PERFORMANCE ASSESSMENT OF MIXED WASTES USING THE PATHRAE-EPA MODEL

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ABSTRACT

The development of standards for low-level waste and below regulatory concern waste disposal by the U.S. Environmental Protection Agency has led to the development of the performance assessment code PATHRAE. The PATHRAE code is used to provide estimates of the magnitude of health effects to critical population groups which could potentially occur from disposed radioactive wastes.

The PATHRAE code has been extended to include the transport and health effects assessments for non-radiological contaminants. Thus, PATHRAE is a useful tool for performing multiscenario, multipathway analyses of mixed wastes. It has been applied to radiologically and non-radiologically contaminated CERCLA (Superfund) sites and to DOE contractor-operated disposal facilities.

The EPA-approved approach of using the linear, nonthreshold theory for nonradiological carcinogens facilitates the calculation of the cancer risk for these contaminants. A standard methodology is also applied to nonradiological contaminants that are not carcinogenic.

The acceptable daily intake is input into the code instead of the cancer risk conversion factors. PATHRAE then calculates and prints the ratio of the expected daily intake of contaminants to the acceptable daily intake.

The code prints out the risks and fractions of acceptable daily intakes for each contaminant and for each pathway/scenario combination. It also sums over all carcinogens for each pathway/scenario, and then sums over all pathways/scenarios to obtain total risk to the critical population group.

INTRODUCTION

Attention has recently been focused on the presence and impacts of non-radioactive hazardous wastes in low-level radioactive waste (LLW) disposal facilities and contaminated sites. An analysis tool has been developed to predict non-radiological contaminant migration through multiple pathways and subsequent uptakes and risks by individuals in the population at risk. The code, called PATHRAE-MIX, is a modification of the PATHRAE-EPA[1] multipathway risk assessment code developed in support of the Environmental Protection Agency's (EPA) technical basis for LLW and below regulatory concern waste disposal regulation (10CFR193). PATHRAE-MIX can be used to calculate transport, uptake, doses and risks for radiological and non-radiological contaminants. For non-carcinogens the measure of risk is given by the ratio of the estimated daily intake (EDI) to the acceptable daily intake (ADI). Heavy metals as well as organic compounds are modeled in the code.

The doses and risks are given for each contaminant. They can also be summed over the carcinogenic contaminants and non-carcinogenic contaminants.

In this paper, a brief description of PATHRAE-EPA will be given, then the modifications to PATHRAE for non-radiological contaminants will be described, and finally an example analysis will be presented.

PATHRAE-EPA

PATHRAE-EPA is a multipathway performance and risk assessment code for the land disposal of radioactive wastes. The PATHRAE methodology models both offsite and on-site pathways through which humans can come into contact with the waste. As shown in Fig. 1, the pathways are:

1. Groundwater migration with discharge to a river.
2. Groundwater migration with discharge to a well.
3. Surface erosion of the cover material and waste and subsequent contamination of surface water.
4. Saturation of waste and surface water contamination (bathtub effect).
5. Food grown on the waste site.
6. Biointrusion into the waste.
7. Direct gamma exposure.
8. Inhalation of radioactive dust on site.
9. Inhalation of radon gas and radon daughters on site.

