

SRNS-TR-2011-00227
Revision 0

**Radionuclide Source Term
for
Direct Metal Oxide (DMO)
at the
Mixed Oxide Fuel Fabrication Facility (MFFF)**

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Nuclear Information
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Radionuclide Source Term for DMO Processes at the MFFF

PURPOSE

This calculation estimates the design emissions of radionuclides from the proposed processing of Plutonium Metal at the Mixed Oxide Fuel Fabrication Facility (MFFF). The calculation includes emissions due to converting plutonium metal from the surplus plutonium in nuclear weapon pits and other surplus Plutonium metal.

BACKGROUND

The Direct Metal Oxide (DMO) processes proposed for the MFFF will process a maximum of 3.5 metric tons/yr. For this calculation the DMO process evaluated will be identical to the DMO equipment proposed for the Pit Disassembly and Conversion project. The process includes oxidation of metal supplied to MFFF from the Surplus Plutonium Program, followed by calcination at 950 degrees centigrade.

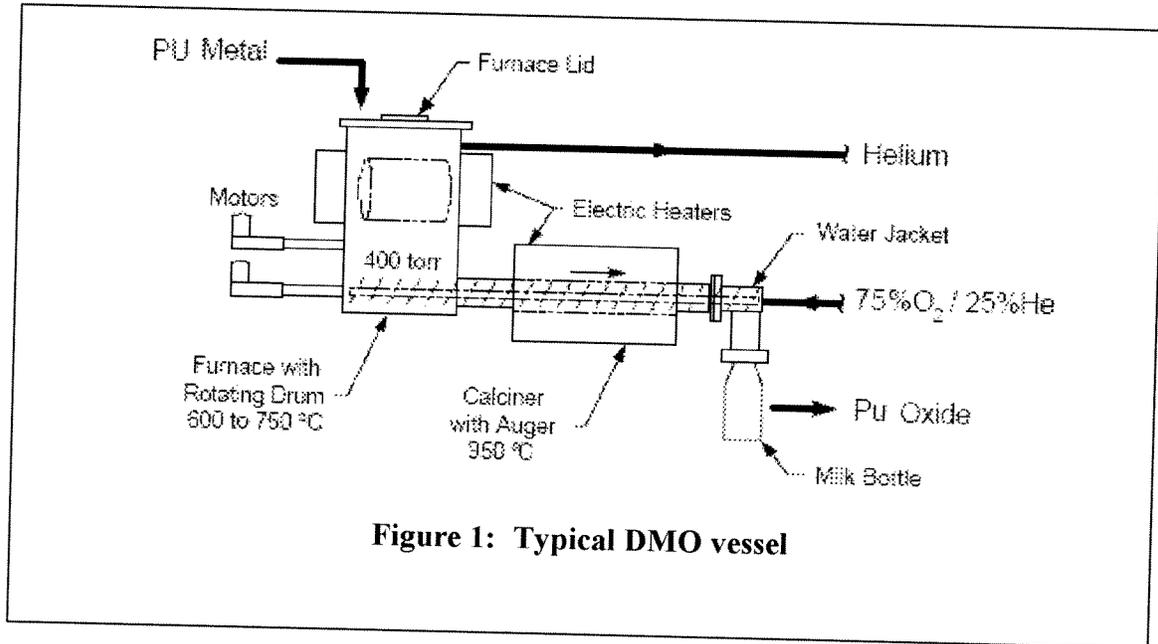
The estimated emissions from this process are evaluated using the South Carolina Department of Health and Environmental Control and the U.S Environmental Protection Agency (EPA) approved alternative calculation for DMO emissions for the Pit Disassembly and Conversion Facility [WSRC 2005]. Readers should be aware that these regulator approved calculation methods are specific to the PDCF. Use of these methods for permitting purposes (either to obtain a permit or to invoke the permit exemption in 40 CFR 61.96) in any other facility would require approval by SCDHEC prior to use for that purpose.

This calculation has been performed to estimate emissions for both the Radionuclide National Emission Standards for Hazardous Air Pollutants (NESHAP) and the National Environmental Policy Act (NEPA). The evaluation of control devices is handled differently for these two programs. The MFFF building ventilation system will include high-efficiency particulate air (HEPA) filters. Under the NESHAP program (40CFR61 Subpart H) a HEPA filter has a removal efficiency of 0.01, whereas the NEPA process allows the use of a more realistic factor. For this calculation a HEPA removal efficiency of $3.0E-4$ has been used for NEPA purposes.

