PROBABILISTIC ASSESSMENT OF RADIOLOGICAL IMPACTS FROM TRANSURANICS IN WASTE AT THE SAVANNAH RIVER PLANT*

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ABSTRACT

The U.S. Department of Energy has conducted a comprehensive program at its Savannah River Plant (SRP) to assess environmental impacts from waste processing and disposal operations to assure compliance with provisions of the National Environmental Policy Act (DOE, 1987). This program included evaluation of both radioactive and nonradioactive (hazardous) waste disposal sites. As part of the program this study addressed the effect on performance assessments of transuranic (TRU) nuclides due to the natural variability of properties and parameters used in modeling studies.

As a first step, a comprehensive review was conducted on sources and TRU content of all radioactive wastes in storage and in disposal sites at SRP. A literature review was also performed to compile an updated data base on parameters affecting potential radiological dose impacts from TRU radionuclides in waste. Of particular interest were the recent changes in dosimetric factors for plutonium, neptunium, and americium based upon ICRP-30 and other evaluations (ICRP-30, 1980; Thompson, 1982; ICRP-48, 1986). These changes could result in a wide variation in the derived dose conversion factors. Similarly, there appears to be a wide variation in retentivity of various radionuclides in soil depending on the assumed chemical state of the radionuclide and soil conditions (Baes and Sharp, 1983; Sheppard et al., 1984).

The reasonable range for input parameters for calculation of dose impacts were reviewed. These data provided input to the U.S. Nuclear Regulatory Commission IMPACTS calculational code (USNRC, 1982) which was utilized to determine radiological consequences for various disposal sites at SRP. To accommodate the range of uncertainty in input data, a method was devised for utilizing a probability distribution function for all parameters having a range of reasonable values where there is uncertainty as to the actual value. This paper will focus on the approach used in development of the probabilistic assessment and will discuss certain insights that were derived.

General Comments on Predictive Modeling

Assessing the radiological impacts from the disposal of radioactive wastes has historically involved application of deterministic modeling in which the exercise of theoretical calculational model incorporating a set of pessimistic data assumptions is used to determine the "worst case" consequences. The results can then be compared with relevant standards to determine the acceptability of the specific practice in question.

There are several well known limitations to theoretical modeling. Data limitations exist where the data required to support the model is unavailable. The data may be either unknown or, in some cases, unknowable. Whereas it is extremely difficult to model the unknown, it is impossible to model the unknowable. Although models requiring unattainable data may be technically and mathematically elegant, from practical standpoint they are limited.

Another problem is that there can be serious differences between conceptual models and reality. Unfortunately, the world is not a uniform, infinite, homogeneous slab. The nature of modeling assumes a predictable universe, yet the world, particularly the geologic part of it, is often associated with anomalous and unpredictable occurrences (e.g., fractures, discontinuities, etc.). Increased model complexity

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attempts to account for all possibilities and may give the impression that all conceivable factors have been properly considered. Obviously, however, no degree of complexity can compensate for unanticipated events or unknown parameters. Nonetheless, model predictions can be of use in evaluating the sensitivity of outcomes to various input parameters and for providing a general perspective on the nature of the phenomena.

Finally, the results of a "worst case" assessment can be dependent largely on the imagination of the analyst. Given a "worst case" analysis, it is usually not difficult to top it. Since probability is not considered in "worst case" analyses, the unlikelihood of events is not a constraint in scenario development. One need only to stretch one's imagination, therefore, to determine events and consequences of greater and greater severity. Unfortunately, the results of such analysis are often interpreted as a reflection of reality rather than of an extreme case.

To counter these problems, probabilistic analysis can be applied. An example of this approach is seen in the famous Rasmussen Reactor Safety Study (USNRC, 1975). Although such analysis may also have credibility problems, at least for technological purposes, the probabilistic approach is preferable to the worst case approach. Probabilistic analysis can be advantageous in predictive assessments for waste disposal because the underlying phenomenology is, in fact, stochastic in nature and the probabilistic approach can provide a means of reflecting the uncertainty in input parameters.