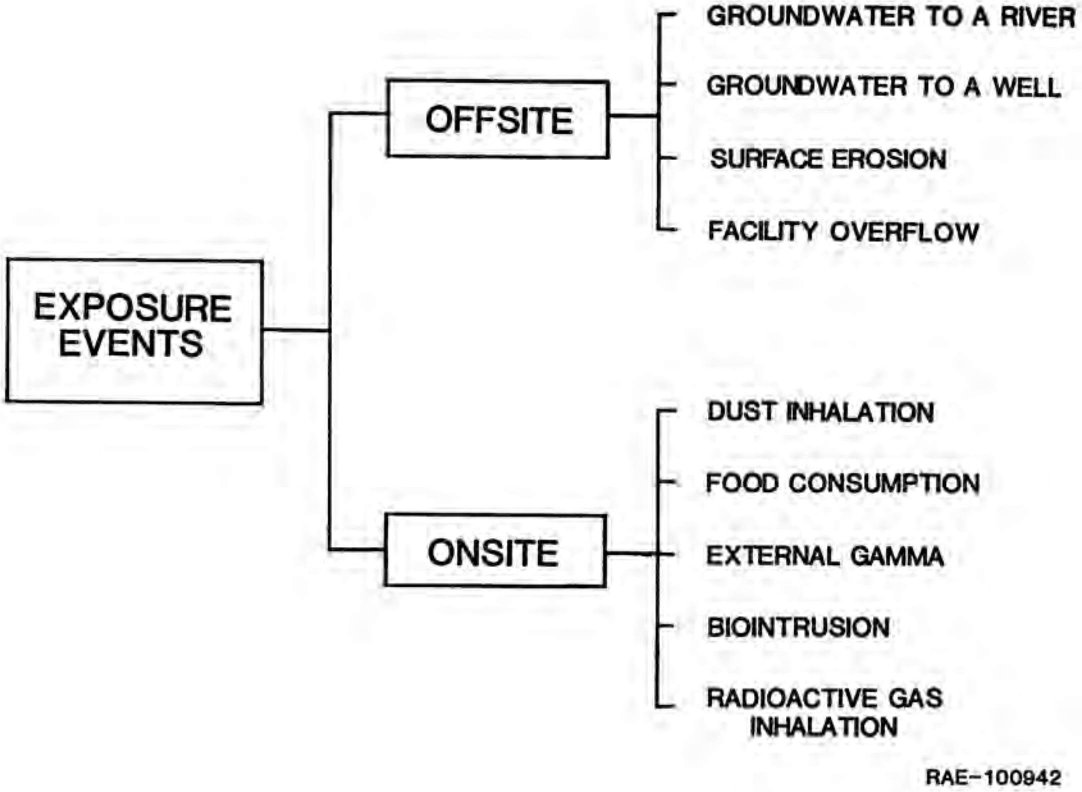

Fig. 1. Major Pathways for Exposure.

10. Inhalation of radioactive particulates offsite (from an on-site incinerator, trench fire, or dust resuspension).

It uses modified one-dimensional analytical solutions to the advection-dispersion differential equation for the groundwater pathways, Gaussian plume with depletion analytical expressions for the atmospheric pathways and simple algebraic expressions to represent inadvertent intrusion and reclaimer events.

The main advantage of PATHRAE is its simplicity of operation and presentation while still allowing a comprehensive set of nuclides and pathways to be analyzed. Site performance for radioactive waste disposal can be readily investigated with relatively few parameters needed to define the problem. Important parameters that limit site performance are also readily identified. For example, key site parameters are found generally to include:

- Depth to the aquifer
- Aquifer distance to accessible location
- Aquifer velocity
- Facility size
- Facility operating time
- Precipitation
- Soil retardation characteristics
- Depth for emplacement of waste
- Cover thickness and impermeability

Of the potentially innumerable ways in which exposures to radiation from radioactive waste may occur, many have not been included in PATHRAE because they are either not restricting or are highly improbable. Only those reasonable pathways which are potentially restricting have been considered in detail. This does not mean that these exposure events will occur. Rather, it is the intent of the PATHRAE code to model a consistent set of events in such a manner as to estimate a range of probably impacts. The resulting range can be used as a basis for decision making among a variety of diverse alternatives.

NUCLIDE INVENTORY

The nuclide inventory for PATHRAE can contain up to 50 nuclides. The inventory can either be specified at all of the designated times or calculated from an initial inventory. In addition, the decay of the nuclide inventory and the ingrowth of daughters can be calculated for the operational and post-operational periods.

GROUNDWATER PATHWAYS

The transport of nuclides in the groundwater system can be calculated with or without longitudinal and transverse dispersion terms. The ingrowth of daughter nuclides during transport in the groundwater system can be included using any of seven three-member decay chains. The decay chains are:

1. Cm244 → Pu240 → U236
2. Pu240 → U236 → Th232
3. Am243 → Pu239 → U235
4. Pu241 → Am241 → Np237
5. Pu238 → U234 → Th230 → Ra226
6. Pu242 → U238 → U234
7. U238 → Th230 → Ra226

Some of these chains are approximate representations of longer chains. For example, decay chain five is calculated assuming all of the Pu238 decays to U234 in a time period that is short compared to the nuclide transit time in the aquifer.

An example of the pathway equations is given by the groundwater pathway. In general the equations can be grouped into three components representing the waste form or release rate, the transport pathway, and environmental uptake. For simplicity, the results of the environmental foodchain analysis are represented in the equations by the symbol U, called the equivalent uptake factor.

