239E6       -2.79E-1        5.08E-1        8.4E-2         0.E0
KG  300.E0         0.026         -7.7630E0       1.0279E0      -7.4360E+07     6.7700E+09
MUG 300.E0         9.68E-6        3.0663E-07     6.9655E-01     2.0500E+02     0.E0
DFG 2.52E0         775.           1.0E0
RL  300.           785.9E0        446.849E0      7.03674E0     -0.03838E0       8.2547E-05    -6.7448E-08
CVL 400.E0         3467.          3.3063E+03    -1.1320E+01     2.9309E-02     0.E0           0.E0
MUL 293.E0         1.E-3         -6.91E0         0.E0           0.E0           0.E0           0.E0
KL  338.E0         0.189E0        2.8370E-01    -2.8100E-04     0.E0           0.E0           0.E0
STL 273.E0         0.027E0        0.06374       -1.9563E-04     3.4280E-07    -5.1321E-10     3.3424E-13
*
**** CARBON DIOXIDE
*
GAS CARBON_DIO    4.40100E+01   -3.93520E+08   GAS    190.0E0
CVG 1.50000E+03    1140.          2.84515E+02    1.55345E+00   -1.14113E-03    4.02762E-07   -5.30735E-11
BV  1.52100E+03    6.835E-4       1.23636E-03   -8.26136E-01   -3.40000E+04    1.95227E+15   -3.17500E+17
*PV  204.E0         7.3617E6       8.55300E+01   -3.48130E+03   -1.13360E+01    2.15050E-02    1.0E0
*HFG 300.          0.4E6          0.4E6          1.E0           0.E0           0.E0           0.E0
KG  1500.          0.090          3.6900E0      -3.8380E-01     9.6400E+02     1.8600E+06
MUG 1500.          5.2032E-5      2.148E-6       4.6E-1         2.9E2          0.E0
DFG 3.941          195.2          0.E0
*RL  300.           0.4E6          0.77E3         1.E0           1.E0           0.E0           0.E0
*CVL 300.           0.4E6          800.E0         0.E0           0.E0           0.E0           0.E0
*
**** CARBON MONOXIDE
*
GAS CARBON_MON    2.80000E+01   -1.10530E+08   GAS
CVG 1.50000E+03    961.0          7.16232E+02   -2.45543E-02    3.78378E-04   -2.23369E-07    3.72738E-11
BV  6.64600E+02    9.019E-4       1.82929E-03   -6.10357E-01   -2.64857E+03    1.65357E+12   -1.02250E+14
PV  132.9          3.50E6         1.2420E2      -1.8150E3      -2.2734E1       1.1795E-1      1.0
KG  1250.E0        0.076          8.3900E-04     6.4090E-01     8.6050E+01     0.E0
MUG 1250.          4.6536E-5      1.1127E-6      5.338E-1       9.47E1         0.E0
DFG 3.941          195.2          0.E0
*
*
*
*
**** USE for dissolved salts in supernatant
*
GAS WASTE         18.0           0.00000E+00    LIQ
RL  300.           3800.0         3800.0         0.E0           0.E0           0.E0           0.E0
CVL 300.           1000.0         1000.0         0.E0           0.E0           0.E0           0.E0
MUL 293.E0         1.E-3         -6.91E0         0.E0           0.E0           0.E0           0.E0
KL  293.E0         0.60E0         0.60E0         0.E0           0.E0           0.E0           0.E0
STL 293.E0         0.07E0         0.07E0         0.E0           0.E0           0.E0           0.E0
*
* TRACE SPECIES WITH NO HEAT CAPACITY - FOR TRACKING PURPOSES
*
GAS STEATRAC       1.E20          0.0            LIQ
```

