CONF-850242--1

DE85 004021

RADIOACTIVE RELEASES FROM A THORIUM-CONTAMINATED SITE IN WAYNE, NEW JERSEY

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ABSTRACT

Various residues and wastes from the production of thorium and rare earths from monazite ore are buried on a hillside in Wayne, New Jersey. In addition, contaminated materials (primarily soils) from nearby vicinity properties are being consolidated onto the Wayne site. The U.S. Department of Energy plans to stabilize all the contaminated materials on an interim basis (20 years) until funding is available to remove them to another location. In order to evaluate the effectiveness of interim stabilization measures, pre-remedial action radioactive releases are compared to estimated releases under a reference stabilization option (one meter of soil cover). Two potential pathways are examined: (1) airborne radioactive gases (thoron and radon) and particulates, and (2) seegage into the near-surface groundwater. The relative reduction of releases into the air and groundwater for the reference stabilization option is analyzed using mathematical models for radioactive gas fluxes and atmospheric dispersion as well as groundwater transport and dispersion. The consequent health implications for nearby individuals and the general population are also estimated. Health effects due to radioactive releases are estimated to be insignificant.

INTRODUCTION

The Wayne site of interest is located in the northeast corner of New Jersey in the western portion of Wayne Township, Passaic County, about 2.9 km north of the town of Wayne. It was formerly used for the processing of thorium ores (monazite sands), which contain naturally occurring radioactive elements. During operations, and subsequently during a decontamination effort, radioactive wastes were buried onsite and are still there. The concentration of thorium-232 ranges from 1.7

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to 2,008 pCi/g and that of radium-226 ranges from 0.8 to 337 pCi/g (Eng et al. 1983). The ratios of radium-226 and uranium-238 concentrations to total thorium concentrations varied widely in soil samples from the site, from approximately 0.3 to 35% of the thorium levels. Ratios of uranium-238 to radium-226 also were inconsistent, and no pattern was noted in these variations. These differences suggest that the materials encountered were from different processes and stages in operations conducted on the site (Frame et al. 1983).

ATMOSPHERIC PATHWAYS

Several potential pathways by which radionuclides could reach the general public through atmospheric transport are: (1) internal dose from inhalation of radioactive materials (gases and particulates), (2) external dose from submersion in a cloud of contaminated dust, and (3) external dose from radioactive particles deposited on the ground. Potential doses are quantified for nearby individuals and for the general public within an 80-km radius of Wayne based on the following assumptions and estimations:

- From radiological survey data, the condition of secular equilibrium is valid for the thorium-232 series nuclides but not for the uranium-238 series nuclides (Frame et al. 1983). The average concentrations of major radionuclides in the buried waste are assumed to be approximately 360 pCi/g for thorium-232 and 100 pCi/g for radium-226.
- Pre-remedial action particulate releases due to wind erosion of barren contaminated soil are estimated assuming that 10% of the waste-burial area is barren and using a wind erosion rate of 0.49 kg/ha/yr (Argonne Natl. Lab. 1982). Particulate releases are estimated to be 3.4×10^{-4} Ci/yr of thorium-232, 3.9×10^{-5} Ci/yr of uranium-238, and 9.3×10^{-5} Ci/yr of radium-226.
- Steady releases of radon and thoron are calculated by assuming that (a) the average depth of the contaminated materials is 2.5 m, (b) the unsaturated zone (average 13% moisture) on the top is 0.6 m and the saturated zone on the bottom is 1.9 m, and (c) a 1-m clean soil cover (also 13% moisture) is used for the reference stabilization option. Gas diffusion coefficients of 2.4×10^{-5} for saturated soils and 4.2×10^{-2} cm^2/s for unsaturated soils are used (Rogers et al. 1982).
- The population distribution for the 15 million people within 80 km of the Wayne site is estimated based on 1980 county census data.
- Meteorological conditions at Wayne are assumed to be similar to those at Newark, New Jersey, for which meterological data are available.
- To convert from radiation doses to health effects, the lifetime risks of cancer mortality per person-rem are assumed to be 120×10^{-6}, 2×10^{-6}, 90×10^{-6}, and 20×10^{-6} for the whole body, bone, lung, and bronchial epithelium, respectively (U.S. Dept. Energy 1983).