METHODOLOGY DESCRIPTION

DMO Particulate Emissions

In the DMO module, plutonium metal will be reacted with oxygen at controlled temperatures and pressures in a reaction vessel to produce plutonium dioxide. The DMO process is conducted in closed vessels under vacuum at elevated temperature.



The basic chemistry of the DMO process is



During the oxidation steps in the DMO process, the reactor vessel remains open to a vacuum source therefore some resuspension is possible. The oxygen flows through the calciner and into the reaction vessel where oxygen is consumed in the reaction given by equation 1. Helium then exits the reaction vessel near the top of the vessel (Figure 1). For this calculation, the conservative approach is taken and all of the particles smaller than those that can theoretically resuspend are assumed to do so.

In a simple model for resuspension, those particles that

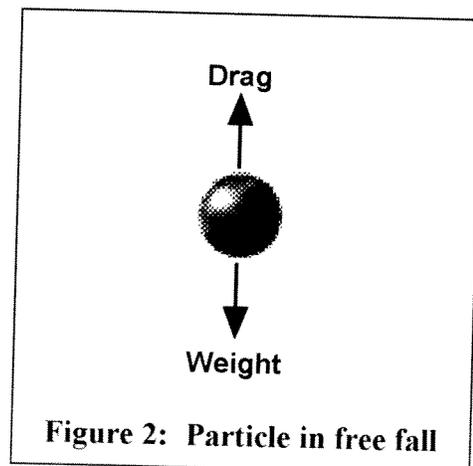


exhibit a drag that is greater than the force due to their mass will resuspend. The drag can be calculated as

$$Drag = \frac{1}{2} \rho_f v^2 A_f C_d \quad (2)$$

and the force due to weight, for a spherical shaped particle is

$$F_{obj} = ma = \frac{4}{3} \pi r^3 \rho_p g \quad (3)$$

where: ρ_f = Density of the fluid, kg/m^3
 v = Velocity difference between particle and fluid, m/sec
 A_f = Frontal area of particle, m^2
 C_d = Drag Coefficient, dimensionless
 r = Radius of particle, m
 ρ_p = Density of the particle, kg/m^3
 g = Acceleration of gravity, 9.8 m/s^2

The Drag Coefficient can be found with the following equation.

$$C_d = 0.4 + \frac{24}{\text{Re}} + \frac{6}{1 + \text{Re}}$$

For Reynolds numbers in the Stokes region ($\text{Re} < 1$), the equation for C_d reduces to

$$C_d = \frac{24}{\text{Re}} \quad (4)$$

where: $\text{Re} = \frac{vl}{\nu}$

and l = Characteristic length, which for a sphere is the diameter, m
 ν = Kinematic viscosity, m^2/s

The gas velocity in the typical DMO process is less than 0.1 m/sec. Assuming that oxygen is the gas used in the process and the particle size of interest will not exceed 10 μm the maximum Reynolds number will be found as follows

$$\text{Re} = \frac{\nu l}{\nu}$$

$$\text{Re} = \frac{(0.1 \text{ m/s})(10\text{E} - 6)}{1.59\text{E} - 05 \text{ m}^2/\text{s}}$$

$$\text{Re} = 0.06$$

Since this Reynolds number is less than 0.1 the simplifying assumptions for C_d are valid. Even so, a check of the Reynolds number will be required for each calculation to verify that it is below 0.1.

Making the conservative assumption that any particle with a drag that is greater than the force due to the object will resuspend in the gas flow, then any particle where

$$F_{obj} < Drag \tag{5}$$

will be carried away by the gas flow. Substituting into equation (5) and solving for the radius of the particle results in

$$\frac{4}{3}\pi r^3 \rho_p g < \frac{1}{2}\rho_f \nu^2 A_f C_d$$

$$r^3 < \frac{\frac{1}{2}\rho_f \nu^2 A_f C_d}{\frac{4}{3}\pi \rho_p g}$$

$$r^3 < \frac{3\rho_f \nu^2 A_f C_d}{8\pi \rho_p g}$$

Finally substituting for C_d , A_f , and r in the above equation, the maximum particle diameter (d_a) that meets our initial assumption is found as

