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October 13, 1989

Dr. R. B. Codell
U.S. Nuclear Regulatory Commission
One White Flint North Building
1555 Rockville Pike
Room 4D-11, MS 4H-3
Rockville, MD 20852

Dear Dr. Codell:

DRAFT GENERIC GROUND-WATER MODEL FOR RESIDUAL RADIOACTIVE MATERIALS

Thank you for agreeing to review our draft ground-water model for evaluating residual radioactive materials. As we discussed, we are attempting to model a very complex and difficult problem in a generic manner; thus, we need to avoid under-prediction of potential ground-water system response. At the same time, we need the results to be meaningful to the problem at hand. We assumed dilution of the inventory in the annual volume of water used by an individual (91 m^3) and included a simple leach rate expression, as shown by the two-box model described in Appendix B, enclosed. I have discussed this problem with Bill Nelson of our staff, and he thinks that this is an adequate approach, given our statement that "the magnitude of the results may only provide an indication of when additional site data or modeling sophistication are warranted."

Please let me know your comments by TELEFAX on FTS (509) 375 2019 or by telephone on FTS (509) 375-3849. I am trying to submit the next partial draft for NRC review by next Wednesday, so I am afraid that I need your comments quite soon. Thank you again for your efforts.

Sincerely,

W. E. Kennedy, Jr.

W. E. Kennedy, Jr., Group Leader
Environmental Health Physics
Occupational and Environmental
  Protection Section
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WEK:cs

Enclosure

cc: Dr. R. A. Meck - U.S. NRC (TELEFAX)

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B.4 GROUND WATER INGESTION

Residual radioactive contamination in soil has the potential to contaminate groundwater in either the saturated or unsaturated zones. The primary mechanisms controlling potential ground water contamination include infiltration and leaching, transport through the unsaturated zone, and transport through the saturated zone. Many additional processes influence these mechanisms including precipitation rates, land surface properties, soil properties, the chemical nature of the radioactive contamination, spatial distributions of the contamination, and advection/retardation in the aquifer. More complete discussions of ground water can be found in Freeze and Cherry (1979), Isherwood (1981), and Wilson and Miller (1979). Previous efforts by the NRC have established a family of models that have fairly broad application to matters related to waste management. These models include those in references by Goode et al. (1986), Konikow and Bredenhoeft (1978), Tracy (1982), Codell, Key, and Whelan (1982), and Codell (1984).

The wide variability of physical and chemical conditions that potentially influence ground water, and the dependence on many parameters that may have a coupled dependency, makes it difficult to model ground water systems. In addition, a conceptual model of a ground water system is an approximation of reality and may not represent all of the behavior of that system. The cost of site characterization, model selection, and model validation may be prohibitive if a trivial source of contamination exists. As a result of the potential system variability, modeling uncertainty, and data collection/modeling costs, generic modeling attempts generally encourage the use of worst-case (overly conservative) parameters, assumptions, and models to avoid under-prediction of a ground water system response. The existence of site data and may allow the use of more realistic and sophisticated models, but the data may be point values (in both location and time) and may still not appropriately represent the actual system being modeled.

The purpose of generic modeling conducted for this document is to derive an aquifer concentration from residual radioactive materials in soil in a conservative manner that will provide an indication of when additional site data or modeling sophistication are warranted. It is recognized that the results may be prohibitive for all but trivial cases.

The modeling approach developed for the onsite disposal of radioactive wastes (Goode et. al. 1986) is potentially applicable to residual radioactive soil contamination. Goode et. al. (1986) provide a discussion of a methodology for estimating the potential contamination of ground water by materials disposed in soils by licensees. The methodology includes the formulation of a conceptual model, representation of the conceptual model mathematically, estimating conservative parameters, and predicting receptor concentrations. Conservative models, assumptions, and parameter selections (i.e., those that are likely to overestimate the receptor concentration) are used for this methodology because of the need to assure that underestimates of the potential impacts do not occur. When valid site data exist, more realistic parameters should be used to refine the predictions.

