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U.S. Nuclear Regulatory Commission
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Reference: U.S. Geological Survey TRIGA Reactor (GSTR), Docket 50-274, License R-113
Request for Additional Information (RAI) dated September 29, 2010

Subject: Response to Questions 17.1 and 17.2 of the Referenced RAI

Mr. Wertz:

Our responses to Questions 17.1 and 17.2 are provided in the following pages.

Our need for outside assistance to answer the detailed, technical RAI questions is being addressed by a DOE contract with the Colorado School of Mines (CSM). The work under this contract has begun and a meeting with reactor staff from Oregon State University is scheduled to occur next month, on July 19-20.

Sincerely,

Tim DeBey
Tim DeBey
USGS Reactor Supervisor

I declare under penalty of perjury that the foregoing is true and correct.

Executed on 6/29/11

Copy to:
Betty Adrian, Reactor Administrator, MS 975

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NRR

Response to request for additional information questions numbered 17.1 and 17.2.

The Geological Survey TRIGA Reactor (GSTR) Safety Analysis Report (SAR) section 13.2.3.2.2.3 calculates the dose rate at 3 feet above the reactor tank cover grating, after a loss of coolant accident (LOCA) from direct radiation from the core. Section 13.2.3.2.2.4 calculates the dose to a person standing in the reactor room after a LOCA from scattered radiation and not from direct radiation from the core. Section 13.2.3.2.2.5 calculates the dose to a person standing at the east fence of the Denver Federal Center (DFC) during a LOCA from scattered radiation and not from direct radiation from the core. All the dose calculations after a LOCA in the SAR are incorrect and need to be updated. The basic assumption for the calculations is that the reactor has been operating at a maximum power level of 1 MW for one continuous year, and then the cooling water is instantly lost. This is a very conservative assumption, since there is no conceivable way the GSTR could be operated continuously, 24 hours per day, at 1 MW for one year, nor is there any way all of the cooling water could be instantly lost. The GSTR normally operates on a 10-hour-per-day shift for 5 days per week.

The first point of interest for calculating the dose rate is located at a point on the axis of the core cylinder at a distance of 746.8 cm from the top grid plate of the core. This is the distance from the top of the core to a point about 3 feet above the tank cover grating. The reactor core, shutdown and drained of water, was treated as a point source of 1-MeV photons. No accounting was made of sources other than fission product decay gamma rays, and no credit was taken for attenuation through the fuel, fuel element end pieces, and the upper grid plate. The first of these assumptions is optimistic, the second conservative, and the net effect is conservative. The equation to calculate the flux of gamma rays at the dose point is [1]

$$I = \frac{S^*e^{-\mu h}}{4\pi x^2}, \tag{1}$$

where:
I = gamma flux intensity in $\gamma/cm^2/s$;
S = source strength in γ/s;
μ = core attenuation coefficient (0/cm, not accounted for in model to yield conservative calculation);
h = core height (28.1 cm); and
x = distance from top of core to dose point (746.8 cm).

The source strength is calculated from [2]

$$S = A*3.7e10 = 1.4e6*P(t^{-0.2}-(t+T)^{-0.2})*3.7e10, \tag{2}$$

where:

A = total fission product activity as a function of time (Ci);
P = reactor thermal power (1 MW);
t = time after shutdown (days); and
T = operating time (365 days).

The flux is calculated at 5 different times after shutdown: 10 seconds, 1 hour, 1 day, 1 week, and 1 month. After the gamma flux is calculated we can use a conversion factor to determine the effective dose equivalent rate. The dose conversion factor, K, for effective dose equivalent per unit photon fluence was obtained from ICRP 51, Table 2 [3]. This has been calculated for photons incident on an anthropomorphic phantom from various geometries. The worst case (highest dose factor) was for the anteroposterior geometry. For 1-MeV photons or gammas, the anteroposterior value of K is 4.60×10^{-12} Sv cm^2. The effective dose equivalent rate is then calculated by multiplying the gamma flux times this K value, converting to rem (factor of 100 Rem/Sv) and converting to a time base of one hour by multiplying by a factor of 3600 s/hr. Using equations (1) and (2) the total fission product activity, source strength, flux, and effective dose equivalent are shown in Table 17.1.