$$d_a < \sqrt{\frac{18\rho_f v v}{\rho_p g}} \quad (6)$$

For particles that are not spherical the above derivation will still provide a good estimate of the DMO emissions. The diameter calculated in equation (6) is actually the aerodynamic diameter. The aerodynamic diameter is the diameter of a spherical particle having a density of 1 gm/cm³ (1000 kg/m³) that has the same inertial properties (i.e. terminal settling velocity) in the gas as the particle of interest. It is necessary to use a particle size definition that directly relates to how the particle behaves in a fluid such as air. The term "aerodynamic diameter" has been developed by aerosol physicists in order to provide a simple means of categorizing the sizes of particles having different shapes and densities with a single dimension. The particle shape has an effect on the drag coefficient (C_d). Perry [1973] depicts value of C_d graphically for several shapes including a sphere, which has the largest drag coefficient. A larger C_d in equation (4) will result in the determination of a larger particle diameter, which is conservative.

Using particle size data for the material of concern, the mass fraction below the maximum aerodynamic diameter becomes the quantity of material available for release. A particulate control factor (F_f) is included to account for a process filter in the vacuum system used to contain the oxide product in the pressure vessel.

The mass of material released in the process can then be estimated with the following equation.

$$W_{Pu} = (MF)(Q_{Pu})(F_f) \quad (7)$$

where: W_{Pu} = Estimated release due to Pu-particle resuspension, g/yr
 MF = Mass fraction, dimensionless
 Q_{Pu} = Quantity of Plutonium handled, grams/yr
 F_f = Particulate control efficiency factor, dimensionless

For a mixture of isotopes, the mass of material releases (W_{Pu}) must be corrected based on the weight percent of the material. Then by applying the specific activity for the isotope of concern the estimated effluent release in curies can be found.

$$E_{Pu} = W_{Pu} M_{pi} S_i \quad (8)$$

where E_{Pu} = Estimated effluent release, Ci/yr
 M_{pi} = Weight percent of isotope i , dimensionless
 S_i = Specific Activity for isotope i , Ci/gram

Calcining Emissions

The PuO₂ is calcined to 950°C, a temperature that is well below the melting point of PuO₂ (2400°C). Calcining emissions can be best represented by Vapor Pressure calculations for the radionuclides of concern¹.

An estimate of the partial pressure of component *i* above the oxide can be found using Raoult's Law.

$$p_i = X_i P_i^\circ \quad (9)$$

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

When values for the component mix are given in Weight Percent, the mole fraction can be found by assuming that there are 100 grams of total oxide. For this case the number of grams of each component is equal to the weight percent. 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.

$$Z_i = \frac{\text{Weight Percent}}{M_{mi}} \quad (10)$$
$$X_i = \frac{Z_i}{\sum Z_i}$$

where: Z_i = Moles of component *i*, g-mole
 M_{mi} = Molecular Weight of metal isotope *i*, g/g-mole

Then by Dalton's Law, the total vapor pressure of the oxide is simply the sum of the individual partial pressures.

$$P_v = \sum p_i \quad (11)$$

where: P_v = Total vapor pressure, atm

¹ Emissions due to entrainment have been accounted for in the DMO Emissions section.

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

$$y_i = \frac{p_i}{P_v} \quad (12)$$

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

The molecular weight of the vapor can now be found

$$M_v = \sum y_i M_i \quad (13)$$

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

The density of the vapor above the oxide powder at the elevated 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.

$$\rho_g = \frac{M_v P_v}{R_u T} \quad (14)$$

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

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

$$W_i = \rho_g F_g \tau X_{vi} (1440 \text{ min/ day}) \quad (15)$$

where: W_i = Mass emissions due to calcination, g/yr
 F_g = Furnace exhaust rate, cc/min
 τ = Annual operational time, day/yr
 X_{vi} = Mass fraction of component i in vapor, dimensionless

The vapor mass fraction can be found as

$$X_{vi} = \frac{y_i M_i}{M_v} \quad (16)$$

The curies released can now be found from the specific activity and the oxide mass emissions for the radionuclide of concern. Since the gas flow in the process is small compared to the effluent exhaust rate, i.e. a few cfm versus several thousand cfm, it is assumed that the material will cool sufficiently for the effluent control devices to remove particulate material. The estimated emissions due to calcining can now be found as

$$E_{Ci} = W_i S_i \quad (17)$$

where: E_{Ci} = Emission of radionuclide i from oxide processed in a year, Ci/yr
 S_i = Specific activity of isotope i , Ci/g