Gas fluxes from soil are calculated using a finite-difference model. Without cover, the gas fluxes are estimated to be 5.7 Ci/yr for radon and 3,500 Ci/yr for thoron. Only 3.6 Ci/yr of radon and an insignificant amount of thoron are expected with a 1-m soil cover. Without cover, the potential doses to nearby individuals are predicted to be only a small fraction of natural background radiation (Tables 1 and 2). For example, the maximally exposed individual has an annual

Table 1. Estimated Radiological Doses and Health Effects to Nearby Individuals and the General Public†[1]

Individual/ Location	Distance and Direction from Center of Waste Field	Dose (mrem/yr)			
		Whole Body	Bone	Average Lung	Bronchial Epithelium
WITHOUT COVER					
Resident A	90 m E	0.62	13.6	13.2	303
Resident B	300 m S	0.07	1.58	1.50	22.2
Resident C	210 m W	0.08	1.64	1.60	23.2
Resident D	150 m NE	0.39	8.47	8.23	162
EDC (person-rem/yr)		6.22	24.2	127	137
Potential cancer mortality (10^{-6}/yr)		746	48	11,430	2,740

Individual/ Location	Distance and Direction from Center of Waste Field	Dose (mrem/yr)			
		Whole Body	Bone	Average Lung	Bronchial Epithelium
WITH COVER					
Resident A	90 m E	<0.01	<0.01	<0.01	6.02
Resident B	300 m S	<0.01	<0.01	<0.01	0.73
Resident C	210 m W	<0.01	<0.01	<0.01	0.82
Resident D	150 m NE	<0.01	<0.01	<0.01	3.97
EDC (person-rem/yr)		0.09	0.20	0.08	11.7
Potential cancer mortality (10^{-6}/yr)		11	0.4	7	237

†[1] Bases for radiological analysis are given in the text.

Table 2. Doses to Maximally Exposed Individual†[1] Compared to Doses from Natural Background Sources

Annual Dose from Buried Wastes (Values from Table 1)	Comparable Dose
0.62 mrem (whole body)†[2]	Equal to dose received from riding about 56 minutes in a jet plane at 10,000 m (33,000 ft) because of increase in cosmic radiation with altitude
13.6 mrem (bone)†[2]	120 mrem received from natural radiation sources (background) per year
13.2 mrem (average lung)†[2]	130 mrem received from natural background radiation per year
302 mrem (bronchial epithelium)†[3]	320 to 600 mrem received from radon from natural background radiation per year

†[1] Estimated doses to Resident A prior to remedial actions (without soil cover)--taken from Table 1.

†[2] Conversion factors are given in reports of Argonne National Laboratory (1982) and National Council on Radiation Protection and Measurements (1975).

†[3] Assuming an outdoor radon-222 concentration of 0.3 pCi/L (Moses et al. 1963), an indoor concentration of 1 pCi/L (U.N. Sci. Comm. At. Radiat. 1977), and dose conversion factors for radon-222 of 1000 mrem/yr per pCi/L for outdoor background conditions (infinite source) and 625 mrem/yr for indoor conditions (50% equilibrium of radon daughters) (U.S. Nucl. Reg. Comm. 1980).

excess whole-body dose (over natural background) of only 0.62 mrem, which is equal to the dose received from riding less than one hour in a jet plane at 10,000 m. The 1-m soil cover can effectively reduce the doses by three or more orders of magnitude, primarily because the 1-m cover eliminates particulate releases and greatly retards the movement of thoron.

Doses to the general public are evaluated in terms of the 100-year environmental dose commitment (EDC). The radiation doses to the general population near the Wayne site from natural background are 1,500,000, 1,800,000, 2,700,000, and 5,000,000 person-rem per year for whole body, bone, lung, and bronchial epithelium, respectively. The population doses are predicted to be negligible compared to the doses the same population would receive from natural background sources of radiation (Table 1).