Table 17.1: Total fission product activity, source strength, flux, and dose after shutdown

Time After Shutdown	Fission Product Activity (Ci)	Source Strength (γ/s)	Flux of gamma rays ($\gamma/cm^2/s$)	Dose 3 ft above grates (R/hr)
10 sec	8.15E+06	3.02E+17	4.30E+10	7.12E+04
1 hour	2.21E+06	8.19E+16	1.17E+10	1.93E+04
1 day	9.70E+05	3.59E+16	5.12E+09	8.48E+03
1 week	5.20E+05	1.92E+16	2.75E+09	4.55E+03
1 month	2.86E+05	1.06E+16	1.51E+09	2.50E+03

The second point of interest for calculating the effective dose equivalent rate is located in the SE corner of the reactor bay, 3 ft above the floor, and 16 ft away from the vertical line intersecting the center of the core. This point is the furthest distance a person can get from the edge of the reactor and remain in the reactor bay. The ceiling immediately over the reactor tank is a staggered ceiling with a steel access hatch and concrete support. To yield a conservative dose calculation it will be modeled as a concrete slab located 18.3 ft above the floor of the reactor bay. In reality the scattering will not be as great as calculated because the radiation from the unshielded core will undergo less interaction with the roof. A representation of this model is shown in Figure 17.1.

For the dose position of interest, we are looking at gamma rays that are scattered at an angle of 46.28°, and travel a total distance of 22.1 ft (673.6 cm) from the scatter point to the position. A representation of this geometry is shown in Figure 17.2. Gammas that have an initial energy of 1 MeV and are scattered according to Figure 17.2 have a scattered energy calculated by [1]

$$E = \frac{Eo}{1+\frac{Eo(1-\cos(\beta))}{0.51}}, \tag{3}$$

where:

Eo = the initial energy of the gamma ray (1 MeV); and

β = the scattering angle of the gamma ray relative to the initial vector of travel (133.72°).