Tritium Emissions

A potential for tritium contamination of the Pu metal exists. Any tritium contamination would be expected to evolve during the DMO/Calcining process. An estimate of tritium emissions can be found using the contamination level as

$$E_H = (C_h)(Q) \quad (18)$$

where E_H = Estimated tritium release, Ci/yr
 C_h = Tritium contamination level, Ci Tritium/kg Pu
 Q = Quantity of Pu processed, kg/yr

Total Process Emissions

The sum of each mechanism of emission discussed above will yield in the facility estimated emissions. Therefore the facility emissions is found as

$$E_t = E_H + E_{Pu} + E_{Ci} \quad (19)$$

where E_t = Total process emissions, Ci/yr
 E_H = Tritium emissions (Eq. 18), Ci/yr
 E_{Pu} = DMO Pu emissions (Eq. 8), Ci/yr
 E_{Ci} = Calcining emissions (Eq. 17), Ci/yr

CALCULATION

DMO Pu Process

- Given:
- 1) Oxygen density² = 0.19057 kg/m³ at 750 °C & 400 torr
 - 2) Oxygen Kinematic Viscosity³ = 2.53E-04 m²/s at 750 °C & 400 torr
 - 3) Helium density = 0.02394 kg/m³ at 750 °C & 400 torr
 - 4) Helium Kinematic Viscosity = 1.84E-03 m²/s at 750 °C & 400 torr
 - 5) 3.5 MT Pu/yr processed

- Assumptions:
1. Pu Oxide will be Weapons Grade.
 2. All oxides will be approximately 35 years old at the time of processing.
 3. Process Pressure = 400 torr
 4. Process Temperature = 750 °C
 5. Process unit diameter = 35.56 cm
 6. Number process units = 6
 7. Process Gas flow rate = 2.5 liters/min.
 8. Mass fraction of PuO₂ < 5 microns = 0.01 (Wayne, 2009)
 9. PuO₂ density = 11.5 g/cm³ or 11500 kg/m³ (Wayne, 2009)
 10. The particulate control on the reaction vessel is a simple filter with an efficiency of 0.001 or 99.9%.

The first step is to determine the particle size of concern. Although the process gas is a mixture of 25% Helium and 75% oxygen, the largest particle size assuming 100% helium or 100% oxygen as the process gas will provide a conservative value.

² Density of a gas can be found with the ideal gas law

³ The dynamic viscosity of a gas can be found at elevated temperature with Sutherland's Formula. The kinematic viscosity is equal to the dynamic viscosity divided by the density.

The velocity of the process gas flow can be estimated by dividing the flow rate by the area of the process unit or

$$v = \frac{2500 \text{ cc/min}}{\pi(35.56 \text{ cm}/2)^2 (60 \text{ sec/min})} = 0.0420 \text{ cm/sec}$$

$$v = 0.00042 \text{ m/sec}$$

Then for 100% oxygen, the maximum particle size for resuspension is found with Equation (6)

$$d < \sqrt{\frac{18\rho_f v v}{\rho_p g}}$$

$$d < \sqrt{\frac{(18)(0.19057 \text{ kg/m}^3)(0.00042 \text{ m/s})(2.53 \text{ E} - 04 \text{ m}^2/\text{s})}{(11500 \text{ kg/m}^3)(9.8 \text{ m/s}^2)}}$$

$$d < 1.8 \text{ E} - 06 \text{ m} \text{ or } 1.8 \mu\text{m}$$

And for 100% helium, the maximum particle size for resuspension is found with Equation (6)

$$d < \sqrt{\frac{18\rho_f v v}{\rho_p g}}$$

$$d < \sqrt{\frac{(18)(0.02394 \text{ kg/m}^3)(0.00042 \text{ m/s})(1.84 \text{ E} - 03 \text{ m}^2/\text{s})}{(11500 \text{ kg/m}^3)(9.8 \text{ m/s}^2)}}$$

$$d < 1.7 \text{ E} - 06 \text{ m} \text{ or } 1.7 \mu\text{m}$$

In either case the particle size of concern is those less than 2 μm .

A check of the Reynolds number to ensure that it is low ($\text{Re} < 1$) confirms the simplifying assumptions and confirms that equation (4) is valid for this case.

