INTERSTATE NUCLEAR SERVICES
A DIVISION OF UNIFIRST CORPORATION

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Mr. Frank Costello
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Division of Radiation Safety and Safeguards
US Nuclear Regulatory Commission, Region I
475 Allendale Rd.
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Dear Frank,

As per our phone conversations, I have prepared an examination of inhalation and whole body dose effects for the sludge drying beds at the Royersford POTW. I followed established methods and built in a lot of conservatisms while calculating for the maximally exposed individual. The approach is similar to a pathway analysis prepared for American Nuclear Insurers which examined seven pathways for one of our other facilities. To demonstrate the methods and describe an approximate range, doses were calculated only for the predominant nuclide, Co-60. Most of the findings in this analysis are less than the NRC below regulatory concern guidance of 10 mrem/year.

I appreciate your offer to review and comment on this work as a fellow Health Physicist. Your response does not have to be NRC sanctioned unless you so desire.

Thank you in advance for your feedback.

Sincerely,

Michael J. Bovino, CHP
Manager, Health Physics and Engineering

cc: G. Bakevich
J. Badey
file

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CASE I. Inhalation of Contaminated Sludge-Borne Dust From Drying Beds at the Royersford Publicly Owned Treatment Works (POTW)

This pathway examines the potential internal dose to POTW operators who may work around contaminated sludge. The following was modeled by the author and incorporated established methods where practical. Many of the givens were obtained by personal conversation with the Royersford POTW staff, Royersford engineers and INS effluent records (see references).

Givens:

1) Co-60 average concentration (7/88 - 12/90) = 4.9 E-6 μCi/ml.
2) Water discharged (avg. 7/88 - 12/90) = 1.1 E5 ft^3/yr.
3) Eventual volume of Royersford POTW drying bed = 22,750 ft^3.
4) Dose conversion factors taken from Reg Guide 1.109.
5) Sludge resuspension factor, (mass loading, M_L) taken from ORAU study (Reference # 4).

Assumptions:

1) All nuclides released to the sewer from INS, Royersford are entrained in POTW sludge and are eventually deposited in the drying beds.
2) The drying bed is in operation for seven years before clean-out is required.
3) No credit taken for decay of nuclides during seven year life of the bed.
4) Radionuclides are evenly distributed throughout the sludge.
5) INS, Royersford continues to release at concentrations found during the period from 7/88 - 12/90.
6) The maximally exposed individual is a POTW worker who works on the sludge drying beds 100% (8 hours) of his work day and breathes 9600 liters of air in an eight hour day.
7) The density of wet sludge is estimated to be between water and clay: 1.3 gm/cm^3
8) Calculation performed for Co-60 only. Actual dose calculation requires iteration for each nuclide as illustrated in the equations below. Co-60 represents 34% of the average concentration of gamma emitters. The true dose will vary due to gamma energy differences and dose conversion factors for other nuclides and the contribution by beta emitters.

The Activity Concentration of Sludge for Nuclide i is given by:

$$C_i^S = \frac{Q_i^W}{V_s} \qquad (1.1)$$

Where:

Q_i^W is the annual release rate of nuclide i into the wastewater (sewer) system, in μCi/yr.

V_s is the volume of the sludge in the drying bed, in ft^3.

Substituting into Equation 1.1 for Co-60, the Activity Concentration is:

$$C_i^S = \left(\frac{4.9\ E\text{-}6\ \mu Ci}{ml}\right)\left(\frac{1.1\ E5\ ft^3}{yr}\right)\left(\frac{2.8\ E4\ ml}{ft^3}\right)\left(\frac{7\ yr\ accumulation}{22{,}750\ ft^3\ of\ sludge}\right)$$

$$= \frac{4.6\ \mu Ci}{ft^3}$$

The Annual Dose from Inhalation of Contaminated Sludge-borne Dust is given as:

$$D_j^S = B_R\, M_L \sum_i C_i^S\, DFA_{ija} \qquad (1.2)$$

Where:

B_R is the adult breathing rate, in m^3/yr.

M_L is the mass loading rate (resuspension), in $\mu g/m^3$.

DFA_{ija} is the inhalation dose factor for radionuclide i, organ j, and age group a, in mrem/pCi.