Groundwater migration with discharge to a river is calculated from the following equation.

$$D = \frac{Q\lambda_L f_o U_1 (DF)}{q_w} \qquad (1)$$

where

D = nuclide dose equivalent (mrem/yr)

Q = inventory of the isotope available in a given year (pCi)

q_w = flow rate of the river (m^3/yr)

f_o = fraction of inventory arriving at the river from transport through the *aquifer*

L = fraction of each nuclide leached from the inventory in a year (1/yr)

U_1 = annual equivalent uptake of water by an individual (m^3/yr)

DF = dose conversion factor (mrem/pCi)

The components of the equation are:

Release Rate = $Q\lambda_L$

Transport Pathway = f_o

Environmental Uptake = $\frac{U_1}{q_w}(DF)$

The term f_o is determined from the analytical solution to the following differential equations describing the one-dimensional migration of contaminants and their degradation products:

$$R_1 \frac{dC_1}{dt} + V \frac{dC_1}{dx} = D \frac{d^2C_1}{dx^2} - R_1K_1C_1$$

$$\vdots \qquad\qquad \vdots$$

$$R_i \frac{dC_i}{dt} + V \frac{dC_i}{dx} = D \frac{d^2C_i}{dx^2} - R_iK_iC_i + R_{i-1}K_{i-1}C_{i-1} \qquad (2)$$

where

C_i = concentration of contaminant i in groundwater

R_i = contaminant retardation coefficient

V = aquifer velocity

D = dispersion coefficient

K_i = rate constant for decay or degration

For C_1, f_o defined as $C_1(x=0)/C_1(x)$, is given by:[2]

$$f_o = \frac{1}{N} \sum_{j=1}^{N} \left[F_j(t) - F_j(t-1/\lambda_L) \right] \qquad (3)$$

where

$F_j(t)$ = $0.5\, U(t) \left[\text{erfc}\,(z-) + \exp(d_j)\, \text{erfc}\,(z+) \right]$

$U(t)$ = unit step function

$z\pm$ = $\frac{\sqrt{d_j}\left[1 \pm t/(Rt_{wj})\right]}{\sqrt{2\, t/(Rt_{wj})}}$

d_j = distance from sector center to access location, divided by the dispersity

t_{wj} = water travel time from sector center to access location (yr)

N = number of mesh points in numerical integration

The numerical integration referred to above is a means by which the point source analytical solution for dispersive transport can be extended to approximate an area source. As shown in Fig. 2, the disposal facility of length L is divided into N sectors of equal length. A point source of the appropriate magnitude is placed at the center of each sector. The distance, d_j, is proportional to the distance from the center of sector j to the access location. The point source analytical solutions are then summed over all sectors to approximate an area source.

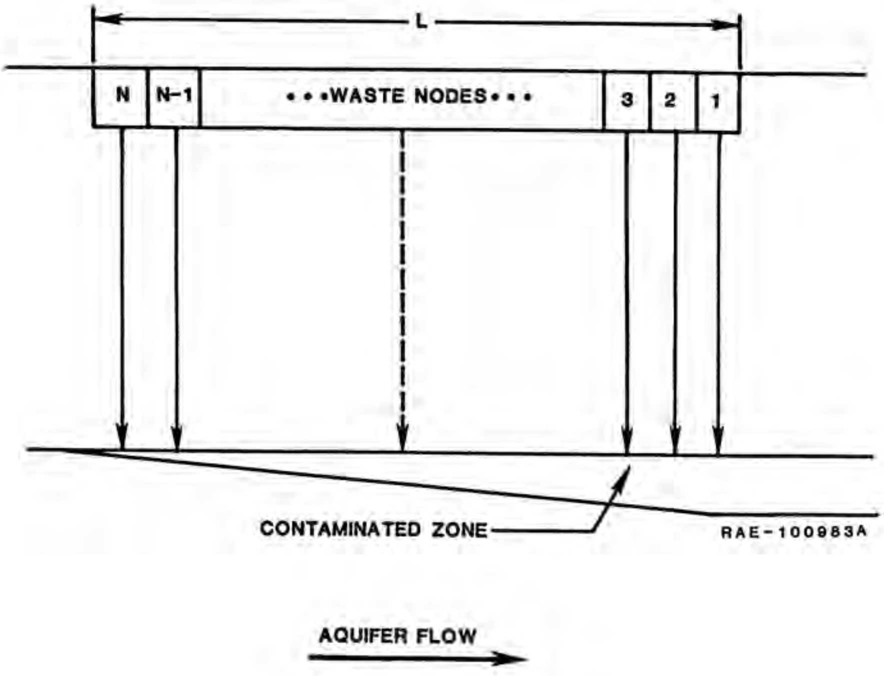

Fig. 2. Representation of Area Source Term for Groundwater Flow.

