This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-96SR18500 with the U.S. Department of Energy.

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WSRC-TR-2001-00375
Revision 0
August 14, 2001

Radionuclide Releases During Normal Operations for Ventilated Tanks

Ventilated Tank
Source Term Determination

Purpose

This calculation estimates the design emissions of radionuclides from Ventilated Tanks used by various facilities. The calculation includes emissions due to processing and storage of radionuclide material.

Background

Various operations with radionuclide containing material involves the use of tanks with active ventilation systems. The tanks addressed by this calculation are fixed roof and horizontal type tanks. The non-ventilated versions of these type of tanks are addressed in "Compilation of Air Pollutant Emission Factors, AP42" published by the Environmental Protection Agency (EPA). AP42 uses the vapor pressure of the material in the tank to estimate emissions. Because the tanks in AP42 are not ventilated, the passive losses must be estimated by factors affecting breathing loss and fill rate. For the ventilated tanks the losses are not passive, but active and are determined by the ventilation flow rate.

The following calculation is similar to the EPA AP42 method with the exceptions noted above. This calculation uses the Vapor Pressure of the material in the tank and the ventilation flow rate to determine estimated releases.

In some tanks there maybe a hundred different chemicals. For these cases, as shown in the Example Calculation, Appendix D of 40 CFR 61 is used as a screening tool to reduce the number of detailed calculations required. This graded approach to determining the emissions is conservative, in that the estimated emissions from Appendix D for those radionuclides not included in the detailed vapor pressure calculation is added to the emissions from those radionuclides determined by the Vapor Pressure Calculation.

Methodology Description

The radionuclide source term from a ventilated tank is composed of the releases from the vapor space in the tank. In some cases the tank may have extreme agitation that produces an entrained liquid droplet stream. For tanks with entrained droplet, some form of product recovery system, such as a demister is employed. In this case the vapor pressure at the exit of the demister would be used to estimate the source term.

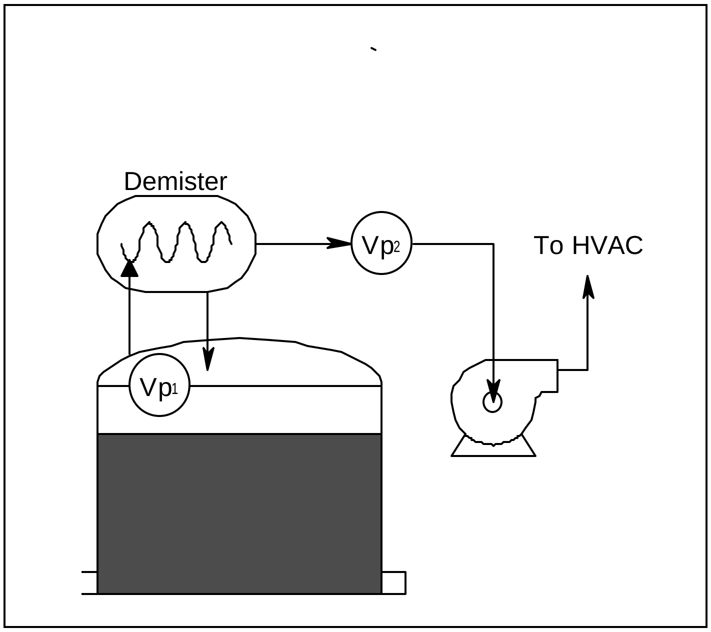

Figure 1: Tank Schematic

Referencing Figure 1 the tank emissions would be estimated at Vp_1 when a demister is not present and at Vp_2 when a demister is present. The first step in the process is to perform a screening emission estimate with Appendix D to 40 CFR 61. Emission from any radionuclide that contributes significantly based on the Appendix D evaluation would be evaluated based on the following methods. These radionuclides are termed Level II radionuclides. The estimated emissions for the tank would then be the sum of emissions based on Appendix D without the Level II radionuclides and the estimates of emission for the Level II radionuclides based on the following method

Level II Radionuclide Evaluation

An estimate of the partial pressure of component *i* above the solution or at the demister exhaust can be found using Raoult's Law.

$$p_i = X_i P_i^\circ \qquad (1)$$

where: p_i = partial pressure of component *i*, atm
X_i = Mole fraction of component *i* in tank solution, dimensionless
P_i° = Vapor pressure of pure component *i*, atm

The number of moles of each component is calculated and divided by the total number of moles resulting in the mole fraction for each component.

$$Z_i = \frac{Weight\ Percent}{M_i}$$

$$X_i = \frac{Z_i}{\sum Z_i} \tag{2}$$

where: Z_i = Moles of component *i*, g-mole
M_i = Molecular Weight of component *i*, g/g-mole

Then by Dalton's Law the total vapor pressure of the solution or the demister exhaust gas is simply the sum of the individual partial pressures.

$$P_v = \sum p_i \tag{3}$$

where: P_v = Total vapor pressure, atm

The mole fraction of each component in the vapor is now found by following through with Raoult's Law.

$$y_i = \frac{p_i}{P_v} \tag{4}$$

where: y_i = Vapor mole fraction of component *i*, dimensionless

The molecular weight of the vapor can now be found

$$M_v = \sum y_i M_i \tag{5}$$

where: M_v = Molecular weight of vapor mixture, g/g-mole

The density of the vapor at the exhaust temperature is then found using the ideal gas law. As the vapor pressures are very small, it can be assumed that the vapors are acting much like an ideal gas.

$$\rho_g = \frac{M_v P_v}{R_u T} \tag{6}$$

where: ρ_g = Density of vapor, g/cc
R_u = Universal gas constant, $82.05 \frac{cc \cdot atm}{g-mole \cdot {}^\circ K}$
T = Temperature, °K

The emissions are then found as the product of the density of the vapor, the flow rate out of the tank or demister, the length of time the material is in the tank, and the vapor mass fraction of each component.

$$W_i = \rho_g F_g \tau X_{vi} (1440 \text{ min}/\ day) \tag{7}$$

where: W_i = Mass emissions, g/yr
F_g = Tank ventilation rate, cc/min
τ = Annual time of operation, day/yr
X_{vi} = Mass fraction of component *i* in vapor, dimensionless

The vapor mass fraction can be found as

$$X_{vi} = \frac{y_i M_i}{M_v}. \tag{8}$$

The curies released due to the Level II radionuclides can now be found from the specific activity and the mass fraction for the isotope of concern.

$$E_{Ci} = W_i S_i C_f \tag{9}$$

where: E_{ci} = Emission of radionuclide *i*, ci/yr
S_i = Specific activity of isotope *i*, ci/g
C_f = Control factor for each control device type, dimensionless

Example Calculation

Caustic Side Solvent Extraction (CSSX) Pilot Plant

Given: 1) Inorganic compound vapor pressures. See Attachment A
2) PuO_2 vapor pressure = 1.12E-09 atm at 1450 °C (Wick, 1980, p.341)
4) AmO_2 vapor pressure = 4.145E-11 atm at 1327 °C (Schultz, 1976, p.153)
5) H_2O vapor pressure = 5.549E-2 atm at 35 °C (Dean, 1992, p 5.28)
6) HNO_3 vapor pressure = 7.890E-02 atm at 35 °C (Weast, 1972, p D-177)
7) Facility will have HEPA filters on the effluent.
8) Control Factor for HEPA per 40 CFR 61 Appendix D = 0.01

Assumptions:
1. For EPA Appendix D assume 100,000 gallons feed per year
2. Tank ventilation flow rate (F_g) = 10 cfm (283,168 cc/min)
3. Tank Temperature (T) = 35 °C
4. Facility has multiple tanks, see Figure 2 below.

