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May 27, 1980
TLL 251

TMI Program Office
Attn: J. T. Collins, Deputy Program Director
U. S. Nuclear Regulatory Commission
c/o Three Mile Island Nuclear Station
Middletown, Pa. 17057

Dear Sir:

Three Mile Island Nuclear Station, Unit II (TMI-2)
Operating License No. DPR-73
Docket No. 50-320
Submerged Demineralizer System

In our letter, TLL 201, dated May 2, 1980, we stated that backup support calculations for the SDS Technical Evaluation Report would be submitted by May 23, 1980.

Enclosed please find calculations that support statements made in the TER, Chapter 7, Accident Analysis. These calculations justify the statements and conclusions made therein.

Sincerely,

/s/ G. K. Hovey

G. K. Hovey
Director, TMI-II

GKH:LJL:hah

Enclosure

cc: B. J. Snyder

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APPENDIX I

ANALYSIS OF HYPOTHETICAL ACCIDENTS

TECHNICAL EVALUATION REPORT
SUBMERGED DEMINERALIZER SYSTEM

MAY 23, 1980

Inadvertent pumping of containment water into the fuel storage pool.

Assumptions:

1) The effluent line from the final filter develops a leak which is not detected immediately. Contaminated water is released into the pool at a rate of 30 gpm for a period of 15 minutes (450 gallons) at concentrations present in the containment sump.
2) It is assumed that the toal activity of concern is made up of the cesium isotopes 134 and 137. The reported concentration in the contaminated sump is 40 μCi/ml of Cs-134 and 176 μCi/ml of Cs-137.
3) Assume the volume of water in the fuel storage pool is 233,000 gallons.

Calculate the expected exposure rate for an individual on the walkway at a point 6 feed above the surface of the water.

Concentration of isotopes in the fuel pool:

Dilution Factor $\frac{450 \text{ gal.}}{233{,}450 \text{ gal.}} = 1.928 \times 10^{-3}$

Cs-134 $40\ \mu\text{Ci/ml} \times 1.928 \times 10^{-3} = 0.077\ \mu\text{Ci/ml}$

Cs-137 $176\ \mu\text{Ci/ml} \times 1.928 \times 10^{-3} = 0.34\ \mu\text{Ci/ml}$

The total activity in the 233,000 gallon fuel pool is:

Cs-134 $0.077\ \mu\text{Ci/ml} \times 3.79 \times 10^{3}\ \text{ml/gal} \times 2.33 \times 10^{5}\ \text{gal} = \underline{68\ \text{Ci}}$

Cs-137 $0.34\ \mu\text{Ci/ml} \times 3.79 \times 10^{3}\ \text{ml/gal} \times 2.33 \times 10^{5}\ \text{gal} = \underline{300\ \text{Ci}}$

Approximation of the dose rate at a point "P" which is a distance "a" above the surface of an infinite slab of thickness "h" can be calculated from the following equation (Goldstein).

$$\phi_p = \frac{S_v}{2\mu_s}\left[E_2(b_1) - E_2(b_3)\right]$$

Where ϕ_p = flux at point P
S_v = volume source strength
μ_s = macroscopic cross section of source
$b_3 = b_1 + \mu_s h$
$b_1 = \mu_a a$
μ_a = macroscopic cross section of air

Evaluate μ_a and μ_s assuming a 0.66 MeV photon for both isotopes

---

Mass attenuation coefficient
Water = 0.090 cm^2/g
Air = 0.080 cm^2/g

Density
Water = 1.0g/cm^3
Air = 1.293×10^{-3} g/cm^3

$\mu_s = (0.090\ cm^2/g)(1.0\ g/cm^3) = 0.09\ cm^{-1}$

$\mu_a = (0.080)(1.293 \times 10^{-3}) = 1.0 \times 10^{-4}\ cm^{-1}$

Calculate b_1 and b_3 (same for both isotopes)

