12A Calculation of Airborne Radionuclides

12A.1 Calculation of Airborne Radionuclides

This appendix presents a simplified methodology to calculate the airborne concentrations of radionuclides in a compartment. This methodology is conservative in nature and assumes that diffusion and mixing in a compartment is basically instantaneous with respect to those mitigating mechanisms such as radioactive decay and other removal mechanisms. The following calculations need to be performed on an isotope-by-isotope basis to verify that airborne concentrations are within the limits of 10CFR20:

(1) For the compartment, all sources of airborne radionuclides need to be identified such as:

(a) Flow of contaminated air from other areas

(b) Gaseous releases from equipment in the compartment

(c) Evolution of airborne sources from sumps or water leaking from equipment

(2) Second, the primary sinks of airborne radionuclides need to be identified. This will primarily be outflow from the compartment but may also take the form of condensation onto room coolers.

(3) Given the above information the following equation will calculate a conservative concentration.

$$C_i = \frac{1}{V}\sum_j \frac{S_{ij}}{\left(\lambda_i + \sum_k R_{ijk}\right)}$$

Where:

C_i = Concentration of the i^{th} radionuclides in the room

V = Volume of room

S_{ij} = The j^{th} source (rate) of the i^{th} radionuclide to the room. These sources are discussed below.

R_{ijk} = The k^{th} removal constant for the j^{th} source and the i^{th} radionuclide as discussed below.

λ_i = Radionuclide decay constant

Evaluation Parameters

The following parameters require evaluation on a case-by-case basis dictated by the physical parameters and processes germane to the modeling process:

(1) S_{ij} is defined as the source rate for radionuclide i into the compartment. Typically, these sources take the form of:

(a) Inflow of contaminated air from an upstream compartment. Given the concentration of radionuclide i, c_i, in this air and a flow rate of “r”, the source rate then becomes $S_{ij} = rc_i$.

(b) Production of airborne radionuclides from equipment. This typically takes two forms, gaseous leakage and liquid leakage.

(i) For gaseous leakage sources, the source rate is equal to the concentration of radionuclide i, c_i, and the leakage rate, “r”, or $S_{ij} = rc_i$.

(ii) For liquid sources, the source rate is similar but more complex. Given a liquid concentration c_i and a leakage rate, “r”, the total release from the leak is rc_i. The fraction of this release which then becomes airborne is typically evaluated by a partition factor, P_f which may be conservatively estimated from:

Noble Gases

$$P_f = 1$$

All others

$$P_f = \frac{h_t - h_f}{h_s - h_f}$$

where:

h_t = Saturated liquid enthalpy

h_f = Saturated liquid enthalpy at one atmosphere = 419 J/g

h_s = Saturated vapor enthalpy at one atmosphere = 2676 J/g

Therefore, the liquid release rate becomes, rc_iP_f.

(2) R_{ijk} is defined as the removal rate constant and typically consists of:

(a) Exhaust rate from the compartment. This term considers not only the exhaust of any initially contaminated air, but also any clean air which may be used to dilute the compartment air.

(b) Compartment filter systems are treated by the equation:

$$R_{ijk} = (1 - F_i) * r_i$$

where

r_i = Filter system flow rate

F_i = Filter efficiency for radionuclide i

(c) Other removal factors on a case-by-case basis which may be deemed reasonable and conservative.

Example Calculation

(Values used below are examples only and should not be used in any actual evaluation.) This example will look at I-131 in a compartment $6.1 \times 6.1 \times 7.6 = 282.80\text{m}^3 = V$. First, all primary sources of radionuclides need to be identified and categorized.

(1) Flow into the compartment equals 424.8 m^3/h with the input I-131 concentration equal to 7.4 x 10^{-3} Bq/L (from upstream compartments) or 0.888 Bq/s. No other sources of air either contaminated or clean air are assumed.

(2) The compartment contains a pump carrying reactor coolant with a maximum specified leakage rate of 0.000034 m^3/h at 287.8°C.

(a) Conservatively it can be estimated based upon properties from steam tables (Note 1) that under these conditions 44% of the liquid will flash to steam and become airborne. Along with the flashing liquid, it is assumed that a proportional amount of I-131 will become airborne; therefore, $P_f = 0.44$.

(b) Using the design basis iodine concentrations for reactor water from Table 11.1-2 of 598 Bq/g of I-131, it is calculated that the pump is providing a source of I-131 of 1.85 Bq/s to the air (Note 2).

Second, the sinks for airborne material need to be identified. This example includes only exhaust which is categorized as flow out of the compartment at 150% per hour or 4.2×10^{-4} per second.

Therefore, for an equilibrium situation, the I-131 airborne concentration from this liquid source would be calculated from the following equation:

$$C = \frac{1}{v}\left(S_1/(\lambda + R_1) + S_2/(\lambda + R_2)\right)$$

where

V	=	Volume of compartment = 282.8 m^3
S_1	=	Source rate in Curies per second = 1.85 Bq/s from liquid
S_2	=	Source rate from inflow = 0.888 Bq/s
λ	=	Isotope decay constant in units per second = 9.977×10^{-7}/s
R_1	=	R_2 = removal rate constant per second (exfiltration) = 4.2×10^{-4} per second

The result is

C	=	2.3×10^{-4} Bq/L of I-131.

NOTE:

(1) The assumption of 44% flashing at 287.8°C is extremely conservative; see Reference 12A-1 for a discussion of fission product transport.

(2) Water density assumed at 0.743 g/cm^3 based upon standard tables for water at 287.8°C.

12A.2 References

12A-1 Paquette, et al, "Volatility of Fission Products During Reactor Accidents", Journal of Nuclear Materials, Vol 130 Pg 129–138, 1985.