GROUNDWATER PATHWAY

The ground surface at the site rises from about 60 m MSL (mean sea level) near the northwestern corner to about 69 m MSL on the eastern side. The site contains two soil types: (1) urban land-riverhead complex (in the flatter western areas where buildings are located), comprised of well-drained soils with a deep water table (>1.8 m deep), and (2) urban land-rockaway complex (in the hilly eastern area of the site where the wastes are buried), comprised of well-drained soils with a high seasonal water table (0.5 to 0.76 m deep) (Seglin 1975). The site is underlain by unconsolidated glacial deposits of clay, silt, sand, and gravel to a depth of about 21 m. The glacial deposits are underlain by sedimentary reddish-brown mudstone, sandstone, and siltstone of the Brunswick Formation of Triassic age (Carswell and Rooney 1976). Both the glacial deposits and the Brunswick Formation are major sources of groundwater in the region.

Information regarding movement of groundwater at the Wayne site is not yet available. However, the presence of an artesian well on the site and a nearby spring on a farm suggests that groundwater from the bedrock Brunswick aquifer moves towards the ground surface (Eng et al. 1983). Groundwater in the consolidated glacial deposits probably follows surface contours and hence probably flows from east to west across the site.

A potential pathway for radiation exposure in the vicinity of the waste-burial area is direct ingestion of contaminated groundwater. Radionuclides will be leached out of the buried wastes and residues by infiltration of rainfall and carried into the groundwater system. Because there is a limited amount of site-specific data for the bedrock aquifer and because the groundwater from the bedrock aquifer moves toward the ground surface, only the transport of radionuclides in the shallow near-surface aquifer is considered in this study. The groundwater flow is assumed to be under steady-state and isothermal conditions. Groundwater movement is conservatively assumed to be unidirectional in the east-west direction. With regard to groundwater contamination in the surficial aquifer, the radionuclide of most concern is radium-226 because radium is more mobile than the other contaminants (Gilbert et al. 1983). The movement of radium-226 through the saturated aquifer is governed by (1) the mass conservation requirement, (2) ingrowth of radium-226 from radioactive decay of thorium-230, and (3) radioactive decay of radium-226.

In this study, a three-dimensional model developed at Oak Ridge National Laboratory (Yeh 1981) is adapted to calculate groundwater concentrations at a particular time and location. A list of input data for the groundwater migration analysis is given in Table 3. The release rate of radium-226 from the waste burial area is estimated by the ion-exchange model (Gilbert et al. 1983). Because of the uncertainties relative to hydrogeological conditions at the site, selected values of input parameters in Table 3 tend to be conservative. The potential contamination of groundwater in the burial site under existing conditions (without soil cover) and for the reference stabilization option (with 1 m of soil cover) are analyzed by determining the

Table 3. Summary of Parameters Used for Calculation of Ra-226 Concentration in Groundwater

Parameter	Unit	Value
Annual precipitation	m/yr	1.22
Surface runoff coefficient	-	0.15
Evapotranspiration rate	m/yr	0.63
Infiltration rate	m/yr	0.41
Bulk density of soil	kg/m^3	1,380
Effective porosity	-	0.1
Hydraulic conductivity	m/s	1.0×10^{-7}
Hydraulic gradient	-	0.08
Longitudinal dispersivity	m	50
Vertical dispersivity	m	5
Traverse dispersivity	m	5
Distribution coefficient	m^3/kg	0.1
Radioactive decay constant:		
Ra-226	1/yr	4.33×10^{-4}
Th-230	1/yr	9.02×10^{-6}
Leach constant	1/yr	1.98×10^{-3}
Waste field dimensions	m	$40 \times 140 \times 2.5$

ratio of the radium-226 concentration in groundwater (C) to the radium-226 concentration in the waste (S). The concentration of radium-226 in the groundwater can then be computed by multiplying this ratio by the radium-226 concentration in the waste.