EPA Appendix D Screening Analysis

The detailed Appendix D evaluation for the example facility is contained in Attachment B. Based on this evaluation Cesium, Strontium, Plutonium and Americium will be carried through as Level II radionuclides.

Level II Evaluation

The half life of the Level II isotopes can be found in many texts, such as *Handbook of Health Physics and Radiological Health*, edited by Bernard Shleien, 3rd edition, Williams & Wilkins, Baltimore. The resulting specific activities are presented below in Table 1.

Table 1: Specific Activities

Isotope	Half-life (yr)	Atomic Weight	Specific Activity (Ci/g)
^{134}Cs	2.062	134	1.295E+03
^{135}Cs	2300000	135	1.152E-03
^{137}Cs	30.17	137	8.657E+01
^{90}Sr	28.6	90	1.390E+02
^{238}Pu	87.75	238	1.713E+01
^{239}Pu	24131	239	6.204E-02
^{240}Pu	6569	240	2.269E-01
^{241}Pu	14.4	241	1.031E+02
^{242}Pu	375800	242	3.934E-03
^{241}Am	432.2	241	3.435E+00
^{242m}Am	152	242	9.727E+00

There are five basic release pathways for this example. Each is via a ventilated tank. Figure 2 gives a typical flow plan for the example facility.

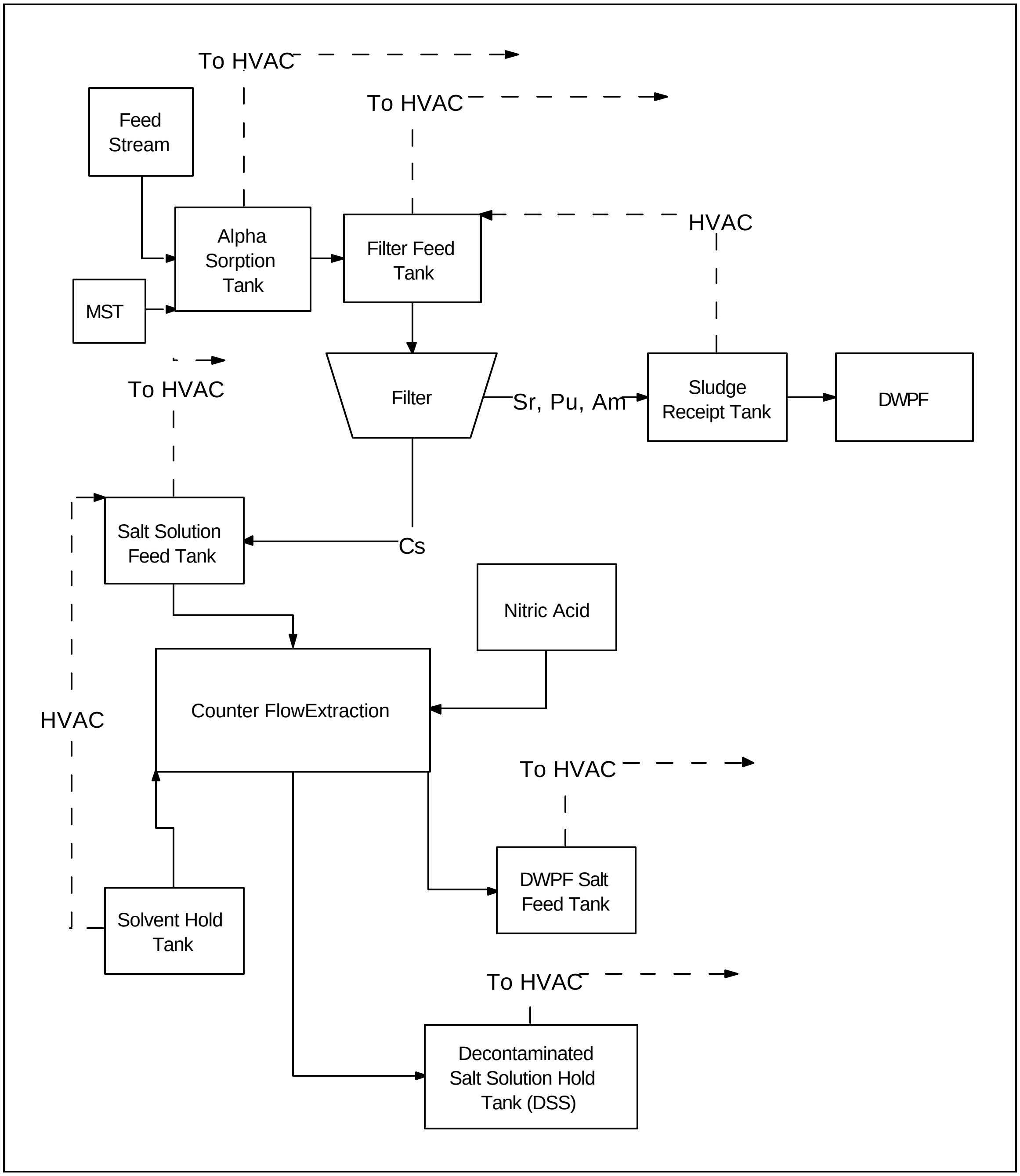

Figure 2: Typical Flow Plan

For each of the five tanks the Mole Fraction of the components of each compound is found with Equation (2). The chemical composition for each tank is based on the process flow documents at the time this example was prepared.

$$Z_i = \frac{Weight\ Percent}{M_i}$$

$$X_i = \frac{Z_i}{\sum Z_i}$$

The results for are tabulated in Tables 1 - 5 below.

Table 1: Alpha Sorption Tank

Compound	Grams/hr	Molecular Weight (g-gmole)	Moles	(Eq. 2) X_i
$NaNO_2$	7.541E+03	69.00	1.093E+02	5.758E-02
$NaNO_3$	1.175E+04	84.99	1.383E+02	7.287E-02
NaOH	2.084E+04	40.00	5.210E+02	2.745E-01
CsOH	1.450E+00	149.90	9.671E-03	5.095E-06
$Sr(OH)_2$	1.465E-02	121.64	1.204E-04	6.344E-08
PuO_2	2.983E-01	271.05	1.101E-03	5.799E-07
AmO_2	4.729E-02	275.13	1.719E-04	9.057E-08
Water	2.035E+04	18.02	1.129E+03	5.950E-01

Table 2: Filter Feed Tank

Compound	Grams/hr	Molecular Weight (g-gmole)	Moles	(Eq. 2) X_i
$NaNO_2$	4.412E+03	69.00	6.395E+01	3.157E-02
$NaNO_3$	6.877E+03	84.99	8.092E+01	3.995E-02
NaOH	1.222E+04	40.00	3.055E+02	1.508E-01
CsOH	1.527E+00	149.90	1.018E-02	5.027E-06
$Sr(OH)_2$	1.024E+00	121.64	8.420E-03	4.157E-06
PuO_2	2.086E+01	271.05	7.696E-02	3.799E-05
AmO_2	3.307E+00	275.13	1.202E-02	5.934E-06
Water	2.838E+04	18.02	1.575E+03	7.776E-01