```
RL  300.E0          1.E3            1.E3            0.E0            0.E0            0.E0            0.E0
CVL 300.            0.E0            0.E0            0.E0            0.E0            0.E0            0.E0
MUL 293.E0          1.E-3           -6.91E0         0.E0            0.E0            0.E0            0.E0
KL  293.E0          0.60E0          0.60E0          0.E0            0.E0            0.E0            0.E0
STL 293.E0          0.07E0          0.07E0          0.E0            0.E0            0.E0            0.E0
*
GAS WASTTRNC        1.E20           0.0             LIQ
RL  300.            1200.           1200.           0.E0            0.E0            0.E0            0.E0
CVL 300.            0.E0            0.E0            0.E0            0.E0            0.E0            0.E0
MUL 293.E0          1.E-3           -6.91E0         0.E0            0.E0            0.E0            0.E0
KL  293.E0          0.60E0          0.60E0          0.E0            0.E0            0.E0            0.E0
STL 293.E0          0.07E0          0.07E0          0.E0            0.E0            0.E0            0.E0
*
* IDEAL CALORICALLY PERFECT GAS TO BE USED FOR INTER-COMPARTMENTAL FLOW
* VALIDATION
*
GAS PERFECT         2.80130E+01     0.00000E+00     GAS
CVG 1.50000E+03     830.            8.30000E+02     0.00000E-01     0.00000E-04     0.00000E-07     0.00000E-11
BV  1.40000E+03     0.0000000       0.000000000     0.000000000     0.000000000     0.000000000     0.000000000
PV  126.100E+00     3.3818E6        5.9826E1        -1.0976E3       -8.6689E0       4.6346E-2       1.0E0
HFG 300.            0.E0            0.E0            0.E0            0.E0            0.E0            0.E0
KG  300.E0          0.026           0.026           0.E0            0.E0            0.E0
MUG 1.5E3           5.3917E-5       7.632E-7        5.8823E-1       6.775E1         0.E0
DFG 3.798           71.4            0.E0
*
* HEXONE: VALUES FROM DIPPR EXCEPT PLACEKEEPER DFG, MUL, KL, STL
*
GAS HEXONE          102.0           -2.8849E+08     GAS+LIQ   298.15E0
CVG 300.E0          1546.E0         432.954E0       4.23129E0       -1.83502E-3     3.18376E-7      -1.84088E-11
BV  300.E0          -0.032          2.668E-3        -2.939E0        -4.132E5        -6.327E17       4.712E18
PV  571.4E0         3.2728E6        1.5270E2        -1.0034E4       -1.9766E1       1.6353E-5       2.0E0
HFG 189.15          4.8797E7        5.768E7         0.4160E0        0.E0            0.E0            0.E0
KG  300.E0          0.02            0.02            0.E0            0.E0            0.E0
MUG 400.            1.0E-5          1.0E-5          0.E0            0.E0            0.E0
DFG 3.941           195.2           0.E0
RL  300.            796.0           796.E0          0.E0            0.E0            0.E0            0.E0
CVL 300.            2136.E0         1061.E0         3.58E0          0.E0            0.E0            0.E0
MUL 293.E0          1.E-3           -6.91E0         0.E0            0.E0            0.E0            0.E0
KL  293.E0          0.60E0          0.60E0          0.E0            0.E0            0.E0            0.E0
STL 273.E0          0.027E0         0.06374         -1.9563E-04     3.4280E-07      -5.1321E-10     3.3424E-13
*
*   SOOT IS USED FOR FIRE CALC'S - ALWAYS AN LIQUID
*
GAS SOOT            12.0            0.0             LIQ
RL  300.            1000.           1000.           1.E0            0.E0            0.E0            0.E0
CVL 300.            100.            100.            0.E0            0.E0            0.E0            0.E0
MUL 293.E0          1.E-3           -6.91E0         0.E0            0.E0            0.E0            0.E0
KL  293.E0          0.60E0          0.60E0          0.E0            0.E0            0.E0            0.E0
STL 293.E0          0.07E0          0.07E0          0.E0            0.E0            0.E0            0.E0
*
* 'GAS' WATER IS DEFINED TO MIMIC THE THERMAL PROPERITES (HEAT TRANSFER AND
* THERMAL CAPACITY) OF THE WATER IN THE GAP BETWEEN MCO AND CASK
* USED BY MCO MODEL ONLY
*GAS WATER          31000.          0.E0            LIQ   298.15E0
*CVG 323.15         4180.           4180.           0.              0.              0.              0.
*BV  323.15         0.000000        0.0000000       0.00000000      0.00000000      0.000000000     0.00000000
*PV    1.0E5        .101325E6       -46.0           0.0             0.0             0.0             0.0
*HFG 300.           2.4E6           2.4E6           0.E0            0.E0            0.E0            0.E0
*KG  300.E0         0.64            0.64            0.E0            0.E0            0.E0
** OLD: KG  0.64            0.68            0.68            0.60
*MUG 323.15         54.71E-5        54.71E-5        0.              0.              0.
*DFG 3.941          195.2           0.E0
*RL  300.           1000.           1000.           0.E0            0.E0            0.E0            0.E0
*CVL 300.           4180.           4180.           0.E0            0.E0            0.E0            0.E0
*
*
*
GAS     NO          30.006    -9.0249E+07     GAS
CVG   1500.00  9.13700E+02    7.17350E+02 -1.43322E-01  5.40520E-04  -3.25420E-07  5.90940E-11
BV     310.94  -5.84660E-04   3.59281E-04 -1.69993E-01 -1.20858E+04   6.76979E+14 -8.06720E+16
PV     180.15  6.47740E+06    1.45820E+02 -3.53800E+03 -2.36200E+01   6.76410E-02  1.00000E+00
HFG    180.15  0.00000E+00    0.00000E+00  1.00000E+00  0.00000E+00   0.00000E+00  0.00000E+00
KG    1000.00  7.18780E-02    2.41000E-04  8.27300E-01  1.70000E+01   0.0
MUG   1500.00  5.73680E-05    1.46700E-06  5.12300E-01  1.25400E+02   0.0
DFG      3.49     116.7000    0.00E+00
*
GAS     SO2         64.065    -2.9684E+08   GAS+LIQ
CVG   1500.00  7.50493E+02  2.05690E+02   1.19640E+00    -1.01750E-03   3.89220E-07    -5.48730E-11
BV    2154.00  6.05200E-04  1.04107E-03  -9.25154E-01    -1.10763E+05  -1.15923E+16   -4.38461E+16
PV     430.75  7.81380E+06  5.03500E+01  -4.17510E+03    -4.14580E+00   1.95500E-06    2.00000E+00
HFG    197.67  4.47471E+05  7.32126E+05   1.30700E+00    -1.32600E+00   4.90000E-01    0.00000E+00
KG    1000.00  4.28440E-02  4.57000E-04   7.24000E-01     5.85000E+02   0.00000E+00    0.00000E+00
MUG   1000.00  3.84440E-05  6.86300E-07   6.11200E-01     2.17000E+02   0.00000E+00    0.00000E+00
```