$b_1 = \mu_a a$, a = 6 feet = 183 cm
$b_1 = (1.0 \times 10^{-4}\ cm^{-1})(183\ cm)$
$b_1 = 1.83 \times 10^{-2}$

$b_3 = \mu_s h + b_1$, h = 38 feet = 1.16×10^3 cm
$b_3 = (0.09\ cm^{-1})(1.16 \times 10^3\ cm) + 1.83 \times 10^{-2}$
$b_3 = 104$

$$\phi_p = \frac{Sv}{(2)(0.09\ cm^{-1})} \left[E_2 (1.83 \times 10^{-2}) + E_2 (104) \right]$$

From Goldstein's <u>Fundamentals of Shielding</u>

E_2 for 1.83×10^{-2} is 0.913

E_2 for 104 is less than 3.83×10^{-6}

$$\phi_p = \frac{Sv}{0.18} (0.913)\ cm$$

$$\phi_p = 5.07\ Sv\ cm$$

<u>Calculate Sv, volume source strength</u>

For Cs-137:

$Sv = 0.34\ \mu Ci/ml = 1.26 \times 10^4\ dis/cm^3 \cdot s$

Photons 0.662 MeV, 85%

E eff = 0.56 MeV/dis

$Sv = (1.26 \times 10^4\ dis/cm^3 \cdot s)(0.55\ MeV/dis)$

$Sv = 7.06 \times 10^3\ MeV/cm^3 \cdot s$

For Cs-134:

$Sv = 0.077\ \mu Ci/ml = 2.85 \times 10^3\ dis/cm^3 \cdot s$

Photons	0.570 MeV	23%
	0.610 MeV	98%
	0.796 MeV	99%
	1.370 MeV	3.4%
	1.040 MeV	1.0%
	1.170 MeV	1.9%

E eff = 1.60 MeV/dis

$Sv = (2.85 \times 10^3\ dis/cm^3 \cdot s)(1.60\ MeV/dis)$

$Sv = 4.56 \times 10^3\ MeV/cm^3 \cdot s$

Total Sv

$Sv = (7.06 \times 10^3 + 4.56 \times 10^3)\ MeV/cm^3 \cdot s$

$Sv = 1.16 \times 10^4\ MeV/cm^3 \cdot s$

$\phi_p = (5.07\ \text{cm})(1.16 \times 10^4\ \text{MeV/cm}^3 \cdot \text{s})$

$\phi_p = 5.88 \times 10^4\ \text{MeV/cm}^2 \cdot \text{s}$

<u>Calculate the exposure rate given the flux at point P.</u>

The mass-absorption coefficient for air for 600 KeV photons is 0.03 cm^2/g (Morgan and Turner, p. 108).

Exposure Rate (ER) at point P.

$$ER = \frac{(5.88 \times 10^4\ \text{MeV/cm}^2 \cdot \text{s})(0.03\ \text{cm}^2/\text{g})(1.6 \times 10^{-6}\ \text{ergs/MeV})}{87.7\ \text{ergs/g} \cdot \text{R}}$$

$ER = 3.22 \times 10^{-5}\ \text{R/s}$

$ER = 116\ \text{mR/h}$

NOTE: This exposure rate (ER) is lower than the value of 430 mr/hr reported in the TER. The lower value results from a realistic approximation of activity levels, decayed to October 1, 1980, the anticipated date for initiation of SDS operation.

Off-Site Direct Dose from Inadvertent Pumping of Containment Water into the Fuel Storage Pool.

Assumptions:

1) The isotopes of concern are Cs-134 and 137.

2) The concentrations of Cs-134 is 0.077 µCi/ml and Cs-137 is 0.34 µCi/ml.

3) The distance to the closest off-site point is approximately 200 meters.

4) The fuel pool is a point source for exposure estimates at a distance of 200 meters.

5) There is no source self-absorption.

6) The fuel pool wall is approximately 1.5 meters thick of reinforced concrete.

