Solution Set for Problems Contained in
"Criticality Safety for Health Physicists"

1. D
2. B
3. A
4. B
5. C
6. C
7. D
8. A
9. C

10.(a) Neutron and gamma doses from initial pulse at 100 meters.

Using $$D_{neutrons} = \frac{\upsilon F \rho_l}{4\pi r^2} x DCF(E_{ave}), \qquad (7)$$

Where

υ = 2.5 neutrons/fission
F = 1.25 x 10^{18} fissions
ρ_l = 0.20 (20% leakage)
r = 10,000 cm

From table 7: $DCF_n(E_{ave})$ = 5.1 x 10^{-10} rad/(n/cm^2) or 1.02 x 10^{-9} rem/(n/cm^2)
QF = 2

Inserting values and solving yields D_n = 0.51 rem at 100 meters

For photons, using

$$D_{photons} = \sum_{all\ E_{ave's}} \frac{\delta(E_{ave})F}{4\pi r^2} x DCF_p(E_{ave}), \qquad (8)$$

where

F = 1.25 x 10^{18};
$\delta(E_{ave})$ x $DCF_p(E_{ave})$ = 8.1 x (5.06 x 10^{-10}) *Prompt gammas @ 0.895 MeV/photon*
+ 1.0 x (5.4 x 10^{-10}) *prompt gammas @ 0.98 MeV/photon*
+ 1.0 x (2.11 x 10^{-10}) *prompt gammas @ 0.3 MeV/photon*
+ 3.31 x (5.33 x 10^{-10}) *early decay gammas @ 0.961 MeV/photon*
r = 10,000 cm

Solving yields $D_{photons}$ = 6.58 rem at 100 meters.

10.(b) Neutron and gamma dose rates during steady-state operations:

Fission rate = $(1.25 \times 10^{18})/18$ hours = 6.94×10^{16} fissions/hour.

Using this rate for *F* in equation 7 yields DR_n = 0.028 rem/hr.

Likewise for gammas, inserting *F* into equation 8 yields $DR_{photons}$ = 0.365 rem/hr.

10.(c) Total doses for duration of event:

D_n = 0.51 rem + (0.028 x 18) = 1.02 rem.

$D_{photons}$ = 6.58 rem + (0.365 x 18) = 13.15 rem. (See note in 10e below.)

Total Effective Dose Equivalent = 14.17 rem.

10.(d) Doses from the environmental release were calculated on the following spreadsheet:

This calculation yields an Effective Dose Equivalent = 2.07 rem,
with ~93.7% from noble gases

Solution to Problem 10(d)

# of fissions =	2.50E+18			
X/Q =	9.00E-04 (Ci/m^3)/(Ci/sec)			
Release Duration =	18 hours	--->	0.00205	years
		--->	64800	seconds
Room Exchange Rate =	8 / hour			

Isotope	Halflife	Fission Yield (Ci/fission)	DCF (mrem/yr) (µCi/m^3)	Total Yield(1) (µCi)	DR	ARF	Release Rate(2) (µCi/sec)	Room Release Fraction	Plume Conc.(3) (µCi/m^3)	Dose Rate(4) (mrem/yr)	Dose(5) (mrem)	% of Total Dose
Kr-85m	4.4 hr	1.50E-17	817	3.75E+07	1	1	5.79E+02	97.50%	5.08E-01	4.15E+02	0.85	0.04%
Kr-87	76 m	9.90E-17	4470	2.48E+08	1	1	3.82E+03	93.60%	3.22E+00	1.44E+04	29.53	1.43%
Kr-88	2.8 hr	6.50E-17	1130	1.63E+08	1	1	2.51E+03	97.00%	2.19E+00	2.47E+03	5.08	0.25%
Kr-89	3.18 m	4.20E-15	10200	1.05E+10	1	1	1.62E+05	42.00%	6.13E+01	6.25E+05	1282.85	62.00%
I-131	8.05 d	8.70E-19	1910	2.18E+06	1	0.25	8.39E+00	100.00%	7.55E-03	1.44E+01	0.03	0.00%
I-132	2.26 hr	1.10E-16	11900	2.75E+08	1	0.25	1.06E+03	96.30%	9.20E-01	1.09E+04	22.47	1.09%
I-134	52 m	4.50E-16	13800	1.13E+09	1	0.25	4.34E+03	90.91%	3.55E+00	4.90E+04	100.63	4.86%
I-135	6.68 hr	4.70E-17	8340	1.18E+08	1	0.25	4.53E+02	98.70%	4.03E-01	3.36E+03	6.90	0.33%
Xe-135	9.14 hr	3.60E-17	1250	9.00E+07	1	1	1.39E+03	99.00%	1.24E+00	1.55E+03	3.18	0.15%
Xe-135m	15.6 m	2.20E-16	2150	5.50E+08	1	1	8.49E+03	75.00%	5.73E+00	1.23E+04	25.29	1.22%
Xe-137	3.9 m	4.90E-15	955	1.23E+10	1	1	1.89E+05	43.40%	7.38E+01	7.05E+04	144.80	7.00%
Xe-138	17.5 m	1.30E-15	6270	3.25E+09	1	1	5.02E+04	77.00%	3.48E+01	2.18E+05	447.49	21.63%

Total Dose = 2069.10 mrem

Notes:

(1) = [fission yield] * [# of fissions] * 1E6 mCi/Ci
(2) = [total yield] / [duration (seconds)] * DR * ARF
(3) = [release rate] * [X/Q]
(4) = [plume conc.] * DCF
(5) = [Dose Rate] * [duration (years)]

10.(e) Note: The self-absorption of photons in the solution was not included in the above calculations (it was not expected to be included for this problem). If included, it would have reduced the gamma component by a factor of 4. Therefore, total gamma dose from direct radiation would be 3.29 rem, and total neutron+gamma dose would be 4.31 rem.

The use of point-energy values for neutrons may introduce a bias compared to spectral-weighted conversion factors. However, spectral shifts in the transit of neutrons over a 100 meter distance through air would also introduce bias. (For class discussion, any thoughts on how this would change the answer?)

One would expect all direct doses to be lowered by attenuation in air and intervening shielding, such as building walls.

Decay-in-transit of short-lived radionuclides in plume would have some effect, greater at longer distances, and would reduce dose from plume. This was neglected at 100 meters since for a wind speed of 2 m/s there would only be a 50 second transit time.

10.(f) Consideration should be placed on shielding of the facility. Enhanced and filtered ventilation would not be effective against noble gas releases unless it can delay release for long time periods (10's of minutes). This seems impractical and very expensive. Shielding of the building and/or remote siting would be easier and more cost effective.