Approach

To demonstrate the application of probabilistic assessment, a simplified problem involving only one radionuclide at one SRP disposal site and one release scenario was evaluated. For purposes of this assessment, a probabilistic analysis of the radiological consequences of neptunium-237 that might be released from the SRP solid waste burial ground via the groundwater pathway was made.

Following the IMPACTS calculational format for the groundwater transport scenarios, the "maximum" individual dose to the receptor can be determined as the product of several factors. Uncertainty in each of these factors may be reasonably characterized as log- normal in nature. This allows for rather simple and straight forward propagation of uncertainties through the calculation. It should be noted that where input parameters cannot be characterized log-normally, more complicated numerical calculational methods must be applied. A comprehensive methodology for performing such analyses was recently described by Cox and Atwood (1985).

Assessment

Prior to performing the analysis, a thorough review of the basis for, and probable variation of all key parameters was performed (Cohen, 1987). In addition, an International Atomic Energy Agency report (IAEA, 1987) describing parameter variation was reviewed. The key parameters assessed included: the Dose Conversion Factor (radiation dose per unit ingestion), Partition Ratio (leach rate), Retardation Coefficient (Kd), and assumed water intake rate (l/yr).

To probabilistically evaluate the example problem, the assumptions listed in Table I were made. All input parameters other than those specified in *Table I are* assumed to be the fixed default parameters in the IMPACTS code. The calculational output is given in Fig. 1. From this calculation it appears that the geometric mean dose is 0.32 mrem/yr. The uncertainty in this value resulting from the combined uncertainties in the input values is characterized a geometric standard deviation (g) = 46.7.

Accordingly, the 1.0 range extends from 0.007 to 15.0 mrem/yr (i.e., there is an 68% probability that the actual "maximum" individual dose would lie within this range). There would be a 95% probability that the dose would be equal to or less than 178 mrem/yr, and a 99% probability of a dose less than 2.4 rem. It should be noted that these are conditional probabilities; i.e., it is presumed that an actual well is dug within 5 m of the burial grounds in the centerline of the groundwater plume and that this well actually provides the entire annual drinking water supply to the receptor. Table II summarizes the statistical results.

These results indicate that, depending upon the degree of conservatism one desires to apply in selecting input parameters, the calculated dose could range from relatively insignificant values to doses well in excess of current standards for radiation exposure. Although a complete probabilistic assessment of all radionuclides at all disposal sites is beyond the scope of the present study, the results of the sample problem calculation indicate how incorporation of uncertainty in such calculations can affect the results. However, a serious drawback to such analyses lies in the fact that current regulatory standards provide no clear guidelines that would allow for reasonable interpretation of such results. Accordingly the probabilistic assessment is provided only to demonstrate the potential effect of considering uncertainty in calculational prediction of dose consequences from underground disposal of radioactive wastes.

BIBLIOGRAPHY

Baes, C.F. and R.D. Sharp, A Proposal for Estimation of Soil Leaching and Leaching Constants for Use in Assessment Models, J. Environ. Qual., 12:1 (1983).

Cox, N.D. and C.L. Atwood, WASTE-PRA: A Computer Package for Probabilistic Risk Assessment

TABLE I

Input Parameters for Sample Problem Using Probabilistic Assessment

[To determine individual dose at "intruder" (close-in) well from Np-237 from SRP waste burial ground]

Parameter	Reasonable Range of Values*	Assumed Geom. Mean	Assumed Geometric Std. Deviation (σg)
Np-237 Conc.			
Inventory: 0.15 Ci			
Waste Vol: 5.4×10^4 m^3	---		
Solid Waste Conc: 2.7×10^{-6} Ci/m^3		2.7×10^{-6} Ci/m^3	2.5
Partition Ratio (leach rate, yr^{-1})	1×10^{-6} to 8×10^{-3}	4.7×10^{-4} (IMPACTS default value)	10
Retardation Coefficient	1.0 to 1,000	600 (IMPACTS default value)	10
Water Intake Rate (L/yr)	200-800	500	2
Np-237 Dose Conversion Factor (rem/Ci)	2.7×10^5 to 4.0×10^7	4.6×10^6	10

* From IAEA, 1987.