7) The walls of the fuel handling building are approximately 1.5 meters thick of reinforced concrete.

Calculate the exposure 200 meters from the source, assuming no shielding.

The gamma exposure factors for the cesium isotopes are (Radiological Health Handbook, p. 131):

Cs-134	0.87 R/hr · Ci at 1 meter
Cs-137	0.33 R/hr · Ci at 1 meter

The exposure at 200 meters from both isotopes is:

$$\frac{(0.87\ \text{R/hr} \cdot \text{Ci} \times 68\ \text{Ci}) + (0.33\ \text{R/hr} \cdot \text{Ci} \times 300\ \text{Ci})}{(200)^2} = 4 \times 10^{-3}\ \text{R/hr}$$

This exposure will be greatly reduced by the two separate 1.5 meter thick shields of reinforced concrete. The standard gamma absorption equation for wide-beam radiation will be utilized to estimate this reduction (Radiological Health Handbook, p. 30).

$$I = BI_0e^{-\mu x}$$

Where I_o = original radiation exposure rate
I = attenuated radiation exposure rate
μ = linear absorption coefficient
x = absorber thickness
B = "buildup" factor

$\mu/\rho = 0.03\ cm^2/g$ (Morgan & Turner, p. 108)

$\rho = 2.3\ g/cm^3$

$x = 3.0\ m$

$I_o = 4 \times 10^{-3}\ R/hr$

Find μ: $\mu/\rho = 0.03\ cm^2/g$, $\rho = 2.3\ g/cm^3$

$$\mu = 0.03\ cm^2/g \times 2.3\ g/cm^3$$

$$\mu = 0.07\ cm^{-1}$$

The dose build-up factor (B) is found on page 145 of the Radiological Health Handbook. The number of relaxation lengths is:

$$\mu x = 0.07\ cm^{-1} \times 300\ cm$$

$$\mu x = 20.7$$

The shielding properties of concrete are similar to those of aluminum. From the tables, a 0.5 MeV photon and 20 relaxation lengths will yield a dose build-up factor of 141. This calculation will assume a build-up factor of 150.

$$I = BI_0e^{-\mu x}$$

$$I = (150)(4 \times 10^{-3}\ R/hr)\ e^{-0.07 \times 300}$$

$$I = 4.5 \times 10^{-10}\ R/hr$$

The direct dose to an individual at the site boundary from the inadvertent pumping of containment water into the fuel storage pool will be approximately 4.5×10^{-10} R/hr.

Airborne Off-Site Releases from Inadvertent Pumping of Containment Water into the Fuel Storage Pool

Assumptions:

1) Any activity spilled into the pool will be evenly distributed immediately.

2) The "Pool Clean-up Leakage Containment Ion-Exchanger System" will remove activity from the fuel pool. This system will treat the pool water at the rate of 100 GPM. This flow rate results in a turnover rate of once per 39 hour period.

3) The inventory of isotopes available to become airborne will not decrease for one week. At the end of the one week period, seven purification half lives have occurred and no activity remains to become airborne.

4) The volume of the fuel pool is 2.33×10^5 gallons. This volume turns over to the surface as the rate of the "Ion-Exchanger System" (100 GPM is available for suspension).

5) The entrainment factor for activity in water to be suspended in air is 10^{-6}.

6) The air from the fuel pool building will be filtered by 2 banks of HEPA filters resulting in a DF of 10^4.

Calculate the amount of activity for one isotope that will be released in air during the one week period required to clean the pool water. State it as a fraction of activity released during normal SDS operation.

The activity in the fuel pool for Cs-137 from this incident has been calculated to be 0.34 µCi/ml.