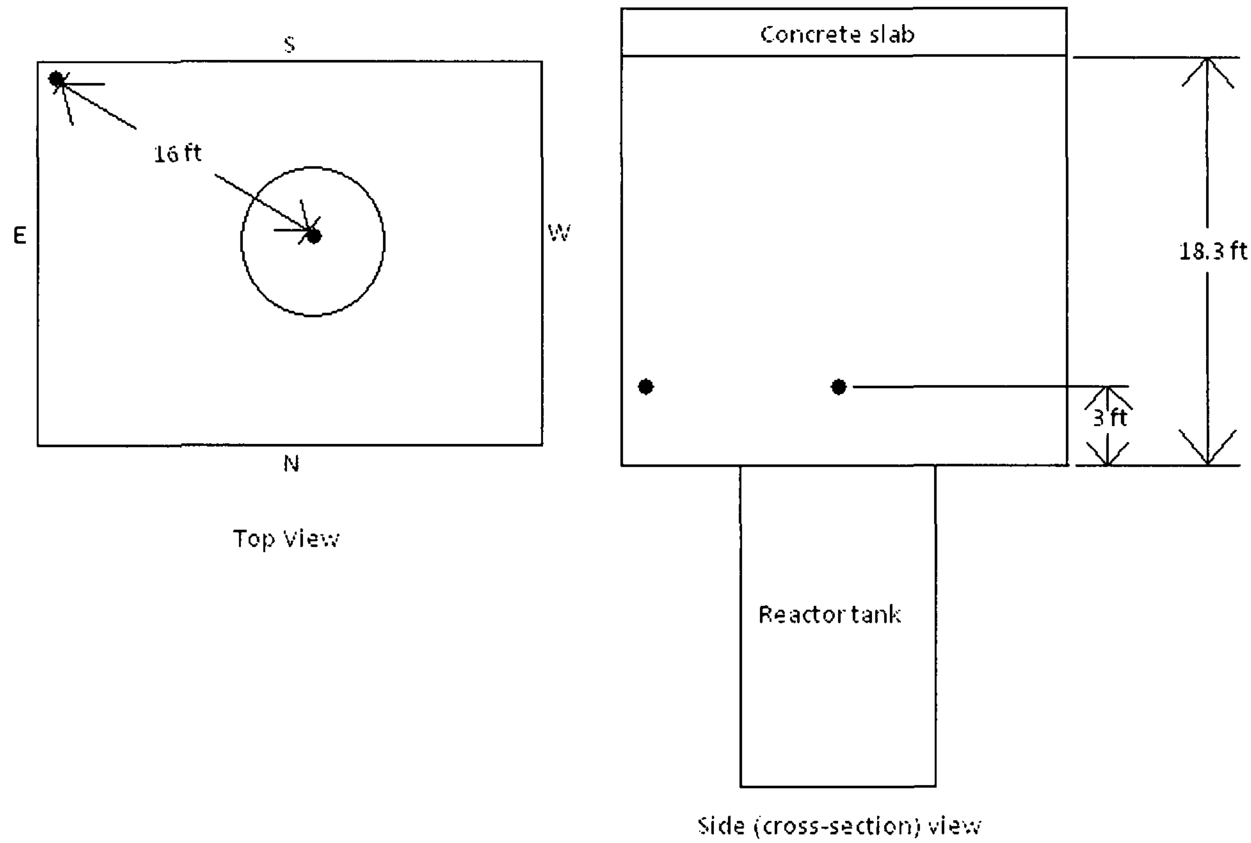

Figure 17.1 Top and side views of the model for calculating the scattered dose in the SE corner after a LOCA

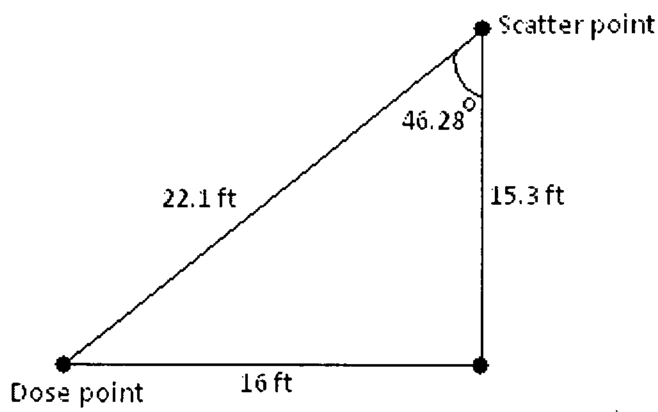

Figure 17.2 Representation of the geometry for the calculations

The resulting energy of the scattered gamma rays is 0.232 MeV. The flux of gamma rays that are scattered from interaction with the concrete slab is calculated by [1]

$$I = \frac{6.03e23*\rho*Z*Io*C}{A*d^2*\left(\mu o + \frac{\mu 1*\cos(\theta o)}{\cos(\theta 1)}\right)} * \frac{d\sigma}{d\Omega}, \tag{4}$$

where:
ρ = the density of the scattering material (concrete $\rho = 2.35\ g/cm^3$) [4];
Io = the flux of gamma rays at the scatter point determined by equation (1) with x = 1213.1 cm (746.8 cm + 466.3 cm);
C = cross sectional area of the incident beam (cm^2);
Z/A = ratio of the average atomic number to the atomic mass (~0.5 for light elements);
d = distance from scatter point to dose point (22.1 ft = 673.6 cm);
μo = attenuation coefficient in scattering material for incident gamma rays (0.150/cm) [5] ;
$\mu 1$ = attenuation coefficient in scattering material for scattered gamma rays (0.284/cm) [5];
θo = incident angle, measured from normal to incident gamma rays (0^o);
$\theta 1$ =incident angle, measured from normal to dose point (46.28^o); and
$d\sigma/d\Omega$ = is the Klein-Nishina formula for scattering cross section from a single electron (cm^2);

For equation (4) the incident gamma beam is conservatively assumed to be collimated by the reactor tank and equal to the cross sectional area of the reactor tank. Therefore, C equals 41764.6 cm^2 and is calculated by

$$C = \pi*R^2; \tag{5}$$

where R = the tank radius (115.3 cm).

The Klein-Nishina formula is calculated by [1]

$$\frac{d\sigma}{d\Omega} = \frac{r^2}{2}*\left(\frac{E}{Eo} - \frac{E^2*\sin^2\beta}{Eo^2} + \frac{E^3}{Eo^3}\right), \tag{6}$$

where:
r = the classical electron radius (2.82e-13 cm);
E = scattered gamma energy from equation (3) (0.232 MeV);
Eo = incident gamma energy (1 MeV); and
β = the scattering angle of the gamma ray relative to the initial vector of travel (133.72^o).

Using equations (1) through (6) the flux of gamma rays incident upon the SE corner dose point can be calculated. Then as before, the ICRP 51, Table 2 dose factors were used to calculate the effective dose equivalent at that position. The anteroposterior geometry was used as it gave the largest dose factor for 0.232-MeV scattered photons, of 1.20×10^{-12} Sv cm^2. Unit conversion factors of 100 Rem/Sv and 3600 s/hr were also applied. The flux and effective dose equivalent for the SE corner position from Figure 17.1 are shown in Table 17.2.