Substituting into Equation 1.2, the Total Body CEDE, $\left(D_j^5\right)$ from Co-60 is:

$$= \left(\frac{4.6\ \mu Ci}{ft^3}\right)\left(\frac{1.9\ mrem}{\mu Ci\ inhaled}\right)\left(\frac{9600\ l}{8\ hrs}\right)\left(\frac{200\ \mu gm}{m^3}\right)\left(\frac{2000\ hrs}{yr}\right)\left(\frac{m^3}{1000\ l}\right)\left(\frac{gm}{1\ E6\ \mu gm}\right)\left(\frac{ft^3}{2.8\ E4\ cm^3}\right)\left(\frac{cm^3}{1.3\ gm}\right)$$

= 1.2 E-4 mrem/yr

Additional Examination:

Assume that after a seven year period the drying bed gets cleaned out. The additional dose received for the operation is estimated at:

Givens: same as above.

Additional Assumptions:

1) It takes two workers one week to clean out the bed (40 man-hours each).

2) Resuspension of dust increases by a factor of 100, (M_L = 20,000 $\mu g/m^3$).

3) Breathing rate doubles for heavier work (19,200 liters/8 hrs)

Therefore, using equation 1.2 and substituting in the assumptions for this case, the additional inhalation dose in year seven is:

4.6 E-4 mrem/year

Adding the above to the average annual dose from everyday exposure to inhalation (1.2 E-4 mrem/yr) results in a total dose in year seven of 5.8 E-4 mrem. This is well below the 10 mrem/yr Below Regulatory Concern (BRC) suggested limit.

CASE II. Direct Exposure to Radioactively Contaminated Sludge Drying Beds at the Royersford POTW

This pathway examines the potential whole body dose from external exposure to radioactively contaminated sludge to a POTW worker. This pathway was modeled by the author and incorporates established methods where practical. The methodology is one of a shielded infinite plane source (Reference #7).

Givens:

As found in Case I where applicable.

Assumptions:

1) Two subcases were studied; Subcase A describes the buildup factor and associated dose rate from the most recent annual layer of radioactive sludge applied (0.93 ft/yr). Subcase B addresses buildup and dose rate for seven year accumulation period.

2) Sludge is applied in successive layers during the drying bed's seven year lifetime. It will eventually reach a 6-1/2 foot finished height (0.93 ft/yr).

3) The maximally exposed individual is a POTW worker who works on the sludge drying beds 100% (8 hours) of his work day.

4) No credit taken for shielding of previous layers of sludge by successive applications of fresh material.

5) No credit taken for radioactive decay during the life of the drying bed.

6) Sludge density is approximately equal to that of Aluminum. The RHH gives a range for soils from 1.8 to 2.6 g/cm^3. Al has a density of 2.7 g/cm^3 and was chosen because it provides the closest approximation for derivation of buildup factors.

7) 1 R is approximately equal to 1 rem for gamma exposure.

The Activity Concentration of Drying Bed Sludge found in Case I. is given as:

$$\frac{4.6\ \mu Ci}{ft^3} \qquad (2.1)$$

Which is equivalent to:

$$\frac{1.6\ E\text{-}4\ Ci}{m^3} \qquad (2.2)$$

The Exposure Rate To a Worker from Standing on Contaminated Sludge can be Defined by an Infinite Plane and is given as:

$$\dot{X} = \sum_i \frac{\Gamma_i B_i C_i^S}{2\,\mu_s} \left[E_2 b_1 - E_2 b_3 \right] \qquad (2.3)$$

Where:

Γ_i is the specific gamma ray constant for nuclide i, in $R\text{-}m^2/Ci\text{-}hr$.

B_i is the buildup factor of the sludge as its own shield.

C_i^S is the uniform activity per unit volume of sludge for nuclide i, in Ci/m^3.

μ_s is the linear attenuation coefficient of sludge.

E_2 is the shielding function from Ref. x. Found as: E_2 function of b_1, E_2 function of b_3.

b_1 is the relaxation length of the successive sludge caps.

b_3 is the relaxation length of the successive sludge caps plus the new sludge layer.