The release rate of leachate would be about the same for both options, assuming well-drained soils are used for the cover. Only results on a vertical cross section paralleling the east-west direction and passing through the center of waste area are shown in Figures 1 through 3. As indicated by the results given in Figures 1 and 2 for time frames of 20 years and 1,000 years, high radium-226 concentrations would be limited to the area below the waste field. The vertical concentration profiles for radium-226 at 40 m and 80 m from the waste source are shown in Figure 3. No elevated radium-226 concentrations are predicted beyond 80 m from the eastern edge of the waste (about 40 m from the western site boundary). Using the radium-226 concentration of 100 pCi/g in the waste, the concentration of radium-226 in groundwater at 80 m would be zero at 20 years and about 0.1 pCi/L at 1,000 years (Figure 3). These concentrations are within the current EPA drinking water standard of 5 pCi/L (corresponding to C/S of 0.05 in the figures). The concentrations of thorium are not presented because thorium is quite strongly bound to the soil and the extent of its migration is much less due to the relatively high distribution coefficient of this radionuclide (mean value about 60 m^3/kg). Based on these results, it is concluded that the potential impact of radionuclides released from the site does not seem likely to threaten the quality of groundwater outside the site boundary within the time frames considered.

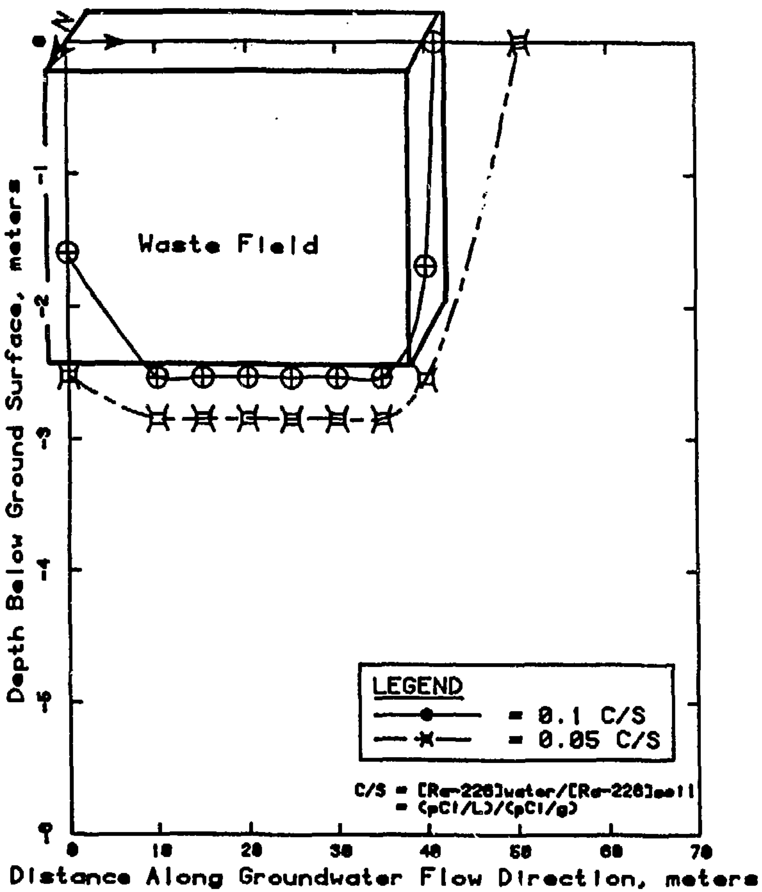

Figure 1. Ratio of Radium-226 Concentration in Groundwater to Concentration in Waste After 20 Years.