Calculate the activity of Cs-137 released off-site in one week.

$$\frac{100 \text{ gal/min.} \times 3785 \text{ ml/gal} \times 0.34\ \mu\text{Ci/ml} \times 10^{-6} \text{ (entr. fact)}}{10^2 \text{ (DF)}} = 1.3 \times 10^{-3}\ \frac{\mu\text{Ci}}{\text{min}}$$

$$1.3 \times 10^{-5}\ \mu\text{Ci/min.} \times 60 \text{ min./hr.} \times 168 \text{ hr./wk.} = 13.0\ \mu\text{Ci/wk.}$$

It was calculated that 347 µCi of Cs-137 will be released from the normal operation of the SDS. This incident could add

$$\frac{13.0\ \mu\text{Ci}}{347\ \mu\text{Ci}} \times 100 = 3.75$$

The amount of potential airborne activity released off-site from this incident is 3.75% of the amount projected from the normal operation of the SDS for a year. The fraction 3.75% will hold for the other isotopes as well.

Pipe Rupture on Filter Inlet Line (above water level)

Assumptions:

1) Contaminated water sprays into the air from around the lead shielding. Approximately 675 gallons of water is released into the pool and 75 gallons spreads onto a surface area of 200 $ft.^2$

2) It is assumed that the total activity of concern is made up of the cesium isotopes 134 and 137. The reported concentrations in the contaminated effluent is 40 μCi/ml of Cs-134 and 176 μCi/ml of Cs-137.

Calculate the exposure rate on the walkway six feet above the pool and the exposure rate three feet above the center of the contaminated area.

Calculation of the exposure rate on the walkway can be done by ratioing the volume of contaminated water released into the pool in the previous accident to the amount of water released in this accident. Application of this ratio to the exposure rate calculated in the previous accident will yield the expected exposure rate from this accident.

$$\text{Ratio} = \frac{675 \text{ gallons}}{450 \text{ gallons}} = 1.50$$

Exposure Rate = (116 mR/h)(1.50)
Exposure Rate = 174 mR/hr

Calculation of the exposure rate three feet above the center of the contaminated area can best be approximated by assuming the area is a circle with an area of 200 ft^2.

$$\text{Area} = 200 \text{ ft.}^2 = 1.86 \times 10^5 \text{ cm}^2$$

$$\text{Radius} = 243.3 \text{ cm}$$

Approximation of the exposure rate at a point "P" which is a distance "a" above the surface of a circular disk source of radiation can be calculated from the following equation (Goldstein).

$$\phi = \frac{Sa}{2}\left[E_1(\mu a) - E_1\left(\mu \sqrt{R^2 + a^2}\right)\right]$$

Where ϕ = flux at point P
Sa = area source strength (Ci/cm^2)
μ = linear attenuation coefficient (cm^{-1})
a = distance from source (cm)
R = Radius of source

For this calculation

$R = 243.3$ cm

$a = 91.4$ cm

$\mu = 1.05 \times 10^{-4}$ cm^{-1}, for 660 KeV photon in air

Calculate Sa for both isotopes

For Cs-137:

$$Sa = \frac{(75 \text{ gals})(3785 \text{ ml/gal})(176\ \mu\text{Ci/ml})}{1.86 \times 10^5 \text{ cm}^2}$$

$Sa = 268.5\ \mu\text{Ci/cm}^2 = 9.93 \times 10^5 \text{ dis/cm}^2 \cdot \text{s}$

$E\ eff = 0.56$ MeV/dis

$Sa = (9.93 \times 10^6 \text{ dis/cm}^2 \cdot \text{s})(0.56 \text{ MeV/dis})$

$Sa = 5.55 \times 10^6 \text{ MeV/cm}^2 \cdot \text{s}$

For Cs-134:

$$Sa = \frac{(75 \text{ gals})(3785 \text{ ml/gal})(40\ \mu\text{Ci/ml})}{1.86 \times 10^5 \text{ cm}^2}$$

$Sa = 60.9\ \mu\text{Ci/cm}^2 = 22.59 \times 10^5 \text{ dis/cm}^2 \cdot \text{s}$