For Oxygen:

$$Re = \frac{\nu l}{\nu}$$

$$Re = \frac{(0.00042 \text{ m/sec})(1.8E-06 \text{ m})}{(2.53E-04 \text{ m}^2/\text{sec})}$$

$$Re = 3.0E-06$$

And for helium:

$$Re = \frac{\nu l}{\nu}$$

$$Re = \frac{(0.00042 \text{ m/sec})(1.7E-06 \text{ m})}{(1.84E-043 \text{ m}^2/\text{sec})}$$

$$Re = 3.9E-07$$

Using particle size data for the material of concern the estimated release from the process can be found with equation (11).

$$W_{Pu} = (MF)(Q_{Pu})(F_f)$$

$$W_{Pu} = (0.01)(3.97E+06 \text{ g PuO}_2/\text{yr})(0.001)$$

$$W_{Pu} = 39.69 \text{ g PuO}_2/\text{yr}$$

The estimated effluent releases can then be calculated with equation (8), assuming a typical Weapons-grade mix given by NNSA [NNSA 2008]. The mixed has been adjusted to account for the Am-241 maximum content of 7,000 $\mu\text{g/gPu}$ (0.07%). The results of these calculations are presented in Table 1.

Table 1: Emission from DMO

Radionuclide	Oxide Weight percent	Weight as oxide (grams/yr)	S_i (Ci/g)	(Eq. 8) E_{Pu} (Ci/yr)
²³⁸ Pu	0.01	0.004	1.510E+01	5.993E-02
²³⁹ Pu	93.8	37.23	5.409E-02	2.014E+00
²⁴⁰ Pu	6	2.38	2.001E-01	4.765E-01
²⁴¹ Pu	0.15	0.06	9.098E+01	5.416E+00
²⁴² Pu	0.025	0.01	3.472E-03	3.445E-05
²⁴¹ Am	0.07	0.03	3.026E+00	8.405E-02

Plutonium Calcination Process

- Given: 1) PuO₂ vapor pressure = 1.12E-09 atm at 1450 °C (Wick, 1980, p.341)
 2) AmO₂ vapor pressure = 4.145E-11 atm at 1327 °C (Schultz, 1976, p.153)

- Assumptions: 1. Pu Oxide will be Weapons Grade.
 2. All oxides will be approximately 35 years old at the time of processing.
 3. Per unit flow rate = 2500 cc/min
 4. Number Calcining units = 6
 5. Calcining occurs 24 hours/day for 365 days/yr
 6. Calcining Temperature = 950 °C

This example will determine the emissions of a typical Plutonium Calcining operation.

Assuming that there are 100 grams of material (the actual number makes no difference, 100 is simply convenient) the Mole Fraction of the components of each oxide is found with Equation (10).

$$Z_i = \frac{\text{Weight Percent}}{M_{mi}} \tag{10}$$

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

The results assuming the isotopic mix adjusted for americium provided in NNSA 2008 are tabulated in Table 2 below.

Table 2: Plutonium Mole Fraction

Radionuclide (as oxide)	Grams	Molecular Weight (g/g-mole)	Moles (as oxide)	(Eq. 10) X_i
²³⁸ Pu	0.01	270.00	3.704E-05	1.003E-04
²³⁹ Pu	93.8	271.00	3.461E-01	9.377E-01
²⁴⁰ Pu	6	272.00	2.206E-02	5.976E-02
²⁴¹ Pu	0.15	273.00	5.495E-04	1.489E-03
²⁴² Pu	0.025	274.00	9.124E-05	2.472E-04
²⁴¹ Am	0.07	273.00	2.564E-04	6.947E-04

An estimate of the partial pressure of each component in the vapor is found with Equation (9). The Total Vapor Pressure is then found as the sum of the individual partial pressures (Equation 11). With these values and Equation (12) the mole fraction of each vapor component is determined. Then using Equation (13) the molecular weight of the vapor is found. And finally, the vapor mass fraction of each oxide component is found with Equation (16). Each equation is reproduced below and results of these calculations are presented in Table 3.

$$p_i = X_i P_i^\circ \quad (9)$$

$$y_i = \frac{p_i}{P_v} \quad (12)$$

$$X_{vi} = \frac{y_i M_i}{M_v} \quad (16)$$

Table 3: Vapor Mole Fraction Calculations (9, 12 & 16)