```
DFG     4.11     335.4000    4.20000E-01
RL     197.67   1.62302E+03 -6.80302E+03   1.25602E+02   -6.76981E-01   1.56414E-03   -1.33785E-06
CVL    263.13   1.35157E+03  5.27537E+02   1.17234E+01   -5.30955E-02   7.76943E-05    0.00000E+00
MUL    239.65   5.62400E-04 -1.68790E+02   6.63850E+03    2.43930E+01  -7.64000E-26    1.00000E+01
KL     400.00   1.32020E-01  3.82180E-01  -6.25000E-04    0.00000E+00   0.00000E+00    0.00000E+00
STL    197.67   4.22200E-02  7.75000E-02  -1.82900E-04    0.00000E+00   0.00000E+00    0.00000E+00
*
* CO2 values for BV
GAS      NO2       46.005   -3.30950E+07  GAS+LIQ
CVG   1500.00   1.10570E+03  3.27312E+02   1.20687E+00  -7.99333E-04  2.43674E-07  -2.80910E-11
BV    1521.00   6.83500E-04  1.23636E-03  -8.26136E-01  -3.40000E+04  1.95227E+15  -3.17500E+17
FV     431.35   1.01280E+07  7.88520E+01  -5.19520E+03  -9.77010E+00  1.99310E-02   1.00000E+00
HFG    296.30   8.28609E+05  8.28609E+05   0.00000E+00   0.00000E+00  0.00000E+00   0.00000E+00
KG     325.00   1.70460E-01  1.70460E-01   0.00000E+00   0.00000E+00  0.00000E+00   0.00000E+00
MUG    460.00   2.43500E-05  2.29100E-06   2.58600E-01  -5.74800E+02  1.50000E+05   0.00000E+00
DFG      3.94     195.2000  0.00000E+00
RL     293.15   1.45500E+03 -1.81580E+05   2.11750E+03  -9.13220E+00   1.74150E-02  -1.24130E-05
CVL    400.00   3.46910E+03  2.01456E+03   3.63630E+00   0.00000E+00  0.00000E+00   0.00000E+00
MUL    273.15   5.29280E-04  9.36370E+01  -3.46740E+03  -1.57730E+01  0.00000E+00   0.00000E+00
KL     261.95   1.41950E-01 -2.72200E-01   3.21060E-03  -6.22100E-06  0.00000E+00   0.00000E+00
STL    261.95   3.33960E-02  8.50500E-02  -1.97100E-04   0.00000E+00  0.00000E+00   0.00000E+00
*
* 'GAS' WATER IS DEFINED TO MIMIC THE THERMAL PROPERITES (HEAT TRANSFER AND
* THERMAL CAPACITY) OF THE WATER IN THE GAP BETWEEN MCO AND CASK
*
GAS WATER        2.80130E+01    0.00000E+00    GAS
CVG 1.50000E+03   4180.          4180.          0.             0.             0.             0.
BV  1.40000E+03   0.0000000       0.000000000    0.000000000    0.000000000    0.000000000    0.000000000
FV  126.100E+00   3.3818E6        5.9826E1      -1.0976E3      -8.6689E0       4.6346E-2      1.0E0
HFG 300.          0.E0            0.E0           0.E0           0.E0           0.E0           0.E0
KG  300.E0        0.567           0.567          0.E0           0.E0           0.E0
MUG 1.5E3         1.7E-3          1.7E-3         0.0            0.0            0.0
DFG 3.798         71.4            0.E0
```

C.5 Input File for Validation with Respect to the DST 241-AZ-101 Ventilation Transient

```
*********************************************************************
*   Underground DST with loss of cooling
*********************************************************************
*
*-------------------------------------------------------------------
CONTROL     ! Major keyword group
*-------------------------------------------------------------------
*
*
 TITLE      ! Keyword; next line is title, title can be any length*  -
 DST AZ-101 SS Conditions; fin heat transfer; 61KW
 restart w/ 100 scfm primary ventilation, no annulus ventilation, condenser
 END TITLE ! Anything after END is a comment
*
*
*
 TIMING     ! Keyword
   TSTART 10001000.     !  START TIME, >0 FOR RESTART RUN
   TLAST  90000000.!  END TIME
   DTMIN              !  MIN TIMESTEP (Seconds)
     0.0      1.0
    10.0      1.0
    100.0     1.0
    1000.0    1.0
   100000.0  50.0
   DTMAX              !  MAX TIMESTEP (Seconds)
    0.0       1.0
    5.0       1.0
    100.0     5.0
    1000.     5.0
```

```
  100000.    100.
   DTPRIN            !  PRINT INTERVAL (Seconds)
   0.0       100000.0
  1000000.  1000000.
  10000000. 10000000.
   PLTMIN            !  MIN PLOT INTERVAL (Seconds)
   0.0       0.05
   10.0      1.0
   100.0     10.0
   1000.0    100.0
   10000.0   1000.0

