

Solution to EXAM-7 (Closed Book): 14:30 June 9, 2004

Problem-1 (30 points): In Youngkwang Unit 5, the average primary coolant leakage into the auxiliary building is 50 kg/day during normal plant operation.

- If there is no ventilation exhaust in the building, find the equilibrium concentration of Xe-131m (C_i/m^3) in the building air.
- Find the required ventilation rate of the auxiliary building to keep the concentration of Xe-131m under DAC which is 2×10^7 Bq/ m^3 .
- Find the annual release rate of Xe-131m to the environment during normal plant operation via this ventilation exhaust of the auxiliary building.

Data: Volume of the auxiliary building = 700 m^3

Xe-131m concentration in the primary reactor coolant during normal power operation = $20 \text{ } \mu\text{Ci/g}$

Half-life of Xe-131m = 11.8 days

1) The auxiliary building encloses the several systems which handle the primary coolant. Typical systems are CVCS (chemical and volume control system) and BRS (boron recycle system).

The rate of change in airborne activity of nuclide i in the building is given by:

$$\frac{dP_i}{dt} = \ell_{pp} C_i - \lambda_i P_i - R_v P_i$$

where,

P_i = activity of nuclide i in the PAB, μCi

ℓ_{pp} = primary leak rate into the auxiliary bldg.

$$= 50 \text{ kg/day} = (50)(1000)/24 = 2083 \text{ g/hr}$$

C_i = activity of nuclide i in the reactor coolant

$$= (20 \text{ } \mu\text{Ci/g})(3.7 \times 10^4 \text{ Bq/} \mu\text{Ci}) = 7.4 \times 10^5 \text{ Bq/g};$$

$$\lambda_i = 0.693/(11.8 \text{ days})(24 \text{ hours/day}) = 2.45 \times 10^{-3} \text{ hr}^{-1};$$

R_v = vent exhaust rate of the auxiliary bldg., vol/hr; $R_v = \frac{F_v}{V_{PAB}}$.

P_v = vent exhaust rate of the auxiliary bldg. in m^3/hr ; and

V_{PAB} = volume of auxiliary bldg. = 700 m^3 .

In an equilibrium state, the airborne concentration of radioactivity in the auxiliary

bldg. atmosphere is:

$$P_i = \frac{\ell_{pp} C_i}{(\lambda_i + R_v) V_{PAB}}$$

If there is no ventilation arte, the concentration becomes:

$$P_i = \frac{\ell_{pp} C_i}{\lambda_i V_{PAB}} = \frac{(2083 \text{ g/hr})(7.4 \times 10^5 \text{ Bq/g})}{(2.45 \times 10^{-3} \text{ hr}^{-1})(700 \text{ m}^3)} = 8.99 \times 10^8 \text{ Bq/m}^3$$

2) To keep the concentration of Xe-131m under DAC ($2 \times 10^7 \text{ Bq/m}^3$), the required ventilation rate becomes:

$$P_i = \frac{\ell_{pp} C_i}{(\lambda_i + R_v) V_{PAB}} \leq DAC$$

$$R_v V_{PAB} \geq \frac{\ell_{pp} C_i}{DAC} - \lambda_i V_{PAB} = \frac{(2083 \text{ g/hr})(7.4 \times 10^5 \text{ Bq/g})}{(2 \times 10^7 \text{ Bq/m}^3)} - (2.45 \times 10^{-3} \text{ hr}^{-1})(700 \text{ m}^3)$$

$$= 77.07 - 1.72 = 75.35 \text{ m}^3/\text{hr}.$$

$$\therefore R_v V_{PAB} \geq 75.35 \text{ m}^3/\text{hr} = 1.81 \times 10^3 \text{ m}^3/\text{day}$$

3) All the leaked Xe-131m will be eventually vented out to the environment. Hence the annual release of Xe-131m becomes:

$$R_i = \ell_{pp} C_i T$$

$$= (2083 \text{ g/hr})(7.4 \times 10^5 \text{ Bq/g}) (365 \text{ days/yr})(24 \text{ hours/day}) = 1.35 \times 10^{13} \text{ Bq/year}$$

Problem-2 (20 points): What are the possible methods of treating gaseous and liquid radioactive wastes in a typical PWR-type nuclear power plant?

1) Waste gas processing system

The process systems used for radioactive gaseous waste treatment in a nuclear power plant are as follows:

- decay tanks for holdup and decay,
- charcoal delay systems for delayed discharge,
- cover gas recycle to VCT (volume control tank) for recycle back to the primary coolant, and
- cryogenic distillation for volume reduction using low temperature separation.

The input to the gaseous waste system (GWS) are from:

- degassing of reactor coolant following cold shutdowns; and volume degassing in the VCT or via degassifier,
- evaporators of BRS (boron recycle system) and, LWS (liquid waste system) condenser venting, and
- venting of RCDT (reactor coolant drain tank) or pressurizer relief tank.