Goode et al. (1986) provide a methodology for predicting the well concentrations for an individual who drinks water from an onsite well. The simple conceptual model that considers immediate release of materials to the soil. The total radionuclide inventory is assumed to be dispersed in the annual flow rate in the aquifer, F, taken to be 91,250 liters of ground water. This volume of water represents the annual volume of water from a domestic well (250 L/day from Miller 1980)) used by one person for all purposes, of which 2 L/day are consumed as drinking water. The concentration of radioactive materials in the water is simply the total inventory divided by 91,250, corrected for radioactive decay. This concentration is described mathematically as (Goode et al. 1986):

$$C_a(t) = \frac{M_0}{(1\ \text{yr})(F)} \int_0^1 e(-\lambda_R t)\ dt \qquad \text{(B.3)}$$

where C_a = the concentration of each radionuclide in the aquifer at time t, pCi/L (Bq/L)

M_0 = the total radioactivity at the time of site release, pCi (Bq)

λ_R = the radioactive decay constant for each radionuclide considered, yr^{-1}
F = the dilution flow, 91,250 L/yr for an individual
t = an averaging time of one year

Equation B.3 does not account for the leach rate of the radionuclide inventory in soils. Leach rates are dependent on the chemical properties of the radionuclides and soil, and the rate of local water movement. To account for leach rate conditions, Equation B.3 can be modified through the following procedure. Figure B.1 shows a representation of the movement of material from a simple two-box leach model. Box 1 in the figure represents the initial inventory, with removal of material by either radioactive decay or leaching into Box 2. The initial quantity of material in Box 1, $Q_1(0)$, equals M_0. The initial quantity of material in Box 2, $Q_2(0)$, equals zero. The material in box two serves as the material used to estimate the annual average concentration in the ground water system.

The rate of removal of material from Box 1 is described by:

$$\frac{dQ_1}{dt} = -(\lambda_R + \lambda_L)\, Q_1 \qquad \text{(B.4)}$$

and the removal of material from Box 2 is described by:

$$\frac{dQ_2}{dt} = \lambda_L Q_1 - \lambda_R Q_2 \qquad \text{(B.5)}$$

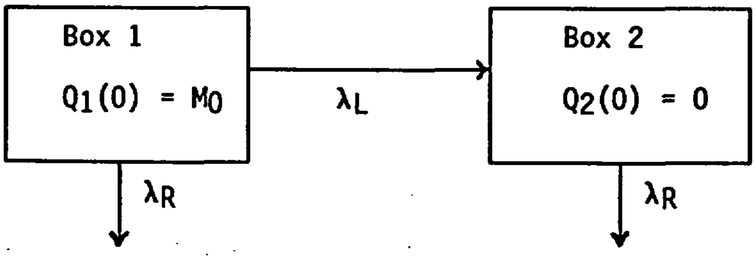

FIGURE B.1. Two-Box Representation of a Simple Leach-Rate System where λ_L = the leach rate constant, yr^{-1}

Q_1 = the quantity of material in the initial inventory, pCi (Bq)

Q_2 = the quantity of material leached from the initial inventory, pCi (Bq)

λ_R = the radioactive decay constant for each radionuclide considered, yr^{-1}

The average concentration in the aquifer is defined by:

$$\overline{W} = \frac{\int_0^t Q_2 dt}{\int_0^t F dt} \qquad (B.6)$$

and the concentration in Box 1 equals:

$$Q_1 = M_0 \, e^{-(\lambda_R + \lambda_L)t} \qquad (B.7)$$

where the parameters are as previously defined.

Solving for the leached quantity, or the quantity in Box 2, results in:

$$Q_2 = M_0 \, e^{-\lambda_R t} \, (1 - e^{-(\lambda_L + 2\lambda_R)t}) \qquad (B.8)$$

where the parameters are as previously defined.

The average concentration in the aquifer, W, is the integral of the concentration in Box 2. Solving this integral equals:

$$\overline{W} = \frac{M_0}{Ft} \left(\frac{1 - e^{-\lambda_R t}}{\lambda_R} \right) - \left(\frac{1 - e^{-(\lambda_R + \lambda_L)t}}{(\lambda_R + \lambda_L)} \right) \qquad (B.9)$$

Previous studies considered a range of leach rates, from 0.1% to 10% per year for reactor wastes and decommissioning/decontamination wastes (Staley, Turi, and Schreiber 1979). For this study, a constant leach rate of 1% (0.01) yr^{-1} is assumed. The dilution flow in the aquifer is assumed to be 9.1×10^5 L/yr, or enough water to supply an average person.

This method does not include any correction for retardation; that is, materials are assumed to move with water. For short-lived radionuclides, this method is conservative because retardation would provide a hold-up period of several years to several decades during ground water transport. For longer lived radionuclides, this method may also be quite conservative because many long-lived radionuclides have leach rate constants smaller than 1% per year. As a result, the expected ground water plume for long-lived materials may be spread out over a long period of time, at a lower concentration. As described in Section 3.0, the ground water migration equations are used to estimate drinking water concentrations resulting from residual radioactive material inventories in surface soils. These drinking water concentrations allow for the calculation of TEDEs through a drinking water scenario. Again, the results of the analysis are intended to provide an indication of when additional site data or modeling sophistication are warranted.