   100000.0 10000.0
   1000000.0 100000.0
   PLTMAX            !  MAX INTERVAL WITHOUT PLOT (Seconds)
   0.0       0.1
   10.0      10.
   100.0    100.
   1000.0 1000.0
   10000.0 10000.0
   100000.0 100000.0
   1000000.0 1000000.0
   DTRST             !  RESTART INTERVAL (Seconds)
   0.0        1.E9
   3.E6       1.E9
*
   FTPCH       0.001        !  FRACTIONAL CHANGE IN T AND P
   FAECH       0.001        !  FRACTIONAL CHANGE IN aerosol mass
   FPPLCH      0.03          !  FRACTIONAL CHANGE FOR PLOTTING
 END TIMING ! TIMING is a comment.
*
* COMPOUND LIBRARY ORDER FOR OUTPUT
*   This section allows user specification of the order
*   in which compound names are printed & placed in the
*   plot files.  This section is optional, but recommended.
*   Using this section saves computation time by limiting
*   the range of loops. This section rearranges internal
*   storage to the user-defined order, and essentially
*   defines a sub-library for this case only.
*
*   Format:
*   The section begins with the keyword COMPOUND followed
*   by the number of compounds to be used for this run.
*   Compound names are placed on succeeding lines,
*     using up to 80 columns.
*   Finish the list with the END keyword.
*   You can comment a line in the list by putting
*     the double asterisk ** in cols. 1 and 2.
*   Example (here column 1 has * for comment):
* COMPOUNDS 8
*    STEAM OXYGEN NITROGEN
*    HEXONE CARBON_DIO
*    WASTE WASTTRAC STEATRAC
* END
*
*   User caveats:
*   1. If this is invoked, it MUST PRECEDE any input section that
*   refers to compound names, such as plotting, sources, etc.
```

```
*   2. The user must name ALL compounds that are used in the
*   calculation, or else the compound will be skipped. For
*   example there may be no combustion products initially
*   present anywhere, but these must be named to be used later.
*   3. Spelling must be identical to names in GASPROP.DAT
*   Check the log file for mis-spelling warnings.
*
 COMPOUNDS 4
   STEAM OXYGEN NITROGEN WASTE
 END
*
*
 PLOT        ! Keyword for plotting section
* Plotting syntax:
*
* PRESSURE n rlist - Pressure, Pa
* GAS-T  n rlist  - Gas Temperature, K
* LIQ-T  n rlist  - Liquid Temperature, K
* LIQ-EL n rlist  - Liquid Level, m
* HS-TI  n hlist  - Heat Sink Temperature - Inner Surface, K
* HS-TO  n hlist  - Heat Sink Temperature - Outer Surface, K
* HS-TA  n hlist  - Heat Sink Temperature - Average, K
* AEROSOL n rlist - Aerosol Mass (Total), kg
* GAS-W  n jlist  - Mass Flowrate, kg/s
* GAS-WX n jlist  - CounterCurrent Mass Flowrate, kg/s
* SPECIAL-X n xlist - Special model state variable
* SPECIAL-R n xlist - Special model rate variable
* GAS-X    GASNAME n rlist  - Gas Mole Fraction
* GAS-RH   GASNAME n rlist  - Gas Relative Humidity
* GAS-MASS GASNAME n rlist - Gas Mass (Species), kg
* AER-MASS GASNAME n rlist - Aerosol Mass (Species), kg
* MASS     GASNAME n rlist - Total Mass (Species), kg
* LIQ-MASS - GASNAME n rlist - Deposited Mass (Species), kg
*
* Pressure, Gas Temperature, and total aerosol mass require a region
* list
*
* Heat Sink Temperatures need a heat sink number list
*
* Flowrates need a junction number list
*
* Gas concentration, relative humidity, individual species gas mass,
* individual species aerosol mass, total (gas+aerosol) individual
* species mass, and individual species deposited liquid mass require
* a region and gas name
*
*  special state & rate variables are:
*  1=  Waste surface entrainment during a burn
*  2=  Tank surface entrainment during a burn
*  3=  Waste surface entrainment during blowdown
*  4=  Unused, reserved for tank surface entrainment during blowdown
*  5=  Total entrainment
*
  PRESSURE     4  1  2  3  4    ! Pressure
  GAS-T        4  1  2  3  4     ! Gas Temps
  LIQ-T        2    1   4         ! L temps
  LIQ-EL       2    1   4         ! L elevations
  GAS-X  NITROGEN   1   1        ! N2 Concentration
```

```
  GAS-X  OXYGEN     1   1          ! O2 concentration
  GAS-X  STEAM      1   1          ! H2O concentration
  GAS-W        4    1   2   3   4  ! Gas flow rates
  HS-TA        7    3 4 5 6 7 8 9
  HS-TI        1   9
  HS-TO        1   9
  AER-MASS WASTE 4 1 2 3 4
 WCOND-PL  STEAM   1   1          ! Condensation rate of steam on pool
  WCOND-HSO STEAM   2   1   18      ! Condensation rate of steam on hs-1
  WCOND-HSI STEAM   4   2   3   4  18 ! Condensation rate of steam on hs-2 &
3
  QGAS-HSO     8   1   3   4   5   6  7  8  13    ! gas-to-hs hx
  QGAS-HSI     7   2   3   4   5  13 15 16    ! gas-to-hs hx
  QGAS-POOL    1   1       ! gas-to-pool hx
  QLIQ-HSI     4   4   5   6   7    ! liquid-to-hs hx
  QLIQ-HSO     1   9                ! liquid-to-hs hx
 END PLOT  ! PLOT is a comment
*
PRINT
      HS 18 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
END
*
 ACTIVE MODELS ! Keyword; MODELS is a comment; 1 = on, 0 = off
  IJUNC   1    ! Junction flow model
  ICCFLW  0   ! Counter-current flow model
  IHSINK  1    ! Heat sinks
  IHXPOL  1    ! gas-pool heat/mass transfer
  ICNDS   1    ! Condensation
  IASED   1    ! Aerosol Sedimentation
  IALEAK  1   ! Aerosol Leakage
  IFOG    1    ! Fog formation
  ISRC    1    ! User-defined sources
  IQDECAY 1    ! Decay power
  IMCO    0    ! MCO models
  ISENS   0    ! Sensitivity runs
  ILXFER  1   ! Liquid transfers
  IDCRT   0    ! DCRT Runs
  IPLTYP  2    ! DO NOT WRAP AROUND
 END ACTIVE MODELS ! ACTIVE MODELS  is a comment
*
*
 MODEL PARAMETERS
  AGAMMA   2.5   ! Shape factor for nonsphericity for coagulation
  ACHI     1.0   ! Shape factor for nonsphericity for stokes'law
  AFEO     1.0   ! Collision efficiency: 1.0 Fuchs, 0.33 Prupacher-Klett
  ENT_BOIL 2.E-7  ! Boiling entrainment coefficient