$E\ eff = 1.6$ MeV/dis

$Sa = (22.59 \times 10^5 \text{ dis/cm}^2 \cdot \text{s})(1.6 \text{ MeV/dis})$

$Sa = 3.6 \times 10^6 \text{ MeV/cm}^2 \cdot \text{s}$

Total Sa

$Sa = (5.55 \times 10^6 + 3.6 \times 10^6) \text{ MeV/cm}^2 \cdot \text{s}$

$Sa = 9.15 \times 10^6 \text{ MeV/cm}^2 \cdot \text{s}$

Calculate E_1 ( )

$$E_1\ (\mu a) = E_1\ (1.05 \times 10^{-4} \times 91.4) = E_1\ (9.6 \times 10^{-3})$$

$$E_1(\mu\sqrt{R^2 + a^2}) = E_1\ (1.05 \times 10^{-4}\sqrt{(243.3)^2 + (91.4)^2}) = E_1\ (2.73 \times 10^{-2})$$

From Goldstein's Fundamentals of Shielding

E_1 for 9.6×10^{-3} is 4.04

E_1 for 2.73×10^{-2} is 3.08

Calculate the flux

$$\phi = \frac{Sa}{2}\ (4.04 - 3.08)$$

$$\phi = (.48)(9.13 \times 10^{5}\ \text{MeV/cm}^2\cdot\text{s})$$

$$\phi = 4.38 \times 10^{5}\ \text{MeV/cm}^2\cdot\text{s}$$

Calculate the exposure rate given the flux at point P.

The mass absorption coefficient for air for 600 KeV photons is 0.03 cm^2/g (Morgan and Turner, p. 103).

Exposure Rate (ER) at point P.

$$ER = \frac{(4.38 \times 10^{6}\ \text{MeV/cm}^2\cdot\text{s})(0.03\ \text{cm}^2/\text{g})(1.6 \times 10^{-6}\ \text{ergs/MeV})}{87.7\ \text{ergs/g}\cdot\text{R}}$$

$$ER = 24 \times 10^{-4}\ \text{R/s}$$

$$ER = 8.64\ \text{R/h}$$

Off-Site Direct Dose from Pipe Rupture on Filter Inlet Line (above water level)

Assumptions:

1) The isotopes of concern are Cs-134 and Cs-137.

2) The distance to the closest off-site point is approximately 200 meters.

3) The fuel pool is a point source for exposure estimates at a distance of 200 meters.

4) There is no source self-absorption.

5) The fuel pool wall is approximately 1.5 meters thick of reinforced concrete.

6) The walls of the fuel handling building are approximately 1.5 meters thick of reinforced concrete.

7) 675 gallons is spilled into the pool with concentrations for Cs-134 of 40 µCi/ml and for Cs-137 of 176 µCi/ml.

8) The 75 gallons spilled out of the fuel pool will be cleaned up immediately.

Calculate the exposure 200 meters from the source.

This calculation will be the same as for the inadvertent pumping of containment water into the pool except for the quantities of water. The ratio of quantities of water spilled into the pool can be multiplyed by the off-site exposure rate calculated for the previous accident to yield the exposure rate from this incident.

$$\frac{675 \text{ gal.}}{450 \text{ gal.}} = 1.5$$

Dose from previous incident = 4.5×10^{-10} R/hr.

$$(1.5)(4.5 \times 10^{-10} \text{ R/hr}) = 6.75 \times 10^{-10} \text{ R/hr}$$

The direct dose to an individual at the site boundary from the pipe rupture on the filter inlet line will be approximately 6.75×10^{-10} R/hr.

Airborne Off-Site Releases from the Pipe Rupture on Filter Inlet Line (above water level)

Assumptions:

1) Any activity spilled into the pool will be evenly distributed immediately.

2) The "Pool Clean-up Leakage Containment Ion-Exchanger System" will remove activity from the fuel pool. This system will treat the pool water at the rate of 100 GPM. This flow rate results in a turnover rate of once per 39 hour period.