Table 3: Decontaminated Salt Solution

Compound	Grams/hr	Molecular Weight (g-gmole)	Moles	(Eq. 2) X_i
$NaNO_2$	4.412E+03	69.00	6.395E+01	3.157E-02
$NaNO_3$	6.877E+03	84.99	8.092E+01	3.995E-02
NaOH	1.222E+04	40.00	3.055E+02	1.508E-01
CsOH	2.328E-05	149.90	1.553E-07	7.666E-11
$Sr(OH)_2$	1.586E-05	121.64	1.304E-07	6.437E-11
PuO_2	3.267E-04	271.05	1.205E-06	5.950E-10
AmO_2	5.283E-05	275.13	1.920E-07	9.479E-11
Water	2.838E+04	18.02	1.575E+03	7.776E-01

Table 4: Salt Solution Feed

Compound	Grams/hr	Molecular Weight (g-gmole)	Moles	(Eq. 2) X_i
$NaNO_2$	4.412E+03	69.00	6.395E+01	3.157E-02
$NaNO_3$	6.877E+03	84.99	8.092E+01	3.994E-02
NaOH	1.222E+04	40.00	3.055E+02	1.508E-01
CsOH	2.206E+01	149.90	1.472E-01	7.265E-05
$Sr(OH)_2$	1.586E-05	121.64	1.304E-07	6.436E-11
PuO_2	3.267E-04	271.05	1.205E-06	5.950E-10
AmO_2	5.283E-05	275.13	1.920E-07	9.479E-11
Water	2.838E+04	18.02	1.575E+03	7.776E-01

Table 5: DWPF Salt Feed

Compound	Grams/hr	Molecular Weight (g-gmole)	Moles	(Eq. 2) X_i
HNO_3	1.252E+00	63.01	1.987E-02	9.010E-06
$CsNO_3$	2.869E+01	194.91	1.472E-01	6.674E-05
$Sr(NO3)_2$	6.898E-07	211.65	3.259E-09	1.478E-12
PuO_2	1.222E-02	271.05	4.507E-05	2.044E-08
AmO_2	1.770E-05	275.13	6.432E-08	2.916E-11
Water	3.974E+04	18.02	2.205E+03	9.999E-01

An estimate of the partial pressure of each component in the vapor is found with Equation (1). The Total Vapor Pressure is then found as the sum of the individual partial pressures (Equation 3). With these values and Equation (4) the mole fraction of each vapor component is determined. Then using Equation (5) the molecular weight of the vapor is found. And finally, the vapor mass fraction of each oxide component is found with Equation (8). Each equation is reproduced below and results of these calculations are presented in Tables 6-10.

$$p_i = X_i P_i^\circ \tag{1}$$

$$y_i = \frac{p_i}{P_v} \tag{4}$$

$$X_{vi} = \frac{y_i M_i}{M_v}. \tag{8}$$

Table 6: Alpha Sorption Tank (1, 4 & 8)

Compound	P_i° (atm)	(Eq. 1) P_i (atm)	(Eq. 4) y_i	y_i x M_i (g/g-mole)	(Eq. 8) X_{vi}
$NaNO_2$	1.97E-03	1.13E-04	3.42E-03	2.36E-01	1.30E-02
$NaNO_3$	1.20E-05	8.76E-07	2.64E-05	2.25E-03	1.23E-04
NaOH	1.86E-13	5.12E-14	1.55E-12	6.18E-11	3.40E-12
CsOH	1.13E-11	5.75E-17	1.74E-15	2.60E-13	1.43E-14
$Sr(OH)_2$	1.20E-08	7.60E-16	2.29E-14	2.79E-12	1.53E-13
PuO_2	1.12E-09	6.49E-16	1.96E-14	5.31E-12	2.92E-13
AmO_2	4.15E-11	3.76E-18	1.13E-16	3.12E-14	1.72E-15
Water	5.55E-02	3.30E-02	9.97E-01	1.80E+01	9.87E-01

where

$$P_{Alpha} = \sum p_i = 3.313E-02 atm$$

and

$$M_{vAlpha} = \sum y_i M_i = 18.2 g/g-mole$$

Table 7: Filter Feed Tank (1, 4 & 8)

Compound	P_i° (atm)	(Eq. 1) P_i (atm)	(Eq. 4) y_i	y_i x M_i (g/g-mole)	(Eq. 8) X_{vi}
$NaNO_2$	1.97E-03	6.21E-05	1.44E-03	9.92E-02	5.48E-03
$NaNO_3$	1.20E-05	4.80E-07	1.11E-05	9.44E-04	5.22E-05
NaOH	1.86E-13	2.81E-14	6.51E-13	2.60E-11	1.44E-12
CsOH	1.13E-11	5.67E-17	1.31E-15	1.97E-13	1.09E-14
$Sr(OH)_2$	1.20E-08	4.98E-14	1.15E-12	1.40E-10	7.75E-12
PuO_2	1.12E-09	4.26E-14	9.85E-13	2.67E-10	1.48E-11
AmO_2	4.15E-11	2.46E-16	5.70E-15	1.57E-12	8.66E-14
Water	5.55E-02	4.31E-02	9.99E-01	1.80E+01	9.94E-01

where

$$P_{vFilter} = \sum p_i = 4.321\text{E-}02 atm$$

and

$$M_{vFilter} = \sum y_i M_i = 18.1 g/g-mole$$

Table 8: Decontaminated Salt Solution (1, 4 & 8)

Compound	P_i° (atm)	(Eq. 1) P_i (atm)	(Eq. 4) y_i	y_i x M_i (g/g-mole)	(Eq. 8) X_{vi}
$NaNO_2$	1.97E-03	6.21E-05	1.44E-03	9.92E-02	5.48E-03
$NaNO_3$	1.20E-05	4.80E-07	1.11E-05	9.44E-04	5.22E-05
NaOH	1.86E-13	2.81E-14	6.51E-13	2.60E-11	1.44E-12
CsOH	1.13E-11	8.65E-22	2.00E-20	3.00E-18	1.66E-19
$Sr(OH)_2$	1.20E-08	7.71E-19	1.78E-17	2.17E-15	1.20E-16
PuO_2	1.12E-09	6.66E-19	1.54E-17	4.18E-15	2.31E-16
AmO_2	4.15E-11	3.93E-21	9.10E-20	2.50E-17	1.38E-18
Water	5.55E-02	4.32E-02	9.99E-01	1.80E+01	9.94E-01

where

$$P_{vDSS} = \sum p_i = 4.321\text{E-}02 atm$$

and

$$M_{vDSS} = \sum y_i M_i = 18.1 g/g-mole$$

Table 9: Salt Solution Feed (1, 4 & 8)

Compound	P_i° (atm)	(Eq. 1) P_i (atm)	(Eq. 4) y_i	y_i x M_i (g/g-mole)	(Eq. 8) X_{vi}
$NaNO_2$	1.97E-03	6.21E-05	1.44E-03	9.92E-02	5.48E-03
$NaNO_3$	1.20E-05	4.80E-07	1.11E-05	9.44E-04	5.22E-05
NaOH	1.86E-13	2.81E-14	6.51E-13	2.60E-11	1.44E-12
CsOH	1.13E-11	8.20E-16	1.90E-14	2.84E-12	1.57E-13
$Sr(OH)_2$	1.20E-08	7.71E-19	1.78E-17	2.17E-15	1.20E-16
PuO_2	1.12E-09	6.66E-19	1.54E-17	4.18E-15	2.31E-16
AmO_2	4.15E-11	3.93E-21	9.10E-20	2.50E-17	1.38E-18
Water	5.55E-02	4.31E-02	9.99E-01	1.80E+01	9.94E-01

where

$$P_{vSS} = \sum p_i = 4.321\text{E-}02 atm$$

and

$$M_{vSS} = \sum y_i M_i = 18.1 g/g - mole$$

Table 10: DWPF Salt Feed (1, 4 & 8)

