BETA HEATING IN DEPOSITED FILM LAYERS OF RADIOACTIVE AEROSOLS

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In a number of severe core damage accidents at a nuclear power plant, radioactive aerosols generated in the vessel are transported through the cooling system piping to the location of the break. During this transport, through a variety of dynamic processes, a certain amount of aerosol is deposited on the inside surface of the carrier piping. The energy emitted by the radioactive decay of the deposited material could be a key factor in determining the long-term behavior of the deposits.

The long-term behavior determines whether the deposits remain permanently in residence or undergo re-vaporization and become available for release to the containment or the environment. To resolve this question it is important to know how much of the decay energy is absorbed by the aerosols in the deposited layer. The amount of gamma decay energy absorbed can easily be obtained by using any of a number of gamma transport techniques, but these are not applicable to beta transport. A simple model, developed by Stone & Webster Engineering Corporation, is presented herein for calculating the amount of beta decay energy absorbed in a film of radioactive aerosol mixture. The aerosol was assumed to have a relatively high density, and to have been deposited in a large diameter pipe. The physical system of an aerosol deposited in a pipe was transformed to a simplified mathematical model of a semi-infinite multilayered slab as shown in Figure 1.

In this mathematical model, it is assumed that the pipe has been collapsed so that the material is infinite (i.e., greater than electron range) in the y and z directions; the void in the pipe (low density in comparison to the aerosol) would not significantly absorb any beta decay energy and is therefore not included in the model.

The number spectrum, f_n, of the beta particles emitted in radioactive decay[1] is approximated by a triangular distribution so that the energy distribution function, f_E is:

$$f_E = \frac{6E}{E_o^{\,2}}\left(1-\frac{E}{E_o}\right)$$

where E_o end point energy of the spectrum.

This distribution function has $\overline{E} = \frac{E_o}{3}$, which is frequently assumed for beta energy calculations.[2]

The beta decay energy deposition rate was assumed to be uniform over the beta particle range. This assumption, coupled with the triangular distribution function, makes possible the estimation of the fraction of the beta energy spectrum absorbed within a slab of thickness, H, due to a plane source on one surface emitting betas 2π isotropically into the slab.

$$\varepsilon_H = \frac{3}{Z_o}\left[\frac{1}{2}\ln Z_o + \frac{1}{4}\left(\frac{1-Z_o^{\,2}}{Z_o^{\,2}}\right) + \frac{1}{2Z_o}\left(1-\frac{2}{3Z_o}\right)\right]$$

where: $Z_o = \frac{H \cdot \rho}{R_o}$

H = Slab thickness, cm
ρ = Material density (g/cm3)
R_o = Range for beta spectrum characterized by endpoint energy E_o.[2]

E_o < 2.5 MeV, $\quad R_o\left(g/cm^2\right) = 0.412 \cdot E_o^{\,(1.265-0.0954\cdot\ln E_o)}$

Eo > 2.5 MeV $\quad Ro\left(g/cm^2\right) = 0.530 \cdot E_o^{\,-0.106}$

For an aerosol film thickness, H (as in Figure I), we can approximate the volume of radioactive aerosols by a series of plane sources, and define S(X) as the plane source at distance, X, from the origin.

If we define $\varepsilon_H(X)$ as the fraction of beta decay energy emitted from a 4π plane source at X and absorbed in the aerosol of thickness, H, then the total beta decay energy that is absorbed in the film is:

$$E_T = \int_0^t S(X) \cdot \varepsilon_H(X) \cdot dx$$

The integral was evaluated numerically to give the beta energy absorbed for a given nuclide or mixtures of nuclides, while accounting for all beta spectra from each isotope. Table 1 presents results of calculations performed for selected iodine (I), cesium (Cs), and tellurium (Te) nuclides, accounting for all major beta emissions.[3] It can be observed from the tabulated data that a film layer of only 0.1 cm is sufficient to result in approximately 90 percent of the beta energy being deposited within the film.

References

[1] Evans, R. D., "The Atomic Nucleus, " McGraw Hill, 1955.

[2] Lamarsh, J. R., "Introduction to Nuclear Engineering," Addison-Wesley, 1975.

[3] Nuclear Regulatory Commission, "Radiation Signature Following a Hypothesized LOCA," SAND76-0740, NUREG 76-6521, September 1977.