 END MODEL PARAMETERS
*
C-----------------------------------------------------------------------
C      DECAY POWER
C
 DECAY
    WASTE   0.03475
 END
*
C-----------------------------------------------------------------------
C      SOURCE GROUP:  GROUPS REPEATED FOR INPUT # OF REGIONS
```

```
C        END OF GROUP DESIGNATED BY 'REGION' OR 'END' KEYWORDS
C      ENTER: TIME, TEMP, FLOWRATES, POWER
C      SYNTAX EXAMPLE:
SOURCES 1                          ! -- KEYWORD AND # SOURCE GROUPS
 REGION  1  GASES 1  PHASE 3        !-- REGION #, # COMPOUNDS, PHASE #
    STEAM              !-- GAS NAMES MUST BE ON NEXT LINE
  0      26.7   0.0 0.00E5 ! MIXER PUMP POWER
  1.0E9 26.7   0.0 0.00E5 ! MIXER PUMP POWER
 END REGION                   !-- ENDS A REGION SOURCE
END SOURCES

* PHASE INDEX: 1=GAS, 2=AERO, 3=LIQUID
*
*
*
END CONTROL    ! End of CONTROL keyword group
*
*
*-----------------------------------------------------------------
*     OPERATIONS
*-----------------------------------------------------------------
*
 OPERATIONS
*
*     OPERATIONS        ! Keyword to begin this section
*
*     Keyword groups go here as described below.  Active groups are:
*     TRANSFER
*
*     END OPERATIONS    ! End is a comment here
*
*     WASTE TRANSFER SYNTAX:  SAME AS REGION & JUNCTION SYNTAX, COLUMNS
*     TRANSFER ilist    Keyword TRANSFER followed by list of indices
*                       each index is a transfer index #
*       KEYWORD  rlist  Keyword name (see list below) and column values
*                       corresponding to ilist above
*      END               End this section
*     Use 5 transfer columns per set maximum, then repeat the group
*     Maximum of 30 defined transfers
*
*     Waste is transferred from region IXR1 to IXR2 at constant
*        volumetric flowrate WV_XFER or at a pulsed flowrate
*        during the active duty cycle time DUTY_ON, followed by
*        the idle cycle duration DUTY_OFF.
*     Transfers start at time T_START and end at time T_END.
*     Rational level controls also exist for transfers.
*     Transfer begins when donor region level exceeds
*        the high level ZL1_HI.  Default begins transfer if the
*        donor level exceeds region top minus 1 cm.
*     Transfer ends when donor region level falls below
*        the low level ZL1_LO.  Default ends at 1 cm elevation.
*     Transfer ends when receiver region level exceeds
*        the high level ZL2_HI.  Default ends transfer if the
*        receiver level exceeds region top minus 1 cm.
*     The program will abort due to errors in PTREG1 or PTREG2
*        if a region becomes "solid", and transfers or
*        sources into a full region are the cause.  Remedy by
*        better control over intended transfers.
```

```
*     Waste can be cascaded in a series of tanks via a series
*        of transfers initiated on level.
*     Waste can flow in both directions controlled by level,
*        using a pair of transfers, one in each direction.
*
*     WASTE TRANSFER KEYWORD DEFINITIONS
*
*     IXR1          "FROM" REGION
*     IXR2          "TO" REGION
*     IDUTY         1= USE DUTY CYCLES, 0= CONSTANT FLOW
*     IR1_HI        1= BEGIN ON HIGH LEVEL IN IXR1, 0= IGNORE
*     WV_XFER       NOMINAL VOLUMETRIC FLOWRATE AT ZERO DP WHEN ACTIVE
*     T_START       TIME TO START XFER FLOW
*     T_END         TIME TO END XFER FLOW
*     DUTY_ON       DUTY CYCLE TIME FOR TRANSFER FLOW IF PERIODIC
*     DUTY_OFF      DUTY CYCLE TIME FOR NO (OFF) TRANSFER FLOW IF PERIODIC
*                   TOGETHER THESE CYCLE TIMES DEFINE A COMPLETE CYCLE
*     ZL1_HI        HIGH LEVEL IN "FROM" REGION THAT BEGINS XFER:
*                    ZLR(IXR1) > ZL1_HI. DEFAULT: 1 CM FROM TOP
*     ZL2_HI        HIGH LEVEL IN "TO" REGION THAT ENDS XFER:
*                    ZLR(IXR2) < ZL2_HI. DEFAULT: 1 CM FROM TOP
*     ZL1_LO        LOW LEVEL IN "FROM" REGION THAT ENDS XFER:
*                    ZLR(IXR1) < ZL1_LO. DEFAULT: 1 CM FROM BOTTOM

 TRANSFER            1
     IXR1            4
     IXR2            3
     IDUTY           0
     IR1_HI          1
     WV_XFER        1.E6
     T_START        0.0
     T_END          1.0E10
     DUTY_ON        100.
     DUTY_OFF       100.
     ZL1_HI        10.0
     ZL2_HI        7.47
     ZL1_LO        1.00
 END TRANSFER