Compound	P_i° (atm)	(Eq. 1) P_i (atm)	(Eq. 4) y_i	y_i x M_i (g/g-mole)	(Eq. 8) X_{vi}
HNO_3	7.89E-02	7.11E-07	1.28E-05	8.07E-04	4.48E-05
$CsNO_3$	6.12E-10	4.09E-14	7.36E-13	1.44E-10	7.97E-12
$Sr(NO3)_2$	5.01E-13	7.40E-25	1.33E-23	2.82E-21	1.57E-22
PuO_2	1.12E-09	2.29E-17	4.13E-16	1.12E-13	6.20E-15
AmO_2	4.15E-11	1.21E-21	2.18E-20	6.00E-18	3.33E-19
Water	5.55E-02	5.55E-02	1.00E+00	1.80E+01	1.00E+00

where

$$P_{vDWPF} = \sum p_i = 5.549\text{E-}02 atm$$

and

$$M_{vDWPF} = \sum y_i M_i = 18.0 g/g - mole$$

The density of the tank vapor at the elevated temperature can now be found with Equation (6).

$$\rho_g = \frac{M_v P_v}{R_u T}$$

Then for the Alpha Sorption Tank

$$\rho_{Alpha} = \frac{(18.2 g / g - mole)(3.313E - 02 atm)}{\left(82.05 \frac{cc \cdot atm}{g - mole \cdot {}^\circ K}\right)(308^\circ K)} = 2.386\text{E} - 05\, g / cc$$

and for the Filter Feed tank

$$\rho_{Filter} = \frac{(18.1 g / g - mole)(4.321E - 02 atm)}{\left(82.05 \frac{cc \cdot atm}{g - mole \cdot {}^\circ K}\right)(308^\circ K)} = 3.094\text{E} - 05\, g / cc$$

and for the Decontaminated Salt Solution tank

$$\rho_{DSS} = \frac{(18.1 g / g - mole)(4.321E - 02 atm)}{\left(82.05 \frac{cc \cdot atm}{g - mole \cdot {}^\circ K}\right)(308^\circ K)} = 3.094\text{E} - 05\, g / cc$$

and for the Salt Solution Feed tank

$$\rho_{SS} = \frac{(18.1 g / g - mole)(4.321E - 02 atm)}{\left(82.05 \frac{cc \cdot atm}{g - mole \cdot {}^\circ K}\right)(308^\circ K)} = 3.094\text{E} - 05\, g / cc$$

and for the DWPF Salt Solution Tank

$$\rho_{DWPF} = \frac{(18.0 g / g - mole)(5.549E - 02 atm)}{\left(82.05 \frac{cc \cdot atm}{g - mole \cdot {}^\circ K}\right)(308^\circ K)} = 3.957\text{E} - 05\, g / cc$$

The estimated emissions from the tanks for each compound are now found using Equations (7). Let, τ = 365 days. The results of this calculation are contained in Table 11.

$$W_i = \rho_g F_g \tau X_{vi} (1440 \text{ min/ } day) \quad (7)$$

Table 11: Mass Emissions by Compound (grams/yr)

Compound	Alpha Sorption Tank	Filter Feed Tank	Decontaminated Salt Solution	Salt Solution Feed Tank	DWPF Salt Solution Tank
CsOH	5.08E-08	5.01E-08	7.64E-13	7.24E-07	-
$Sr(OH)_2$	5.45E-07	3.57E-05	5.52E-10	5.52E-10	-
$CsNO_3$	-	-	-	-	4.69E-05
$Sr(NO3)_2$	-	-	-	-	9.22E-16
PuO_2	1.04E-06	6.79E-05	1.06E-09	1.06E-09	3.65E-08
AmO_2	6.09E-09	3.99E-07	6.37E-12	6.37E-12	1.96E-12

Equation (9) is used to determine the estimated releases in curies. Since Equation (9) contains the specific activity which in this case is based on the metal and not the compounds, Table 11 must first be converted to Mass Emissions by Element. This has been done below as Table 11a.

Table 11a: Mass Emissions by Element (grams/yr)

Element	Alpha Sorption Tank	Filter Feed Tank	Decontaminated Salt Solution	Salt Solution Feed Tank	DWPF Salt Solution Tank
Cs	4.50E-08	4.44E-08	6.77E-13	6.42E-07	3.20E-05
Sr	3.92E-07	2.57E-05	3.98E-10	3.98E-10	3.82E-16
Pu	9.26E-07	6.06E-05	9.50E-10	9.50E-10	3.26E-08
Am	5.38E-09	3.53E-07	5.63E-12	5.63E-12	1.73E-12

As each of the elemental masses is composed of various isotopes. before Equation (9) can be used the ratio of isotopes making up each elemental mass must be determined. The ratios can be determined from the Ci/L data for the project. First the Ci/L data is converted to a gram/L value by multiplying by the specific activity (S_i) for each isotope. The total mass of each isotope per liter is then found. The ratio is then found by dividing the isotopic gram/L value by the total elemental mass. The result for each Tank is presented in Tables 12-16 below.

Table 12: Alpha Sorption Tank

	Ci/L	S_i	gram/L	Ratio
Cs-134	4.260E-06	1.295E+03	3.290E-09	1.017E-07
Cs-135	7.230E-09	1.152E-03	6.276E-06	1.940E-04
Cs-137	2.800E+00	8.657E+01	3.234E-02	9.998E-01
Total			3.235E-02	
Sr-90	3.690E-02	1.390E+02	2.655E-04	1.000E+00
Total			2.655E-04	
Pu-238	1.180E-02	1.713E+01	6.888E-04	1.027E-01
Pu-239	3.430E-04	6.204E-02	5.529E-03	8.246E-01
Pu-240	7.990E-05	2.269E-01	3.521E-04	5.252E-02
Pu-241	2.540E-03	1.031E+02	2.464E-05	3.675E-03
Pu-242	4.330E-07	3.934E-03	1.101E-04	1.642E-02
Total			6.704E-03	
Am-241	3.610E-03	3.435E+00	1.051E-03	9.995E-01
Am-242m	4.810E-06	9.727E+00	4.945E-07	4.703E-04
Total			1.051E-03	

Table 13: Filter Feed Tank

	Ci/L	S_i	gram/L	Ratio
Cs-134	4.260E-06	1.295E+03	3.290E-09	9.652E-08
Cs-135	7.230E-09	1.152E-03	6.276E-06	1.841E-04
Cs-137	2.950E+00	8.657E+01	3.408E-02	9.998E-01
Total			3.408E-02	
Sr-90	2.580E+00	1.390E+02	1.856E-02	1.000E+00
Total			1.856E-02	
Pu-238	8.230E-01	1.713E+01	4.804E-02	1.025E-01
Pu-239	2.400E-02	6.204E-02	3.868E-01	8.250E-01
Pu-240	5.590E-03	2.269E-01	2.464E-02	5.254E-02
Pu-241	1.780E-01	1.031E+02	1.726E-03	3.682E-03
Pu-242	3.020E-05	3.934E-03	7.677E-03	1.637E-02
Total			4.689E-01	
Am-241	2.530E-01	3.435E+00	7.365E-02	9.995E-01
Am-242m	3.360E-04	9.727E+00	3.454E-05	4.688E-04
Total			7.369E-02	