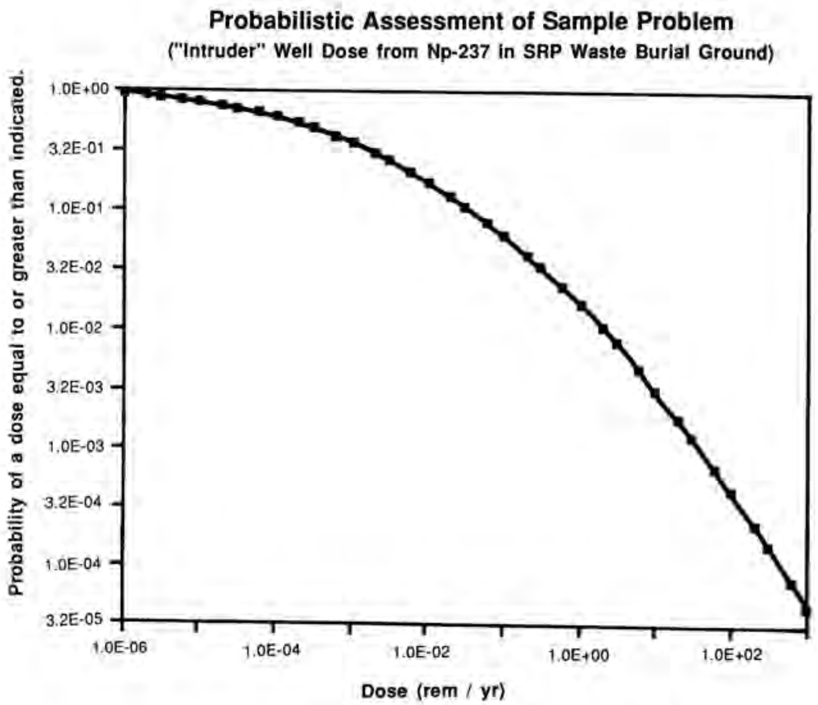

Fig. 1. Probabilistic Assessment of Sample Problem.

TABLE II

Probabilistic Evaluation of Sample Problem

(Maximum Individual Dose via Groundwater Pathway to a nearby well from Np-237 in the SRP waste burial ground)

% Probability of Reaching the Indicated Dose	Maximum Individual Radiological Dose (mrem/yr)
50.0	0.32
16.0	15.0
10.0	44.0
5.0	178.0
1.0	2,440
0.1	46,100
0.001	220,000

of Shallow-Land Burial of Low-Level Radioactive Waste, EGG-EA-7106 (December 1985).

IAEA-TECDOC-401, Exemption of Radiation Sources from Regulatory Control: Application of the Principles to Low Level Waste Disposal in the Terrestrial Environment, International Atomic Energy Agency, Vienna, Austria (1987).

ICRP, International Commission on Radiological Protection, Publication 30, Limits for Intake of Radionuclides by Worker, Pergamon Press (1980).

ICRP, International Commission on Radiological Protection, Publication 48, Annals of the ICRP, The Metabolism of Plutonium and Related Elements, Vol 16 No. 2/3, Pergamon Press (April 1986).

Sheppard, M.I., D.I. Beals, D.H. Thibault, and P. O'Connor, Soil Nuclide Distribution Coefficients and Their Statistical Distributions, AECL-8364, (December 1984).

Thompson, R.C., Neptunium - the Neglected Actinide: A Review of Biological and Environmental Literature, Radiation Research 90:1 (1982).

USDOE, United States Department of Energy, Final EIS, Waste Management Activities for Groundwater Protection, Savannah RIver Plant, Aiken, South Carolina, DOE/EIS-0120 (December 1987).

USNRC, United States Nuclear Regulatory Commission, Final EIS on 10 CFR Part 61: Licensing Requirements for Land Disposal of Radioactive Waste, NUREG-0945 (November 1982).

USNRC, United States Nuclear Regulatory Commission, Users Guide for 10 CFR 61 Impact Analysis Code, NUREG-0959 (January 1983).

USNRC, United States Nuclear Regulatory Commission, Reactor Safety Study, WASH-1400 NUREG 75/014 (October 1975).