END OPERATIIONS
*-----------------------------------------------------------------------
VOLUMES    4       ! total number of control volumes
*-----------------------------------------------------------------------
* No more than 5 columns (regions) at a time
* Units:
* VOLUME m^3, SED_AREA m^2, ELEVATION m, TEMP_GAS K, PRESSURE  Pa
*
*              TANK            ANNULUS      Ambient    Condenser
 REGIONS        1                2            3          4
  VOLUME      5338.            623.78       1.E10      1000.
  SED_AREA     411.              0.0         0.0        0.0
  ELEVATION    0.429              0.0        15.         16.
  TEMP_GAS     45.              22.0         22.        10.0
  PRESSURE     101350.        101350.        101350.    101350.
  ZTOP        12.99            11.0         1.E6       1000.
  Z_LIQ        7.47           0.01          0.00       990.0
  TEMP_LIQ     49.0             28.0         28.0       10.0
 END REGIONS  ! REGIONS is a comment
```

```
*
* Gas composition of each region; specify mole fraction of each gas
* No more than five columns at a time
*
*              TANK        ANNULUS   AMBIENT     CONDENSER
 GASES          1            2         3            4
  STEAM        0.100        0.1       0.0023       0.0100
  OXYGEN       0.189        0.189     0.2077       0.2000
  NITROGEN     0.711        0.711     0.7900       0.7900
 END GASES           ! GASES is a comment
*
*              TANK     ANNULUS   AMBIENT   CONDENSER
LIQUIDS         1          2         3         4
  STEAM         0.780   1.0       1.0       1.0
  WASTE         0.220    0.0      0.0       0.0
END LIQS           ! LIQS is a comment
*
* Aerosol concentration of each region (kg/m^3)
* No more than five columns at a time
*
*AEROSOLS        1          2          3         4        5
* WASTE         0.000      0.0        0.0       0.0      0.0
*END AEROSOLS ! AEROSOLS is a comment
*   OFFSET_TIMETG
*   EXTRAPOLATION_TIMETG
*   TIMETG  REGION # TIME1, TIME2...TIMELAST
*   TGFIX   REGION # TEMP1, TEMP2... TEMPLAST   TEMPS ARE IN C!!!
*   LINEAR INTERPOLATION BETWEEN VALUES
*
*   SIMILAR SYNTAX FOR PRESSURE:
*   OFFSET_TIMETG
*   EXTRAPOLATION_TIMEPG
*   TIMEP  REGION #  TIME1, TIME2...
*   PRFIX  REGION #  PRES1, PRES2...PRESSURES ARE IN PA!!!
*
*  OFFSET_TIMETG=  OFFSET TIME; ENTER LOOKUP TABLE WITH
*                  TIME+OFFSET_TIMETG
*  EXTRAPOLATION_TIMETG= LAST TO USE LAST VALUE IN THE TABLE,
*                      = EXTRAP TO EXTRAPOLATE FROM LAST TWO POINTS,
*                      = PERIOD TO WRAP AROUND.
*  OFFSET_TIMETG          0.
*  EXTRAPOLATION_TIMETG     LAST
* TIMETG 4  0.0     1.E10
* TGFIX  4 15.0     15.0
*
* CONTROL  BOUNDARY P,
*  OFFSET_TIMEPG          0.
*  EXTRAPOLATION_TIMEPG     EXTRAP
* TIMEP 4  0.0        1.E10
* PRFIX  4  1.0135E5 1.0135E5
END
* Major keyword-----------------------------------------------------------
HEAT_SINKS     18 !Total number of heat sinks
*------------------------------------------------------------------------
* No more than 5 columns at a time,
* Repeat the following structure,
* SINKS
* .
```

```
* .
* .
* END
*
* Syntax:
* IGEOM  1 for plane, 0 or 2 for cylinder
* IORIHS 0 for vertical, 1 for horizontal
* RHO    Density (kg/m^3)
* KHS    Thermal Conductivity (W/m/K)
* CPHS   Specific Heat (J/kg/K)
* QV      Volumetric Heat Generation (W/m^3)
* XRI     Inner Radius (m)
* XRO     Outer Radius (m); for plane wall, thickness = XRO-XRI
* AHS     One-sided heat sink area (m^2)
* TIINIT  Initial inside surface temperature (C)
* TOINIT  Initial outside surface temperature (C)
* IMSLAB  Number of slabs; 3 is minimum
* IREGI   Region index for inner surface or 0 (insulated)
*         or -1 for constant temperature
* TIHS    Region surface temperature when IREGI = -1  (C)
* IREGO   Region index for outer surface or 0 (insulated)
*         or -1 for constant temperature
* TOHS    Region surface temperature when IREGO = -1  (C)
* XLHS    Characteristic length for natural convection (m)
* EHSI    Emissivity of inner surface
* EHSO    Emissivity of outer surface
*
*
SINKS        1          2          3          4          5
*          tank       tank top   tank wall  tank wall  tank wall
*         ceiling      soil       first      second      third
 IGEOM       1          1          2          2          2
 IORIHS      1          1          0          0          0
 IMATHS      1          2          1          1          1
 XRI       0.0000     0.0        11.438     11.438     11.438
 XRO       0.0100     4.0        11.448     11.448     11.448
 AHS       411.0    411.0      358.0      143.891    143.891
 TIINIT      45.00    20.0       49.0       49.0       49.0
 TOINIT      45.00    45.0       49.0       49.0       49.0
 IMSLAB       3       20          3          3          3
 IREGI        0        3          1          1          1
 TIHS        0.0      0.0        0.0        0.0        0.0
 IREGO        1        0          2          2          2
 TOHS        0.0      0.0        0.0        0.0        0.0
 XLHS       22.88    22.88      5.0        2.0        2.0
 XZHS        0.0      0.0       2.50       1.0        1.0
 ZBHS       12.99    13.00      8.75       7.0        5.0
 ZTHS       13.00    15.1433   12.98      8.75       7.0
END
*
SINKS        6          7          8          9         10
*          tank wall  tank wall  tank wall  non-convective  tank
*           fourth     fifth      sixth       layer      floor
 IGEOM       2          2          2          1          1
 IORIHS      0          0          0          2          2
 IMATHS      1          1          1          3          1
 XRI       11.438     11.438     11.438     0.0        0.0
 XRO       11.448     11.448     11.448     0.43       0.01
```