Table 14: Decontaminated Salt Solution

	Ci/L	S_i	gram/L	Ratio
Cs-134	0.000E+00	1.295E+03	0.000E+00	0.000E+00
Cs-135	0.000E+00	1.152E-03	0.000E+00	0.000E+00
Cs-137	4.500E-05	8.657E+01	5.198E-07	1.000E+00
Total			5.198E-07	
Sr-90	4.000E-05	1.390E+02	2.878E-07	1.000E+00
Total			2.878E-07	
Pu-238	1.260E-05	1.713E+01	7.356E-07	1.001E-01
Pu-239	3.780E-07	6.204E-02	6.093E-06	8.293E-01
Pu-240	8.450E-08	2.269E-01	3.724E-07	5.069E-02
Pu-241	2.430E-06	1.031E+02	2.357E-08	3.208E-03
Pu-242	4.810E-10	3.934E-03	1.223E-07	1.664E-02
Total			7.347E-06	
Am-241	4.040E-06	3.435E+00	1.176E-06	9.995E-01
Am-242m	5.410E-09	9.727E+00	5.562E-10	4.727E-04
Total			1.177E-06	

Table 15: Salt Solution Feed

	Ci/L	S_i	gram/L	Ratio
Cs-134	0.000E+00	1.295E+03	0.000E+00	0.000E+00
Cs-135	0.000E+00	1.152E-03	0.000E+00	0.000E+00
Cs-137	2.800E+00	8.657E+01	3.234E-02	1.000E+00
Total			3.234E-02	
Sr-90	4.000E-05	1.390E+02	2.878E-07	1.000E+00
Total			2.878E-07	
Pu-238	1.260E-05	1.713E+01	7.356E-07	1.001E-01
Pu-239	3.780E-07	6.204E-02	6.093E-06	8.293E-01
Pu-240	8.450E-08	2.269E-01	3.724E-07	5.069E-02
Pu-241	2.430E-06	1.031E+02	2.357E-08	3.208E-03
Pu-242	4.810E-10	3.934E-03	1.223E-07	1.664E-02
Total			7.347E-06	
Am-241	4.040E-06	3.435E+00	1.176E-06	9.995E-01
Am-242m	5.410E-09	9.727E+00	5.562E-10	4.727E-04
Total			1.177E-06	

Table 16: DWPF Salt Feed

	Ci/L	S_i	gram/L	Ratio
Cs-134	6.480E-05	1.295E+03	5.004E-08	1.017E-07
Cs-135	1.100E-07	1.152E-03	9.549E-05	1.940E-04
Cs-137	4.260E+01	8.657E+01	4.921E-01	9.998E-01
Total			4.922E-01	
Sr-90	1.000E-06	1.390E+02	7.194E-09	1.000E+00
Total			7.194E-09	
Pu-238	1.000E-06	1.713E+01	5.838E-08	2.124E-04
Pu-239	1.000E-06	6.204E-02	1.612E-05	5.866E-02
Pu-240	1.000E-06	2.269E-01	4.407E-06	1.604E-02
Pu-241	1.000E-06	1.031E+02	9.699E-09	3.530E-05
Pu-242	1.000E-06	3.934E-03	2.542E-04	9.251E-01
Total			2.748E-04	
Am-241	1.000E-06	3.435E+00	2.911E-07	7.390E-01
Am-242m	1.000E-06	9.727E+00	1.028E-07	2.610E-01
Total			3.939E-07	

The estimated curie emission levels can now be found using Equation (9) along with the isotopic ratios from the appropriate table.

$$E_{Ci} = W_i S_i C_f \tag{9}$$

The results for each Tank are presented below in Tables 17-21.

Table 17: Alpha Sorption Tank Emissions

Radionuclide	S_i	Isotope Ratio	Estimated Releases (Grams/ yr)	(C_f) Control Factor	(E_{Ci}) Estimated Releases (Ci/yr)
Cs-134	1.295E+03	1.017E-07	4.577E-15	1.000E-02	5.928E-14
Cs-135	1.152E-03	1.940E-04	8.733E-12	1.000E-02	1.006E-16
Cs-137	8.657E+01	9.998E-01	4.500E-08	1.000E-02	3.896E-08
Sr-90	1.390E+02	1.000E+00	3.922E-07	1.000E-02	5.452E-07
Pu-238	1.713E+01	1.027E-01	9.511E-08	1.000E-02	1.629E-08
Pu-239	6.204E-02	8.246E-01	7.633E-07	1.000E-02	4.736E-10
Pu-240	2.269E-01	5.252E-02	4.862E-08	1.000E-02	1.103E-10
Pu-241	1.031E+02	3.675E-03	3.401E-09	1.000E-02	3.507E-09
Pu-242	3.934E-03	1.642E-02	1.520E-08	1.000E-02	5.978E-13
Am-241	3.435E+00	9.995E-01	5.379E-09	1.000E-02	1.848E-10
Am-242m	9.727E+00	4.703E-04	2.531E-12	1.000E-02	2.462E-13

Table 18: Filter Feed Tank Emissions

Radionuclide	S_i	Isotope Ratio	Estimated Releases (Grams/ yr)	(C_f) Control Factor	(E_{Ci}) Estimated Releases (Ci/yr)
Cs-134	1.295E+03	9.652E-08	4.287E-15	1.000E-02	5.551E-14
Cs-135	1.152E-03	1.841E-04	8.178E-12	1.000E-02	9.421E-17
Cs-137	8.657E+01	9.998E-01	4.441E-08	1.000E-02	3.844E-08
Sr-90	1.390E+02	1.000E+00	2.570E-05	1.000E-02	3.572E-05
Pu-238	1.713E+01	1.025E-01	6.214E-06	1.000E-02	1.064E-06
Pu-239	6.204E-02	8.250E-01	5.003E-05	1.000E-02	3.104E-08
Pu-240	2.269E-01	5.254E-02	3.186E-06	1.000E-02	7.230E-09
Pu-241	1.031E+02	3.682E-03	2.233E-07	1.000E-02	2.302E-07
Pu-242	3.934E-03	1.637E-02	9.928E-07	1.000E-02	3.906E-11
Am-241	3.435E+00	9.995E-01	3.524E-07	1.000E-02	1.211E-08
Am-242m	9.727E+00	4.688E-04	1.653E-10	1.000E-02	1.608E-11

Table 19: Decontaminated Salt Solution Emissions

Radionuclide	S_i	Isotope Ratio	Estimated Releases (Grams/ yr)	(C_f) Control Factor	(E_{Ci}) Estimated Releases (Ci/yr)
Cs-134	1.295E+03	0.000E+00	0.000E+00	1.000E-02	0.000E+00
Cs-135	1.152E-03	0.000E+00	0.000E+00	1.000E-02	0.000E+00
Cs-137	8.657E+01	1.000E+00	6.772E-13	1.000E-02	5.863E-13
Sr-90	1.390E+02	1.000E+00	3.979E-10	1.000E-02	5.531E-10
Pu-238	1.713E+01	1.001E-01	9.509E-11	1.000E-02	1.629E-11
Pu-239	6.204E-02	8.293E-01	7.877E-10	1.000E-02	4.887E-13
Pu-240	2.269E-01	5.069E-02	4.815E-11	1.000E-02	1.092E-13
Pu-241	1.031E+02	3.208E-03	3.047E-12	1.000E-02	3.142E-12
Pu-242	3.934E-03	1.664E-02	1.581E-11	1.000E-02	6.219E-16
Am-241	3.435E+00	9.995E-01	5.630E-12	1.000E-02	1.934E-13
Am-242m	9.727E+00	4.727E-04	2.663E-15	1.000E-02	2.590E-16