Radionuclide (as oxide)	P_i° (atm)	(Eq. 9) P_i (atm)	(Eq. 12) y_i	$y_i \times M_i$ (g/g-mole)	(Eq. 16) X_{vi}
²³⁸ Pu	1.120E-09	1.124E-13	1.004E-04	2.711E-02	1.000E-04
²³⁹ Pu	1.120E-09	1.050E-09	9.383E-01	2.543E+02	9.381E-01
²⁴⁰ Pu	1.120E-09	6.693E-11	5.980E-02	1.627E+01	6.001E-02
²⁴¹ Pu	1.120E-09	1.667E-12	1.490E-03	4.066E-01	1.500E-03
²⁴² Pu	1.120E-09	2.768E-13	2.474E-04	6.777E-02	2.500E-04
²⁴¹ Am	4.150E-11	2.883E-14	2.576E-05	7.032E-03	2.594E-05

where

$$P_v = \sum p_i = 1.12E - 09 atm$$

and

$$M_v = \sum y_i M_i = 271.1 g / g - mole$$

The density of the vapor above the oxide powder at the elevated temperature can now be found with Equation (14).

$$\rho_v = \frac{M_v P_v}{R_u T} \quad (14)$$

Then for Pu oxide

$$\rho_{Pu} = \frac{(271.1 g / g - mole)(1.12E - 09 atm)}{\left(82.05 \frac{cc \cdot atm}{g - mole \cdot ^\circ K}\right)(950 + 273.15^\circ K)} = 3.02E - 12 g / cc$$

The estimated mass emissions from a single calcining unit are found using Equation (15). Since it is assumed that there will be 6 calcining units the calcining furnace volume must be multiplied by 6.

$$F_g = (2500 cc / min)(6) = 15,000 cc / min$$

The estimated facility emissions are then found with Equations (17).

$$W_i = \rho_g F_g \tau X_{vi} (1440 \text{ min} / \text{day}) \quad (15)$$

$$E_{Ci} = W_i S_i \quad (17)$$

The results are presented below in Table 4.

Table 4: Calcining Emissions

Radionuclide (as oxide)	S_i (Ci/g)	W_i As metal (g/yr)	(Eq. 17) E_{ci} (Ci/yr)
²³⁸ Pu	1.510E+01	2.384E-06	3.599E-05
²³⁹ Pu	5.409E-02	2.236E-02	1.209E-03
²⁴⁰ Pu	2.001E-01	1.430E-03	2.862E-04
²⁴¹ Pu	9.098E+01	3.575E-05	3.253E-03
²⁴² Pu	3.472E-03	5.959E-06	2.069E-08
²⁴¹ Am	3.026E+00	6.183E-07	1.871E-06

Tritium Emissions

- Given: 1) Tritium Contamination Level = 0.01 Ci T³/kg Pu (NNSA 2008)
2) Process Rate = 3.5 MT Pu/yr = 3500 kg Pu/yr

Tritium emissions can then be estimated with equation (18) as

$$E_H = (C_h)(Q)$$

$$E_H = (0.01 \text{ Ci T}^3 / \text{kg Pu})(3500 \text{ kg Pu} / \text{yr})$$

$$E_H = 35 \text{ Ci} / \text{yr}$$

Total Process Emissions

The total unabated process emissions are then the sum of all three components of the process. The total unabated emissions can be converted from Ci/yr to mrem/yr using the dose conversion factors found in the Update NESHAP Area Specific Dose-Release factors [SRNS 2009]. These factors are based on the F-Area 61 meter stack height, using the EPA approved CAP-88 dose model. The unabated dose is presented in Table 5.

*Used 36.6 m stack height
for the MAF and not
The standard F-Area 61 m stack*

Table 5: Unabated Emissions

Radionuclide (as oxide)	Tritium (Ci/yr)	DMO (Ci/yr)	Calcining (Ci/yr)	Total (Ci/yr)	Dose Conversion (mrem/Ci)	Total Dose (Ci/yr)
²³⁸ Pu	-	5.99E-02	3.60E-05	6.00E-02	1.55	9.29E-02
²³⁹ Pu	-	2.01E+00	1.21E-03	2.01E+00	1.67	3.36E+00
²⁴⁰ Pu	-	4.76E-01	2.86E-04	4.77E-01	1.67	7.96E-01
²⁴¹ Pu	-	5.42E+00	3.25E-03	5.42E+00	2.65E-02	1.44E-01
²⁴² Pu	-	3.44E-05	2.07E-08	3.45E-05	1.59	5.48E-05
²⁴¹ Am	-	8.41E-02	1.87E-06	8.41E-02	2.54	2.14E-01
³ T	3.500E+01	-	-	3.50E+01	2.01E-06	7.04E-05
Total	-	-	-	-	-	4.61E+00