```
 AHS        143.891    143.891        71.946      411.0        411.0
 TIINIT       54.00      54.0          54.0        54.0         54.0
 TOINIT       54.00      54.0          54.0        54.0         54.0
 IMSLAB         3          3             3          20           3
 IREGI          1          1             1           0           0
 TIHS         0.0        0.0           0.0         0.0          0.0
 IREGO          2          2             2           1           0
 TOHS         0.0        0.0           0.0         0.0          0.0
 XLHS         2.00       2.00          1.0        22.88        22.88
 XZHS         1.0        1.0           0.025       0.1          0.0
 ZBHS         3.0        1.0           0.0         0.0         -0.01
 ZTHS         5.0        3.0           1.0         0.43          0.0
END
*
SINKS          11         12            13          14           15
*         tank bottom  tank bottom  annulus top  annulus wall  annulus wall
*            concrete     soil          soil         soil         concrete
 IGEOM         1          1             1           0            0
 IORIHS        2          2             1           0            0
 IMATHS        4          2             2           2            4
 XRI         0.0        0.0           0.0        12.707       12.225
 XRO       0.4572      30.0           4.0       112.707       12.707
 AHS        411.0      411.0         411.0      1223.82       861.59
 TIINIT     49.00      12.0          20.0        49.0         49.0
 TOINIT     49.00      49.0          49.0        25.0         45.0
 IMSLAB      20         20            20          20          20
 IREGI        0         -1             3           0            2
 TIHS       0.0        12.0           0.0         0.0          0.0
 IREGO        0          0             2           0           0
 TOHS       0.0        0.0           0.0        20.0          0.0
 XLHS       0.0        0.0           0.762       0.0         11.0
 XZHS       0.0        0.0           4.0         0.0          0.0
 ZBHS      -0.4826   -10.4826       10.99        0.0          0.0
 ZTHS      -0.0100    -0.4826       15.0        11.0         11.0
END
*
SINKS          16              17              18
*         annulus bottom  annulus bottom    condenser
*            concrete          soil
 IGEOM         1               1               1
 IORIHS        2               2               1
 IMATHS        4               2               5
 XRI         0.0             0.0             0.0
 XRO       0.4572           10.0             0.01
 AHS        56.707          56.707          1000.
 TIINIT     25.00           20.0            10.0
 TOINIT     45.00           45.0            10.0
 IMSLAB       20             20              3
 IREGI        0              -1             -1
 TIHS       0.0             20.0            10.0
 IREGO        2               0               4
 TOHS       0.0             0.0             10.0
 XLHS       0.762           0.0             1000.0
 XZHS       0.0             0.0             0.0
 ZBHS      -0.4572         -10.4826         1015.0
 ZTHS       0.0             -0.4826         1016.0
END
*
```

```
*    name      index    rho     khs      cp      qv     ehs1      ehso
MATERIAL
    STSTEEL     1      8000.    16.     500.    0.     0.75      0.75
    SOIL        2      1500.    1.0    1840.   0.      0.75      0.75
    SLUDGE      3      1640.    0.9    2255.    186.0   0.75      0.75
    CONCRETE    4      2200.    0.6    880.    0.      0.75      0.75
    TUBE        5     10000.0  1000.0 10000.   0.0     0.5       0.5
END
*
COND_NETWORK 3,4,5,6,7,8
SANDWICH  9  1000.  10   1000.  11  1000. 12
SANDWICH  1  1000.  2
SANDWICH  14 1000.  15
SANDWICH  16 1000.  17
*
*
* USER CAN CONTROL HEAT SINK BOUNDARY TEMPERATURE
* SYNTAX:
*         OFFSET_TIMEHS
*         EXTRAPOLATION_TIMEHS
*         TIMTHS IHS ISD TIME1, TIME2...
*         THSFIX IHS ISD TEMP1, TEMP2..
* IHS = HEAT SINK NO.; ISD = SIDE NO. (1 OR 2) FOR IHS
* CONTROL HEAT SINK BOUNDARY T
* OFFSET_TIMEHS          0.
*EXTRAPOLATION_TIMEHS     EXTRAP
* TIMTHS 15 2 0.0      1.E6
* THSFIX 15 2 85.0     85.0
* TIMTHS 30 2 0.0      1.E6
* THSFIX 30 2 85.0     85.0
* TIMTHS 41 2 0.0      1.E6
* THSFIX 41 2 85.0     85.0
* TIMTHS 42 1 0.0      1.E6
* THSFIX 42 1 85.0     85.0
* TIMTHS 43 2 0.0      1.E6
* THSFIX 43 2 85.0     85.0
*
*
END HEAT_SINKS ! HEAT_SINKS is a comment
*-----------------------------------------------------------------------
JUNCTIONS   5 ! 4 Junctions
*-----------------------------------------------------------------------
*
* Syntax:
*  IJTYP   Junction Type: 1 = Normal, 2 = HEPA, 3 = Cover
*  IR1     Upstream Region
*  IR2     Downstream Region
*  AJN     Area (m^2)
*  ABYP    Bypass area for HEPA junction (m^2)
*  PHEPA   HEPA Filter Failure Pressure (Pa)
*  ACOV    Cover Area (m^2)
*  MCOV    Cover Weight (kg)
*  Z1JN    Elevation wrt floor of IR1 opening (m)
*  Z2JN    "          "   "    "   IR2   "     "
*  CJN     Loss coefficient multiplies 0.5*rho*v^2
*  IHORIZ  Orientation: 1 = horizontal, 0 = vertical
*  XWJN    Characteristic width, m
*  XHJN    Characteristic height, m
```