Table 20: Salt Solution Feed Emissions

Radionuclide	S_i	Isotope Ratio	Estimated Releases (Grams/ yr)	(C_f) Control Factor	(E_{Ci}) Estimated Releases (Ci/yr)
Cs-134	1.295E+03	0.000E+00	0.000E+00	1.000E-02	0.000E+00
Cs-135	1.152E-03	0.000E+00	0.000E+00	1.000E-02	0.000E+00
Cs-137	8.657E+01	1.000E+00	6.418E-07	1.000E-02	5.556E-07
Sr-90	1.390E+02	1.000E+00	3.979E-10	1.000E-02	5.531E-10
Pu-238	1.713E+01	1.001E-01	9.509E-11	1.000E-02	1.629E-11
Pu-239	6.204E-02	8.293E-01	7.876E-10	1.000E-02	4.887E-13
Pu-240	2.269E-01	5.069E-02	4.814E-11	1.000E-02	1.092E-13
Pu-241	1.031E+02	3.208E-03	3.047E-12	1.000E-02	3.141E-12
Pu-242	3.934E-03	1.664E-02	1.581E-11	1.000E-02	6.218E-16
Am-241	3.435E+00	9.995E-01	5.630E-12	1.000E-02	1.934E-13
Am-242m	9.727E+00	4.727E-04	2.662E-15	1.000E-02	2.590E-16

Table 21: DWPF Salt Feed Emissions

Radionuclide	S_i	Isotope Ratio	Estimated Releases (Grams/ yr)	(C_f) Control Factor	(E_{Ci}) Estimated Releases (Ci/yr)
Cs-134	1.295E+03	1.017E-07	3.252E-12	1.000E-02	4.211E-11
Cs-135	1.152E-03	1.940E-04	6.205E-09	1.000E-02	7.148E-14
Cs-137	8.657E+01	9.998E-01	3.198E-05	1.000E-02	2.768E-05
Sr-90	1.390E+02	1.000E+00	3.817E-16	1.000E-02	5.306E-16
Pu-238	1.713E+01	2.124E-04	6.930E-12	1.000E-02	1.187E-12
Pu-239	6.204E-02	5.866E-02	1.914E-09	1.000E-02	1.187E-12
Pu-240	2.269E-01	1.604E-02	5.232E-10	1.000E-02	1.187E-12
Pu-241	1.031E+02	3.530E-05	1.151E-12	1.000E-02	1.187E-12
Pu-242	3.934E-03	9.251E-01	3.018E-08	1.000E-02	1.187E-12
Am-241	3.435E+00	7.390E-01	1.281E-12	1.000E-02	4.399E-14
Am-242m	9.727E+00	2.610E-01	4.523E-13	1.000E-02	4.399E-14

The total facility estimated emissions will be the sum of the individual Tank emissions plus the non-Level II emissions from the Appendix D calculation. The sum of the tanks emissions are presented below in Table 22.

Table 22: Total Level II Radionuclide Releases (Ci/yr)

Radionuclide	Alpha Sorption Tank	Filter Feed Tank	Decontaminated Salt Solution	Salt Solution Feed	DWPF Salt Solution Feed	Total
Cs-134	5.93E-14	5.55E-14	0.00E+00	0.00E+00	4.21E-11	4.22E-11
Cs-135	1.01E-16	9.42E-17	0.00E+00	0.00E+00	7.15E-14	7.17E-14
Cs-137	3.90E-08	3.84E-08	5.86E-13	5.56E-07	2.77E-05	2.83E-05
Sr-90	5.45E-07	3.57E-05	5.53E-10	5.53E-10	5.31E-16	3.63E-05
Pu-238	1.63E-08	1.06E-06	1.63E-11	1.63E-11	1.19E-12	1.08E-06
Pu-239	4.74E-10	3.10E-08	4.89E-13	4.89E-13	1.19E-12	3.15E-08
Pu-240	1.10E-10	7.23E-09	1.09E-13	1.09E-13	1.19E-12	7.34E-09
Pu-241	3.51E-09	2.30E-07	3.14E-12	3.14E-12	1.19E-12	2.34E-07
Pu-242	5.98E-13	3.91E-11	6.22E-16	6.22E-16	1.19E-12	4.08E-11
Am-241	1.85E-10	1.21E-08	1.93E-13	1.93E-13	4.40E-14	1.23E-08
Am-242m	2.46E-13	1.61E-11	2.59E-16	2.59E-16	4.40E-14	1.64E-11

The total Facility emissions are summarized in Table 23.

Table 23: Total Estimated Facility Emission

Isotope	Feed (Ci/L)	Ci/Yr Processed	Physical State	Control Factor	Estimated Release (Ci/yr)	Dose Factor (mrem/yr)	Estimated Dose with Level II (mrem/yr)
C-14	1.79E-09	6.78E-04	1.00E-03	1.00E-02	6.78E-09	1.01E-04	6.82E-13
Ni-59	1.03E-06	3.90E-01	1.00E-03	1.00E-02	3.90E-06	5.94E-05	2.32E-10
Ni-63	1.59E-09	6.02E-04	1.00E-03	1.00E-02	6.02E-09	4.55E-05	2.74E-13
Co-60	1.63E-04	6.17E+01	1.00E-03	1.00E-02	6.17E-04	5.84E-02	3.60E-05
Se-79	6.05E-07	2.29E-01	1.00E-03	1.00E-02	2.29E-06	0.00E+00	0.00E+00
Tc-99	1.03E-05	3.90E+00	1.00E-03	1.00E-02	3.90E-05	1.71E-03	6.67E-08
Ru-106	3.80E-06	1.44E+00	1.00E-03	1.00E-02	1.44E-05	2.42E-02	3.48E-07
Rh-106	3.80E-06	1.44E+00	1.00E-03	1.00E-02	1.44E-05	0.00E+00	0.00E+00
Sb-125	9.73E-05	3.68E+01	1.00E-03	1.00E-02	3.68E-04	6.32E-03	2.33E-06
Sn-126	8.09E-07	3.06E-01	1.00E-03	1.00E-02	3.06E-06	2.89E-01	8.86E-07
I-129	9.47E-11	3.58E-05	1.00E-03	1.00E-02	3.58E-10	7.14E-02	2.56E-11
Cs-134					4.22E-11	2.02E-02	8.53E-13
Cs-135					7.17E-14	4.73E-04	3.39E-17
Cs-137					2.83E-05	6.38E-02	1.81E-06
Sr-90					3.63E-05	1.65E-02	5.97E-07
Ce-144	1.96E-06	7.42E-01	1.00E-03	1.00E-02	7.42E-06	5.52E-03	4.09E-08
Pr-144	1.96E-06	7.42E-01	1.00E-03	1.00E-02	7.42E-06	0.00E+00	0.00E+00
Pm-147	2.05E-03	7.76E+02	1.00E-03	1.00E-02	7.76E-03	2.12E-04	1.64E-06
Eu-154	4.00E-04	1.51E+02	1.00E-03	1.00E-02	1.51E-03	4.65E-02	7.05E-05
Th-232	1.71E-08	6.47E-03	1.00E-03	1.00E-02	6.47E-08	1.70E+00	1.10E-07
U-232	2.57E-08	9.73E-03	1.00E-03	1.00E-02	9.73E-08	3.28E+00	3.19E-07
U-233	2.63E-07	9.95E-02	1.00E-03	1.00E-02	9.95E-07	6.18E-01	6.15E-07
U-234	4.12E-07	1.56E-01	1.00E-03	1.00E-02	1.56E-06	6.09E-01	9.50E-07
U-235	3.08E-08	1.17E-02	1.00E-03	1.00E-02	1.17E-07	5.85E-01	6.82E-08
U-236	6.27E-08	2.37E-02	1.00E-03	1.00E-02	2.37E-07	5.76E-01	1.37E-07
U-238	2.78E-06	1.05E+00	1.00E-03	1.00E-02	1.05E-05	5.50E+01	5.79E-04
Np-237	2.30E-06	8.71E-01	1.00E-03	1.00E-02	8.71E-06	2.28E+00	1.98E-05
Pu-238					1.08E-06	1.52E+00	1.64E-06
Pu-239					3.15E-08	1.63E+00	5.15E-08
Pu-240					7.34E-09	1.64E+00	1.20E-08
Pu-241					2.34E-07	2.58E-02	6.02E-09
Pu-242					4.08E-11	1.56E+00	6.38E-11
Am-241					1.23E-08	2.52E+00	3.09E-08
Am-242m					1.64E-11	2.41E+00	3.95E-11
Cm-244	4.90E-04	1.85E+02	1.00E-03	1.00E-02	1.85E-03	1.33E+00	2.46E-03
Cm-245	3.66E-08	1.39E-02	1.00E-03	1.00E-02	1.39E-07	2.60E+00	3.60E-07
						Total =	3.18E-03