2) Liquid Waste Treatment

The liquid treatment methods and their respective DF (decontamination factor)s are summarized as follows:

1. demineralization (ion exchange)*			
	anion	Cs-Rb	others
mixed bed			
RC letdown (Li^+BO_3^-)	100	2	50
radwaste (H^+OH^-)	100(10)	2(10)**	100(10)
evap.condensate polish	5	1	10
BRS	10	2	10
S/G blowdown	100(10)	10(10)	100(10)
Cation bed (any systems)	1(1)	10(10)	10(10)
Anion bed (any systems)	100(10)	1(1)	1(1)
Powdex (any systems)	10(10)	2(10)	10(10)

2. evaporation***		
	iodines	all others
misc. wastes	100	1000
boric acid recovery	100	1000
3. reverse osmosis		
	all nuclides	
laundry wastes	30	
other liquid wastes	10****	
4. filtration		
	all nuclides	
	1	

* DF is a function of relative ion concentration and resin volume.

** Higher due to lower relative concentration of other nuclides.

*** Evaporators are assumed to be unavailable for 3 consecutive days per week.

**** Lower due to I and Cs contents.

Problem-3 (30 points): The mean concentration of the effluent at a point (x,y,z) (Ci/m³) based upon the “continuous Gaussian plume model” for atmospheric dispersion is given by:

$$\bar{\chi}(x, y, z) = Q \frac{1}{2\pi\sigma_y\sigma_z\bar{u}} \exp\left[-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2} + \frac{z^2}{\sigma_z^2}\right)\right]$$

where, Q = continuous and constant point release of radioactivity with no change in downwind direction, Ci/sec; \bar{u} = downwind velocity, m/sec; and σ_i (i = y,z) = plume dispersion parameters in y,z-directions.

1) Show that the atmospheric dispersion factor that should be used for calculating the maximum concentration at the ground from a ground level release becomes as follows:

$$\frac{\bar{\chi}}{Q}(x) = \frac{1}{\pi\sigma_y(x)\sigma_z(x)\bar{u}}$$

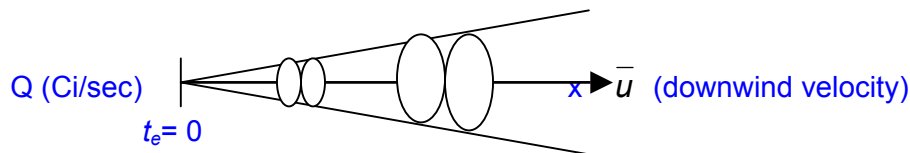
2) Compute the maximum atmospheric dispersion factor at the exclusion area boundary of 700 m away from the reactor center for the ground level release.

Data: wind speed = 1 m/sec wind stability class = F
lateral dispersion parameter at 700 m away from the release point = 28 m
vertical dispersion parameter at 700 m away from the release point = 11 m

1) The radioactivity concentration (Ci/m³) in the air using the “Gaussian plume element model” is given by:

$$\chi(x, y, z, t) = Q_o \frac{(2\pi)^{-3/2}}{\sigma_x\sigma_y\sigma_z} \exp\left[-\frac{1}{2}\left(\frac{(x - \bar{u}[t - t_e])^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2} + \frac{z^2}{\sigma_z^2}\right)\right]$$

Considering no change in downwind direction, for a continuous point source, we can replace Q_o with $\frac{dQ_o}{dt_e} dt_e$. And if $\frac{dQ_o}{dt_e} \equiv Q$ [Ci/sec] is constant, i.e., in case of the continuous point source of Q, the average concentration can be obtained by integrating the release time t_e over (0, ∞):



$$\bar{\chi}(x, y, z) = Q \frac{(2\pi)^{-3/2}}{\sigma_x\sigma_y\sigma_z} \exp\left[-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2} + \frac{z^2}{\sigma_z^2}\right)\right] \int_0^\infty dt_e \exp\left\{-\frac{(x - \bar{u}[t - t_e])^2}{2\sigma_x^2}\right\}$$

Replacing $t' = x - \bar{u}[t - t_e]$ and $dt' = \bar{u}dt_e$

$$\bar{\chi}(x, y, z) = Q \frac{(2\pi)^{-3/2}}{\sigma_x \sigma_y \sigma_z} \exp\left[-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2} + \frac{z^2}{\sigma_z^2}\right)\right] \frac{1}{\bar{u}} \int_0^\infty dt' \exp\left\{-\frac{t'^2}{2\sigma_x^2}\right\}$$

$$\int_0^\infty e^{-a^2 t^2} dt = \frac{\sqrt{\pi}}{2a} \quad \therefore \int_0^\infty dt' \exp\left\{-\frac{t'^2}{2\sigma_x^2}\right\} = \sqrt{2\pi}\sigma_x$$