```
*  XLJN     Characteristic length, m
*  DFJN     Decontamination Factor
*  N90      No. of 90 bends
*
*              INLET                      ANNULUS     ANNULUS  condenser
*              LEAKAGE       OUTLET        INLET       OUTLET   outlet
     PATHS        1            2            3           4        5
        IJTYP     1            1            1           1        1
        IR1       3            1            3           2        4
        IR2       1            4            2           3        3
        IHORIZ    1            0          0           0        0
        XWJN      0.1000     0.1000         0.1524      0.1524    0.01
        XHJN      0.1000     0.1000         0.1524      0.1524    0.01
        XLJN      1000.        20.    5.0          5.0       10.0
        AJN       0.03000    0.03000        0.07297     0.07297   0.030
        Z1JN      1.0          12.0         1.00        12.00     10.0
        Z2JN      12.0         1.0          12.00       1.00      10.0
        CJN       5.           5.0          2.0         2.0     5.0
        DFJN      1.0          1.0          1.0         1.0     1.0
        N90       0            0            0           0        0.0
        KFILTER   1000.      10000.      1000.0      1000.0    15000.
        IFAN      0            0            0           0          1
        WVFAN     0.0          0.0      0.0         0.0        0.047
     END PATHS   ! PATHS is a comment.
*
*
END JUNCTIONS    ! JUNCTIONS is a comment.
```

Appendix D:

Quality Assurance Documentation

Included here are:

1. Calculation Note Cover Sheet, and
2. Calculation Note Methodology Checklist.

FAUSKE & ASSOCIATES, INC.

CALCULATION NOTE COVER SHEET

SECTION TO BE COMPLETED BY AUTHOR(S):

Page: 41

Calc-Note Number: BOMALIN031303 Revision Number: 0

Title: DST Boiling Source Term with HADCRT 1.4

Project: Hanford River Protection Project Project Number or Shop Order: CHG04A

Purpose: Boiling Source Term Analysis for DST.

Results Summary: Results are the same as previously shown in FAI/01-42, Rev. 1.

References of Resulting reports, Letters, or Memoranda (Optional):

Author(s): Name (Print or Type)	Signature	Completion Date
Boro Malinovic	Boro Malinovic	03/13/03

SECTION TO BE COMPLETED BY VERIFIER(S):

Verifier(s): Name (Print or Type)	Signature	Completion Date
Wison Luangdilok	Wison Luangdilok	03/13/03

Method of Verification: Design Review: ____, Independent Review or Alternate Calculations: X, Testing: ____.

Other: ____.

SECTION TO BE COMPLETED BY MANAGER:

Responsible Manager: Name (Print or Type)	Signature	Approval Date
Martin G. Plys	Martin Plys	03/13/03

CALC NOTE NUMBER: BOMALIN031303 REV. 0 PAGE: 42

CALCULATION NOTE METHODOLOGY CHECKLIST

CHECKLIST TO BE COMPLETED BY AUTHOR(S) (CIRCLE APPROPRIATE RESPONSE)

1. Is the subject and/or the purpose of the design analysis clearly stated?.. ..... YES NO
2. Are the required inputs and their sources provided? ..... YES NO . N/A
3. Are the assumptions clearly identified and justified? ..... YES NO . N/A
4. Are the methods and units clearly identified? ..... YES NO . N/A
5. Have the limits of applicability been identified? ..... YES NO . N/A
   (i.e., Is the analysis for a 3 or 4 loop plant or for a single application.)
6. Are the results of literature searches, if conducted, or other background data provided? ..... YES . NO . N/A
7. Are all the pages sequentially numbered and identified by the calculation note number? ..... YES NO
8. Is the project or shop order clearly identified? ..... YES NO
9. Has the required computer calculation information been provided? ..... YES NO . N/A
10. Were the computer codes used under configuration control? ..... YES . NO . N/A
11. Was the computer code(s) used applicable for modeling the physical and/or computational problems identified? ..... YES NO . N/A
    (i.e., Is the correct computer code being used for the intended purpose.)
12. Are the results and conclusions clearly stated? ..... YES NO
13. Are Open Items properly identified ..... YES . NO . N/A
14. Were approved Design Control practices followed without exception? ..... YES . NO . N/A
    (Approved Design Control practices refers to guidance documents within Nuclear Services that state how the work is to be performed, such as how to perform a LOCA analysis.)
15. Have all related contract requirements been met? ..... YES NO . N/A

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