PATHRAE-MIX

Radioactive decay is described by the same quantitative expressions as first-order chemical reactions. Therefore, any chemical reaction or degradation process can be calculated in PATHRAE if it can be represented as a first-order process. Stable elements are represented by internally assigning a decay half-life to 10^{10} years.

The migration of organics in groundwater is also represented by a linear adsorption isotherm. The value of the partitioning coefficient is obtained from the octanol-water partition coefficient, K_{ow} and the fraction of organic carbon in the soil, f_{oc}. The equation for R for organics is

$$R = 1 + \frac{\rho f_{oc} K_{oc}}{p}, \qquad (4)$$

where K_{oc} is given by(3)

$$\log (K_{oc}/1000) = 1.029 \log (K_{ow}/1000) - 0.18 \qquad (5)$$

For vapor-loss effects, a volatility factor is input and applied to the original source term for all pathways.

SAMPLE PROBLEM

An example of the use of PATHRAE-MIX is provided by considering a waste facility with an inventory of six hazardous substances. A square facility with an area of 10,000 m^2 and a capacity of 20,000 m^3 is considered. A well 50 meters from the edge of the facility is assumed to provide drinking water and irrigation water for a group of individuals. Input parameters characterizing the transport of waste materials to the groundwater are shown in Table I. For simplicity, the inventory is assumed to be 1 kg each of chromium, lead, mercury, tetrachloromethane, 1,1,1-trichloroethane, and trichloroethylene.

TABLE I

FACILITY AND TRANSPORT PROPERTIES FOR SAMPLE PROBLEM

Distance from bottom of waste to water table	5 m
Distance to well	50 m
Aquifer velocity	10 m/yr
Aquifer porosity	0.2
Length of perforated well casing in aquifer	10 m
Water infiltration rate	0.4 m/yr

Table II gives contaminant specific data such as leach fractions and equilibrium sorption coefficients (K_d).

The results of the transport and human health risk assessment are summarized in Table III. For carcinogens the risks are reported as health effects per year. For non-carcinogens the risk is measured in terms of the fraction of the ADI ingested by an individual.

TABLE II

CONTAMINANT SPECIFIC DATA FOR SAMPLE PROBLEM

Contaminant	K_d ml/g	Leach Fraction	UCR $(mg/kg/day)^{-1}$	ADI (mg/kg/day)
Chromium	40	1.2E-3	---	2.1E-3
Lead	100	4.7E-4	---	3.0E-3
Mercury	10,000	4.8E-6	---	2.9E-4
Tetrachloromethane	2.2E-2	3.2E-1	1.3E-1	---
111-Trichloroethane	1.1E-2	3.5E-1	1.6E-3	---
Trichloroethylene	1.3E-2	3.4E-1	1.2E-2	---

TABLE III

HUMAN HEALTH RISK ASSESSMENT FOR SAMPLE PROBLEM

	Contaminant Doses Mg Times (yr)					
Contaminant	0	10	50	100	1500	2000
Chromium	0	0	0	0	0	1.6E-06
Lead	0	0	0	0	0	0
Mercury	0	0	0	0	0	0
Tetrachloromethane	3.4E-04	1.4E-04	4.3E-07	8.7E-10	0	0
111-Trichloroethane	3.6E-04	1.1E-04	2.5E-07	3.2E-10	0	0
Trichloroethylene	3.5E-04	1.2E-04	2.8E-07	3.9E-10	0	0

	Carcinogenic Risks Times (yr)					
Contaminant	0	10	50	100	1500	2000
Tetrachloromethane	4.4E-05	1.8E-05	5.6E-08	1.1E-10	0	0
111-Trichloroethane	5.7E-07	1.8E-07	4.0E-10	5.2E-13	0	0
Trichloroethylene	4.2E-06	1.4E-06	3.3E-09	4.7E-12	0	0

	Fractions of ADI Times (yr)					
Contaminant	0	10	50	100	1500	2000
Chromium	0	0	0	0	2.5E-04	7.5E-04

REFERENCES

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