Table-1
FRACTION OF BETA DECAY ENERGY ABSORBED IN A NUMBER OF AEROSOL THICKNESSES (AEROSOL DENSITY -3.0 g/cm^3)

	Fraction Absorbed in Aerosol Film			
	Film Thickness (cm)			
Nuclide	0.0001	0.001	0.01	0.1
I-131	0.025	0.152	0.611	0.955
I-132	0.011	0.071	0.355	0.858
Cs-134m	0.143	0.590	0.951	0.992
Cs-138	0.005	0.036	0.210	0.726
Te-129	0.010	0.069	0.352	0.871
Te-135	0.002	0.017	0.109	0.494

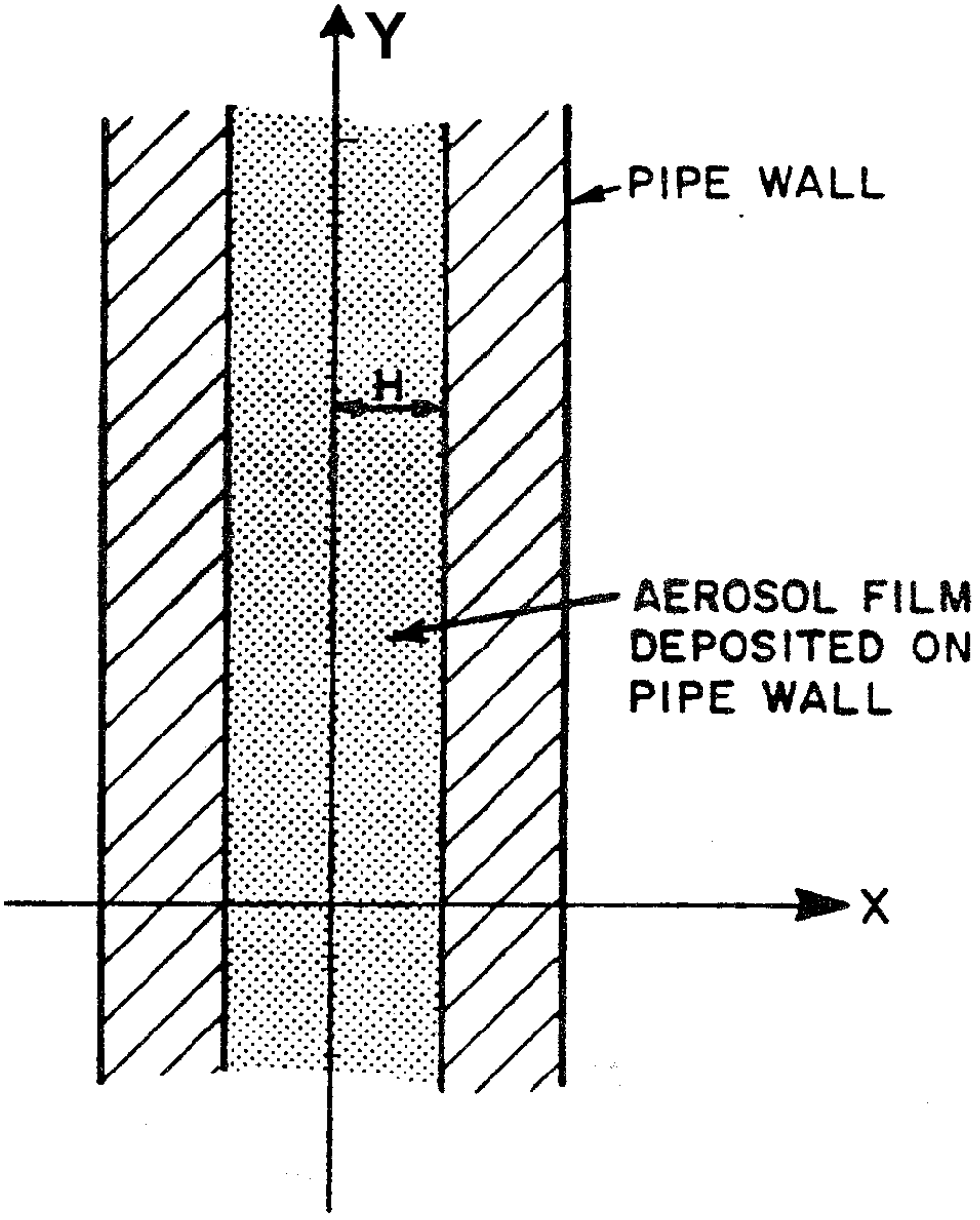

FIGURE 1
COLLAPSED PIPE MODEL