The Total Estimated Facility emissions are found to be 3.18E-03 mrem/yr.

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Attachement A

Vapor Pressures by the Clausius-Clapeyron Equation

Vapor Pressures for many compounds are not readily available in the literature. The Clausius-Clapeyron equation can be used to estimate vapor pressures for either liquid-vapor or solid-vapor phase changes. The Clausius-Clapeyron equation is presented below as Equation A-1.

$$\frac{d(\ln P)}{dT} = \frac{\Delta H_v}{RT^2} \qquad \text{A-1}$$

Integrating equation A-1 between the limits of T_1 and T_2 results in

$$\ln\frac{P_2}{P_1} = \frac{\Delta H_v}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right). \qquad \text{A-2}$$

where	P_2	=	Pressure at Temperature 2, *atm*
	P_1	=	Pressure at Temperature 1, *atm*
	ÄH$_v$	=	Enthalpy of Vaporization, *cal/mole*
	R	=	Gas Constant, 1.987 $cal\ K^{-1}\ mole^{-1}$
	T_1	=	Initial Temperature, *K*
	T_2	=	Second Temperature, *K*

A typical phase diagram is given as Figure A-1

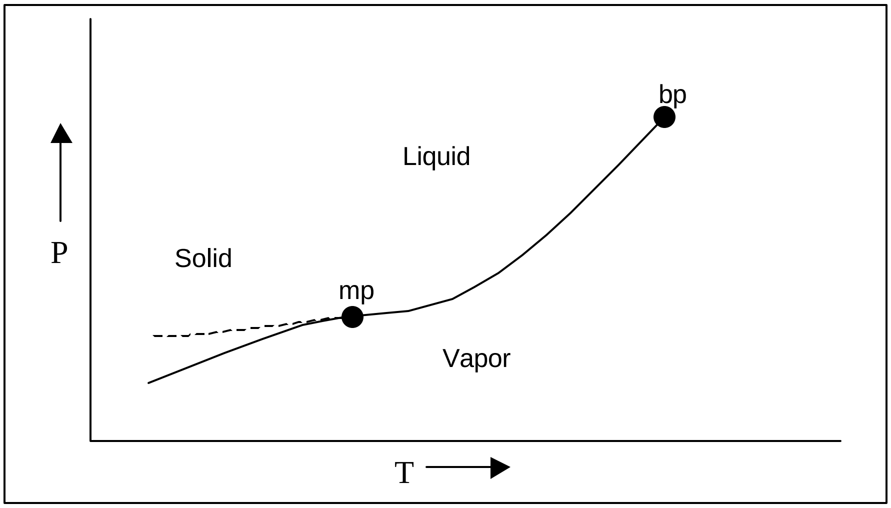

Figure A-1: Typical Phase Diagram

At the boiling point the vapor pressure is by definition 1 atmosphere. An observation made as early as 1884 is that the enthalpies of vaporization increase almost linearly with the boiling temperature. This consistency has resulted in Trouton's rule, which states

$$\frac{\Delta H_v}{T_{bp}} \cong 21 \,{}^{cal}\!/_{K \cdot mole}$$

Using these two facts Equation A-2 can be used to estimate vapor pressures for any compound given it's boiling point. For solids A-2 generates the dashed line in Figure A-1 which leads to a conservative vapor pressure, as the pressure is found be at a higher value than the true value. This approach has been used for many of the compounds found in the example facility.

Another conservative estimate has been incorporated into the vapor pressure calculations for compounds that decompose instead of boiling. The assumption is made that the vapor pressure at the temperature of decomposition is 1 atmosphere when in reality it would be less. The affect is to raise the phase diagram as shown in Figure A-2 by the dashed upper line.

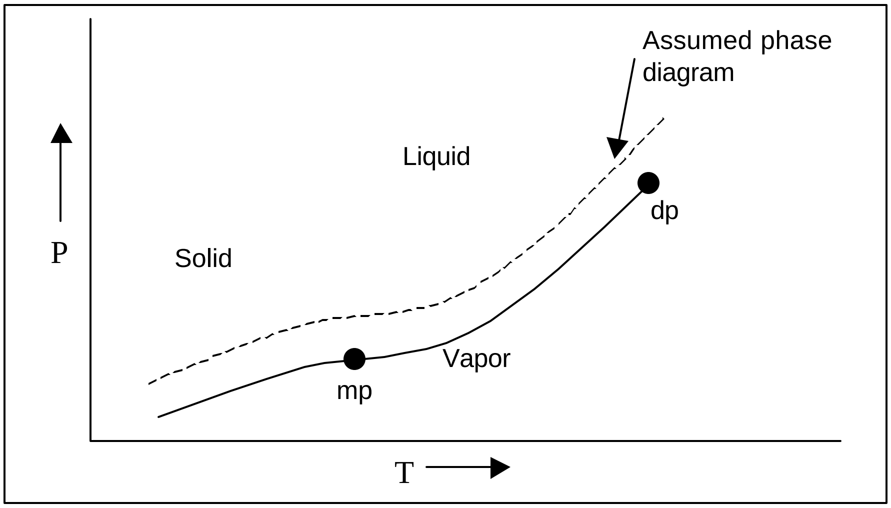

Figure A-2: Phase Diagram with Decomposition Assumption

Boiling Points, Melting Points and Temperature of decomposition for the compounds used in the example calculation are presented below in Table A-1.

Table A-1: Physical Data

Compound	**Melting Point (°C)**	**Boiling Point (C)**
CsOH	272	990
$CsNO_3$	414	849 (d)
$Sr(OH)_2$	535	744 (-H_2O)
$Sr(NO_3)_2$	570	1100
$NaNO_3$	308	500
$NaNO_2$	271	320 (d)

Where (d) indicated the compound decomposes at that temperature.