Abated emissions based on the requirements of 40CFR61 Subpart H are determined by assuming a HEPA control factor of 0.01. These emissions, along with the unabated emissions, are used by SCDHEC to determine the permitting and monitoring requirements. Abated emissions based on Subpart H are simply the unabated emissions (Ci/yr) multiplied by the control factor. Since tritium in gaseous form is not removed by HEPA filters, the control factor was not applied to the tritium unabated source term. The results are presented below as Table 6.

Table 6: Subpart H Abated Emissions

Radionuclide (as oxide)	Tritium (Ci/yr)	DMO (Ci/yr)	Calcining (Ci/yr)	Total (Ci/yr)	Dose Conversion (mrem/Ci)	Total Dose (Ci/yr)
²³⁸ Pu	-	5.99E-04	3.60E-07	6.00E-04	1.55	9.29E-04
²³⁹ Pu	-	2.01E-02	1.21E-05	2.01E-02	1.67	3.36E-02
²⁴⁰ Pu	-	4.76E-03	2.86E-06	4.77E-03	1.67	7.96E-03
²⁴¹ Pu	-	5.42E-02	3.25E-05	5.42E-02	2.65E-02	1.44E-03
²⁴² Pu	-	3.44E-07	2.07E-10	3.45E-07	1.59	5.48E-07
²⁴¹ Am	-	8.41E-04	1.87E-08	8.41E-04	2.54	2.14E-03
³ T	3.50E+01	-	-	3.50E+01	2.01E-06	7.04E-05
Total	-	-	-	-	-	4.62E-02

The abated emissions for NEPA evaluations can use a more realistic HEPA control factor. As a HEPA is rated at 99.97% removal of particulates the removal efficiency is found as $(1-0.9997) = 0.0003$ or $3.0E-04$. Applying this control factor to the particulate emissions for the unabated source term will result in Table 7.

Table 7: NEPA Abated Emissions

Radionuclide (as oxide)	Tritium (Ci/yr)	DMO (Ci/yr)	Calcining (Ci/yr)	Total (Ci/yr)	Dose Conversion (mrem/Ci)	Total Dose (Ci/yr)
²³⁸ Pu	-	1.80E-05	1.08E-08	1.80E-05	1.55	2.79E-05
²³⁹ Pu	-	6.04E-04	3.63E-07	6.04E-04	1.67	1.01E-03
²⁴⁰ Pu	-	1.43E-04	8.59E-08	1.43E-04	1.67	2.39E-04
²⁴¹ Pu	-	1.62E-03	9.76E-07	1.63E-03	2.65E-02	4.31E-05
²⁴² Pu	-	1.03E-08	6.21E-12	1.03E-08	1.59	1.64E-08
²⁴¹ Am	-	2.52E-05	5.61E-10	2.52E-05	2.54	6.41E-05
³ T	3.500E+01	-	-	3.50E+01	2.01E-06	7.04E-05
Total	-	-	-	-	-	1.45E-03

20 years total

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APPENDIX A Specific Activities and Typical Isotope ratios

The specific activities can be calculated from

$$S_i = \frac{0.693 N_o}{T_{1/2} A_w (3.7E10 Bq / Ci) (3.154E07 s / yr)}$$

- where: S_i = Specific activity, Ci/g
 N_o = Avagadro's Number, 6.023E23 atoms/mole
 $T_{1/2}$ = Half-life of isotope, yr
 A_w = Atomic weight of isotope, g

The half life of the isotope can be found in many texts, such as *The Health Physics and Radiological Health Handbook*, edited by Bernard Sheleien, 7 ed, Scinta, Silver Springs, Md

Specific Activities of Oxides

Isotope	Half-life (yr)	Atomic Weight	Specific Activity (Ci/g)
²³⁸ Pu	8.770E+01	270	1.510E+01
²³⁹ Pu	2.440E+04	271	5.409E-02
²⁴⁰ Pu	6.570E+03	272	2.001E-01
²⁴¹ Pu	1.440E+01	273	9.098E+01
²⁴² Pu	3.760E+05	274	3.472E-03
²⁴¹ Am	4.330E+02	273	3.026E+00