3) The inventory of isotopes available to become airborne will not decrease for one week. At the end of the one week period, seven purification half lives have occurred and no activity remains to become airborne.

4) The volume of the fuel pool is 2.33×10^{5} gallons. This volume turns over to the surface as the rate of the "Ion-Exchanger System" (100 GPM is available for suspension).

5) The entrainment factor for activity in water to be suspended in air is 10^{-5}.

6) The air from the fuel pool building will be filtered by 2 banks of HEPA filters resulting in a DF of 10^{4}.

7) The air flow across the fuel pool is 5500 cfm.

Calculate the amount of activity for one isotope that will be released in air during the one week period required to clean the pool water. State it as a fraction of activity released during normal SDS operation.

This calculation was performed for a spill of 450 gallons into the pool. By ratioing this amount to the amount spilled in this incident (675 gallons) and multiplying the ratio by the previous result will yield the percentage for this incident.

$$\frac{675 \text{ gallons}}{450 \text{ gallons}} = 1.5$$

$$3.75\% \times 1.5 = 5.63\%$$

The amount of potential airborne activity released off-site from this incident is 5.63% of the amount projected from the normal operation of the SDS for a year. The fraction 5.63% will hold for the other isotopes as well.

Inadvertent lifting of prefilter above the pool surface

Assumptions:

1) A failure in the [illegible] of the overhead crane system results in the filter be[illegible] unshielded from the pool.

2) The prefilter is loaded with 1000 curies (18% Cs-134, 82% Cs-137).

3) The activity in the prefilter is a point source.

4) The distance to the point of concern is 4.57 meters.

5) There is no source self-absorption.

Calculate the exposure rate from the prefilter at a distance of 4.57 meters.

The gamma exposure factors for the cesium isotopes are (Radiological Health Handbook, p. 131):

Cs-134	0.87 R/hr · Ci at 1 meter
Cs-137	0.33 R/hr · Ci at 1 meter

The number of curies for each isotope are:

Cs-134, (1000 Ci)(0.18) = 180 Ci

Cs-137, (1000 Ci)(0.82) = 820 Ci

The exposure at 4.57 meters from both isotopes is:

$$\frac{(0.87 \text{ R/hr} \cdot \text{Ci} \times 180 \text{ Ci}) + (0.33 \text{ R/hr} \cdot \text{Ci} \times 820 \text{ Ci})}{4.57^2} = 20.5 \text{ R/hr}$$

Off-site Direct Dose from Inadvertent Lifting of Prefilter Above the Pool Surface

Assumptions:

1) A failure in the control system of the overhead crane system results in the filter being removed unshielded from the pool.

2) The prefilter is loaded with 1000 curies (18% Cs-137, 82% Cs-13[illegible]).

3) The activity in the prefilter is a point source.

4) The distance to the closest off-site point is approximately 200 meters.

5) The walls of the auxiliary building are approximately 1.5 meters thick of reinforced concrete.

Calculate the exposure rate at 200 meters from the source, assuming no shielding.

$$\frac{(0.87\ R/hr \cdot Ci \times 180\ Ci) + (0.33\ R/hr \cdot Ci \times 820\ Ci)}{200^2} = 1.07 \times 10^{-2}\ R/hr$$

Utilizing the standard gamma absorption equation for wide-beam radiation and the constants from a previous calculation will yield the exposure rate shielded by the wall. (Exception, B=40 for μx of 10).

$$I = BI_o\, e^{-\mu x}$$

$$I = (40)(1.07 \times 10^{-2}\ R/hr)(e^{-0.07 \times 150})$$

$$I = 1.18 \times 10^{-5}\ R/hr$$

The direct dose to an individual at the site boundary from the inadvertent lifting of a prefilter out of the pool will be approximately 1.2×10^{-5} R/hr.