Inserting,

$$\bar{\chi}(x, y, z) = Q \frac{1}{2\pi\sigma_y\sigma_z\bar{u}} \exp\left[-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2} + \frac{z^2}{\sigma_z^2}\right)\right]$$

where,

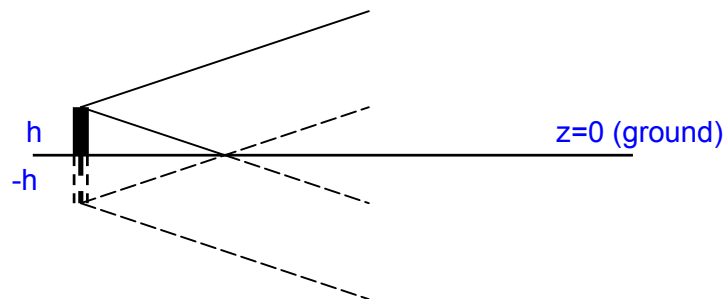
$\bar{\chi}(x, y, z)$ = mean concentration of the effluent at a point (x,y,z), Ci/m³

Q = source strength of emission rate, Ci/sec.

It is a common practice to present the concentration as “atmospheric dispersion factor” and often called “chi-by-cue” or “chi-over-cue” which is defined as sec/m³ as follows:

$$\frac{\bar{\chi}}{Q}(x, y, z) = \frac{1}{2\pi\sigma_y\sigma_z\bar{u}} \exp\left[-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2} + \frac{z^2}{\sigma_z^2}\right)\right]$$

For an elevated continuous release of effluent at height h;



If the release point is h meter high from the ground, we can assume an imaginary source located at z=-h symmetrically reflected by the ground to account for reflected plume. In this case, the chi-by-cue becomes

With real source at z=h;
$$\frac{\bar{\chi}}{Q}(x, y, z) = \frac{1}{2\pi\sigma_y\sigma_z\bar{u}} \exp\left[-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2} + \frac{(z-h)^2}{\sigma_z^2}\right)\right]$$

With imaginary source at $z=-h$;

$$\frac{\bar{\chi}}{Q}(x, y, z) = \frac{1}{2\pi\sigma_y\sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2} + \frac{(z+h)^2}{\sigma_z^2}\right)\right]$$

Summing both equations,

$$\frac{\bar{\chi}}{Q}(x, y, z) = \frac{1}{2\pi\sigma_y\sigma_z u} \exp\left(-\frac{y^2}{\sigma_y^2}\right) \left\{ \exp\left[-\frac{1}{2}\left(\frac{(z-h)^2}{\sigma_z^2}\right)\right] + \exp\left[-\frac{1}{2}\left(\frac{(z+h)^2}{\sigma_z^2}\right)\right] \right\}$$

At the ground level ($z=0$) and for the ground level release ($h = 0$),

$$\frac{\bar{\chi}}{Q}(x, y, z) = \frac{1}{\pi\sigma_y\sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2}\right)\right]$$

For the centerline ground concentration: at $y=0$,

$$\frac{\bar{\chi}}{Q}(x) = \frac{1}{\pi\sigma_y(x)\sigma_z(x)u}$$

2) The atmospheric dispersion constant becomes:

$$\bar{u} = 1 \text{ m/sec}$$

$$\sigma_y(x=700\text{m}) = 28 \text{ m}$$

$$\sigma_z(x=700\text{m}) = 11 \text{ m}$$

$$\frac{\bar{\chi}}{Q}(x) = \frac{1}{\pi\sigma_y(x)\sigma_z(x)u} = \frac{1}{\pi(28\text{m})(11\text{m})(1\text{m/sec})} = \underline{1.03 \times 10^{-3} \text{ sec/m}^3}$$

Problem-4 (10 points): What are the major liquid pathways of radioactive material which reach the human body?

The major liquid pathways of radioactive material to human consist of:

- a) potable water
- b) aquatic foods (fresh water & salt water fish, invertebrate)
- c) shoreline deposits (external exposure)
- d) irrigated foods (vegetation, animal products)

Problem-5 (10 points): Lead, iron, concrete, water are common materials for gamma radiation shielding. Explain the characteristics of each material and its engineering constraints when it is used as the gamma-shield material.

material	lead	iron	concrete	heavy concrete	water
density (g/cm ³)	11.35	7.87	2.2~2.4	3.7~4.8	1
yield strength (psi)	860	25,000	-	-	-
tensile strength (psi)	1,900	40,000	<500		-
maximum temp. (°C)	327 (melting)	1,535 (melting)	93 (dehydration)		100 (boiling)
radiation damage	nil	small	negligible		small
remarks	shrinks about 4% in volume on solidification	strong inelastic & prompt capture γ 's on neutron	careful curing required (7-28 days)		container required