As an example, determine the vapor pressure of CsOH at 100 C with Equation A-2. First using Trouton's rule the Enthalpy of Vaporization is found as

$$\frac{\Delta H_v}{T_{bp}} \cong 21 \, cal/K \cdot mole$$

$$\Delta H_v \cong \left(21 \, cal/K \cdot mole\right)\left(990 + 273.15K\right)$$

$$\Delta H_v \cong 2.653E + 04 \, cal/mole$$

Now substituting into Equation A-2

$$\ln \frac{P_2}{P_1} = \frac{\Delta H_v}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

$$\ln \frac{P_2}{1atm} = \frac{2.653E + 04 \, cal/mole}{1.987 \, cal/K \cdot mole}\left(\frac{1}{(990 + 273.15\,K)} - \frac{1}{(100 + 273.15\,K)}\right)$$

$$\ln P_2 = -25.211$$

$$P_2 = 1.129E - 11 atm$$

Using this technique vapor pressures for each compound can be determined at 100 C. The results are presented below as Table A-2.

Table A-2: Vapor Pressures at 100 C

Compound	Vapor Pressure (atm)
CsOH	1.129E-11
$CsNO_3$	6.123E-10
$Sr(OH)_2$	1.198E-08
$Sr(NO_3)_2$	5.006E-13
$NaNO_3$	1.202E-05
$NaNO_2$	1.967E-03

Attachment B
EPA Appendix D Screen Evaluation

The example facility is estimated to handle approximately 100,000 gallons of feed for purposes of this evaluation. Based on these estimated emissions Cesium, Strontium, Plutonium and Americium should be further refined with the Level II evaluation technique.

Isotope	Feed (Ci/L)	Ci/Yr Processed	Physical State	Control Factor	Estimated Release (Ci/yr)	Dose Factor (mrem/yr)	Estimated Dose (mrem/yr)	Estimated Dose without Level II (mrem/yr)
C-14	1.79E-09	6.78E-04	1.00E-03	1.00E-02	6.78E-09	1.01E-04	6.82E-13	6.82E-13
Ni-59	1.03E-06	3.90E-01	1.00E-03	1.00E-02	3.90E-06	5.94E-05	2.32E-10	2.32E-10
Ni-63	1.59E-09	6.02E-04	1.00E-03	1.00E-02	6.02E-09	4.55E-05	2.74E-13	2.74E-13
Co-60	1.63E-04	6.17E+01	1.00E-03	1.00E-02	6.17E-04	5.84E-02	3.60E-05	3.60E-05
Se-79	6.05E-07	2.29E-01	1.00E-03	1.00E-02	2.29E-06	0.00E+00	0.00E+00	0.00E+00
Tc-99	1.03E-05	3.90E+00	1.00E-03	1.00E-02	3.90E-05	1.71E-03	6.67E-08	6.67E-08
Ru-106	3.80E-06	1.44E+00	1.00E-03	1.00E-02	1.44E-05	2.42E-02	3.48E-07	3.48E-07
Rh-106	3.80E-06	1.44E+00	1.00E-03	1.00E-02	1.44E-05	0.00E+00	0.00E+00	0.00E+00
Sb-125	9.73E-05	3.68E+01	1.00E-03	1.00E-02	3.68E-04	6.32E-03	2.33E-06	2.33E-06
Sn-126	8.09E-07	3.06E-01	1.00E-03	1.00E-02	3.06E-06	2.89E-01	8.86E-07	8.86E-07
I-129	9.47E-11	3.58E-05	1.00E-03	1.00E-02	3.58E-10	7.14E-02	2.56E-11	2.56E-11
Cs-134	4.26E-06	1.61E+00	1.00E-03	1.00E-02	1.61E-05	2.02E-02	3.26E-07	-
Cs-135	7.23E-09	2.74E-03	1.00E-03	1.00E-02	2.74E-08	4.73E-04	1.29E-11	-
Cs-137	2.80E+00	1.06E+06	1.00E-03	1.00E-02	1.06E+01	6.38E-02	6.77E-01	-
Sr-90	3.69E-02	1.40E+04	1.00E-03	1.00E-02	1.40E-01	1.65E-02	2.30E-03	-
Ce-144	1.96E-06	7.42E-01	1.00E-03	1.00E-02	7.42E-06	5.52E-03	4.09E-08	4.09E-08
Pr-144	1.96E-06	7.42E-01	1.00E-03	1.00E-02	7.42E-06	0.00E+00	0.00E+00	0.00E+00
Pm-147	2.05E-03	7.76E+02	1.00E-03	1.00E-02	7.76E-03	2.12E-04	1.64E-06	1.64E-06
Eu-154	4.00E-04	1.51E+02	1.00E-03	1.00E-02	1.51E-03	4.65E-02	7.05E-05	7.05E-05
Th-232	1.71E-08	6.47E-03	1.00E-03	1.00E-02	6.47E-08	1.70E+00	1.10E-07	1.10E-07
U-232	2.57E-08	9.73E-03	1.00E-03	1.00E-02	9.73E-08	3.28E+00	3.19E-07	3.19E-07
U-233	2.63E-07	9.95E-02	1.00E-03	1.00E-02	9.95E-07	6.18E-01	6.15E-07	6.15E-07
U-234	4.12E-07	1.56E-01	1.00E-03	1.00E-02	1.56E-06	6.09E-01	9.50E-07	9.50E-07
U-235	3.08E-08	1.17E-02	1.00E-03	1.00E-02	1.17E-07	5.85E-01	6.82E-08	6.82E-08
U-236	6.27E-08	2.37E-02	1.00E-03	1.00E-02	2.37E-07	5.76E-01	1.37E-07	1.37E-07
U-238	2.78E-06	1.05E+00	1.00E-03	1.00E-02	1.05E-05	5.50E+01	5.79E-04	5.79E-04
Np-237	2.30E-06	8.71E-01	1.00E-03	1.00E-02	8.71E-06	2.28E+00	1.98E-05	1.98E-05
Pu-238	1.18E-02	4.47E+03	1.00E-03	1.00E-02	4.47E-02	1.52E+00	6.79E-02	-
Pu-239	3.43E-04	1.30E+02	1.00E-03	1.00E-02	1.30E-03	1.63E+00	2.12E-03	-
Pu-240	7.99E-05	3.02E+01	1.00E-03	1.00E-02	3.02E-04	1.64E+00	4.96E-04	-
Pu-241	2.54E-03	9.61E+02	1.00E-03	1.00E-02	9.61E-03	2.58E-02	2.48E-04	-
Pu-242	4.33E-07	1.64E-01	1.00E-03	1.00E-02	1.64E-06	1.56E+00	2.56E-06	-
Am-241	3.61E-03	1.37E+03	1.00E-03	1.00E-02	1.37E-02	2.52E+00	3.44E-02	-
Am-242m	4.81E-06	1.82E+00	1.00E-03	1.00E-02	1.82E-05	2.41E+00	4.39E-05	-
Cm-244	4.90E-04	1.85E+02	1.00E-03	1.00E-02	1.85E-03	1.33E+00	2.46E-03	2.46E-03
Cm-245	3.66E-08	1.39E-02	1.00E-03	1.00E-02	1.39E-07	2.60E+00	3.60E-07	3.60E-07