Table 17.2: Flux and dose after shutdown for SE corner

Time After Shutdown	Flux of gamma rays in SE corner ($\gamma/cm^2/s$)	Effective dose equivalent for SE corner (R/hr)
10 sec	1.63E+07	7.01
1 hour	4.42E+06	1.90
1 day	1.94E+06	0.83
1 week	1.04E+06	0.45
1 month	5.70E+05	0.25

The third point of interest for calculating the effective dose equivalent rate is located at the eastern DFC fence, not in the direct beam from the exposed core, but subject to scattered radiation from the reactor bay ceiling, as in the last calculation. The dose point is chosen to be 3 feet above the ground at the closest location along the fence line, where a member of the public could stand. The distance to this point from the center of the reactor bay ceiling above the reactor tank is roughly 968 ft. A representation of this model is shown in Figure 17.3.

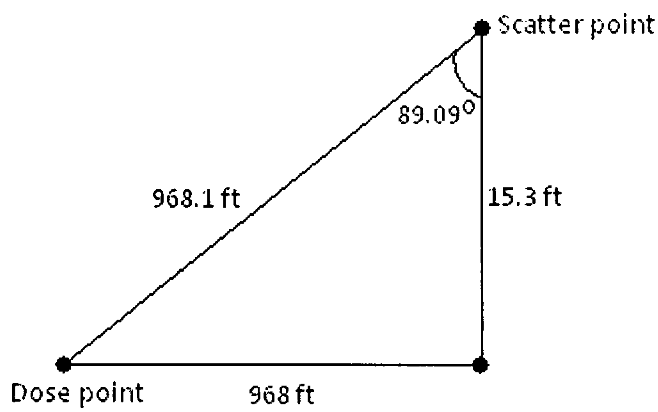

Figure 17.3 Representation of the geometry for the dose calculations at the eastern Federal Center fence.

The calculation methodology is exactly the same as above. Values used for the calculations were the same as above except the following:

x = distance from top of core to scattering point, 1213.1 cm;
$\theta 1$ =incident angle, measured from normal to dose point (89.09°);
β = the scattering angle of the gamma ray relative to the initial vector of travel (90.91°).
E = resulting energy of the scattered gamma rays, 0.334 MeV;
$\mu 1$ = attenuation coefficient in scattering material for scattered gamma rays (0.244/cm) [5];
$d\sigma/d\Omega$ = is the Klein-Nishina formula for scattering cross section from a single electron (1.032e-26 cm^2); and
K = is the dose factor for 0.334 MeV gamma rays, 1.73×10^{-12} Sv cm^2.

Also, for the eastern DFC fence dose point, there is an attenuation factor applied, due to the attenuation of the gamma rays through the 1 ft thick concrete wall of the reactor bay. Attenuation from the remainder of the building structure, the air, and environmental components between the building and fence are conservatively ignored. The attenuation factor is applied according to [4]

$$I = I_o * e^{(-\mu 1 * x)} \tag{7}$$

where:
I = flux of gamma rays at fence with attenuation;
I_o = flux of gamma rays at fence without attenuation;
$\mu 1$ = attenuation coefficient in concrete for the scattered gamma rays (0.244/cm) [5]; and
x = thickness of the concrete wall (1 ft = 30.48 cm).

Table 17.3 shows the flux and effective dose equivalent for the eastern Federal Center fence position.

Table 17.3: Flux and dose after shutdown for eastern fence

Time After Shutdown	Flux of gammas at fence ($\gamma/cm^2/s$)	Effective dose equivalent at fence (mR/hr)
10 sec	1.26E+04	7.83
1 hour	3.41E+03	2.13
1 day	1.50E+03	0.93
1 week	8.02E+02	0.50
1 month	4.40E+02	0.27

References

[1] Introduction to Nuclear Engineering, Richard Stephenson, McGraw-Hill, 1954, pp. 182-200.

[2 Introduction to Nuclear Engineering, 2nd Edition, John R. Lamarsh, Addison-Wesley, 1983, p. 72.

[3] "Data for Use in Protection Against External Radiation," International Commission on Radiation Protection, ICRP Report No. 51, Pergamon Press, March 1987.

[4] Introduction to Health Physics, Herman Cember, Thomas E. Johnson, Fourth Edition, McGraw-Hill, 2009, pp. 167-167.

[5] Radiological Health Handbook, Revised Edition, U.S. Department of Health, Education, and Welfare, U.S. Government Printing Office, 1970, pp.137-140.