To find the buildup factor, (B) of sludge, one must first calculate the relaxation length for the sludge (μx):

$$= \left(\text{mass absorption coeff, } \frac{cm^2}{g}\right)\left(\text{shield density, } \frac{g}{cm^3}\right)(\text{shield thickness, cm}) \qquad (2.4)$$

For subcase A, substituting into equation 2.4, μx is given as:

$$= \left(\frac{0.026\ cm^2}{g}\right)\left(\frac{2.7\ g}{cm^3}\right)(28.3\ cm)$$

$$= 2.0$$

Buildup factor, (B) for Co-60 energy of 1.17 and 1.33 and a μx of 2 is found to be approximately 3.2.

For subcase B, substituting into equation 2.4, μx is given as:

$$= \left(\frac{0.026\ cm^2}{g}\right)\left(\frac{2.7\ g}{cm^3}\right)(198\ cm)$$

$$= 13.9$$

Buildup factor (B) for Co-60 energy of 1.17 and 1.33 and a μx of 13.9 is found to be approximately 29.

The linear attenuation coefficient, (μ) must also be calculated. It is given as:

$$\mu = \left(\text{absorption coeff, } \frac{cm^2}{g}\right)\left(\text{shield density, } \frac{g}{cm^3}\right) \qquad (2.5)$$

Substituting into equation 2.5:

$$= \left(\frac{0.06\ cm^2}{g}\right)\left(\frac{2.7\ g}{cm^3}\right)$$

$$= 0.16/cm$$

For Subcase A, Substituting into Equation 2.3, for Co-60, the Exposure Rate Ground Level of the Sludge Drying Bed is:

$$\dot{X} = \frac{\left(\frac{1.3\ R\text{-}m^2}{Ci\text{-}hr}\right)(3.2)\left(\frac{1.6\ E\text{-}4\ Ci}{m^3}\right)}{2\left(\frac{0.16}{cm}\ \frac{100\ cm}{m}\right)}$$ |* see note below|

$$= 2.1\ E\text{-}5\ R/hr \quad = 21\ \mu R/hr$$

* NOTE: Due to the many uncertainties implicit in this model, the shielding functions have been omitted for simplicity and conservatism.

For Subcase B, Substituting into Equation 2.3, for Co-60, the Exposure Rate Ground Level of the Sludge Drying Bed is:

$$\dot{X} = \frac{\left(\frac{1.3\ R\text{-}m^2}{Ci\text{-}hr}\right)(29)\left(\frac{1.6\ E\text{-}4\ Ci}{m^3}\right)}{2\left(\frac{0.16}{cm}\ \frac{100\ cm}{m}\right)}$$

$$= 1.9\ E\text{-}4\ R/hr \quad = 190\ \mu R/hr$$

For Subcase A, The Annual Dose to the Whole Body is:

$$= \left(\frac{2.1\ E\text{-}5\ R}{hr}\right)\left(\frac{2000\ hrs}{yr}\right)\left(\frac{rem}{R}\right)\left(\frac{100\ mrem}{rem}\right)$$

$$= 4.2\ mrem$$

Which is slightly above the 10 mrem/year Below Regulatory concern suggested limit. While the overall dose will be higher when all nuclides present in the sludge are addressed, one can see that through the application of actual factors such as radioactive decay and limited exposure time at the drying bed (8 hours/day is very conservative), the whole body dose could be reduced significantly.

For Subcase B, The Annual Dose to the Whole Body is:

$$= \left(\frac{1.9\ E\text{-}4\ R}{hr}\right)\left(\frac{2000\ hrs}{yr}\right)\left(\frac{rem}{R}\right)\left(\frac{100\ mrem}{rem}\right)$$

100 mrem/rem

$$= 38\ mrem$$

Which is slightly above the 10 mrem/year [illegible]ry concern suggested limit. However, for reasons presented above, it is believed to be a conservative estimate.

REFERENCES

1. Interstate Nuclear Services Royersford Plant Effluent Data, 1988 - 1990.

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6. Nuclear Regulatory Commission, Below Regulatory Concern, (BRC) Policy Statement, July 3, 1990.

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8. Regulatory Guide 1.109, "Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents For the Purpose of Evaluating Compliance with 10 CFR 50, Appendix I", October 1977.

9. ICRP 26, "Recommendations of the International Commission on Radiological Protection", New York, Pergamon Press, 1977.

10. Radiological Health Handbook, U.S. Public Health Service, January 1970.