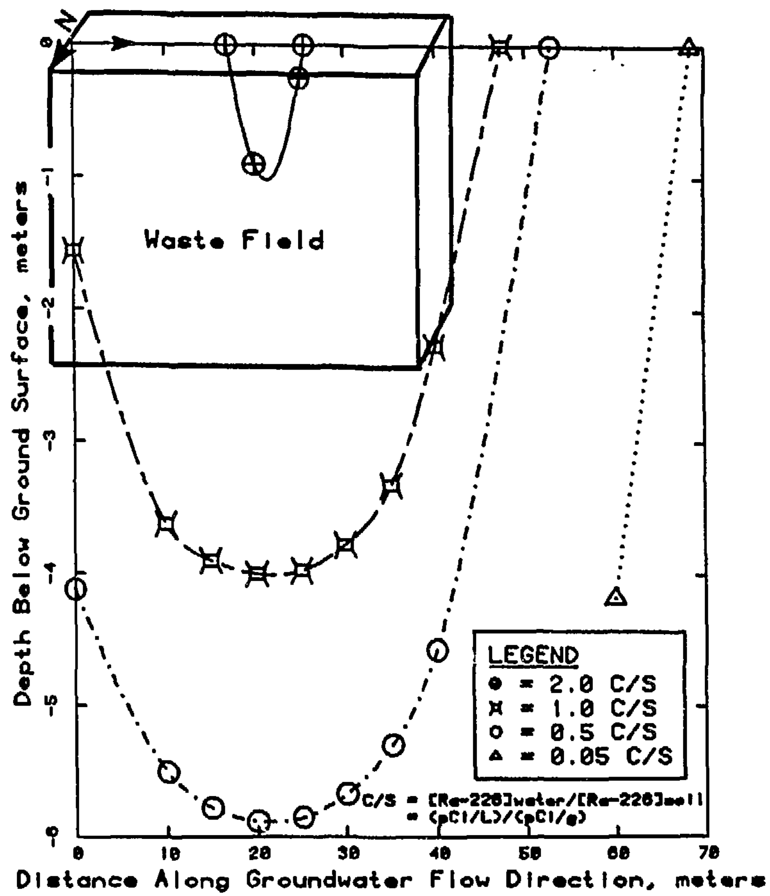

Figure 2. Ratio of Radium-226 Concentration in Groundwater to Concentration in Waste After 1,000 Years.

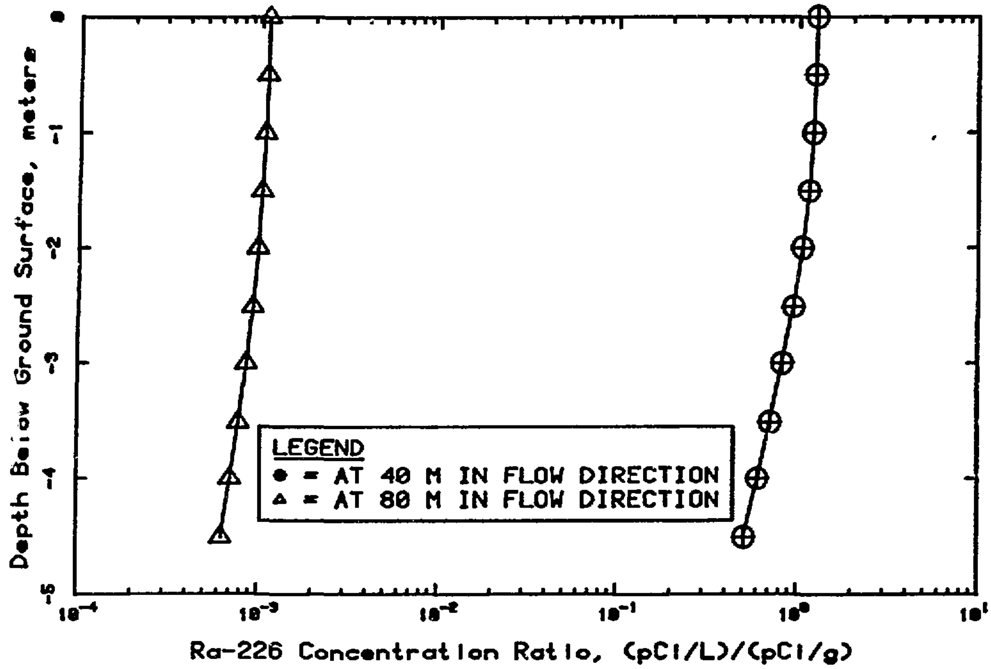

Figure 3. Vertical Concentration Profile for Radium-226 at 40 and 80 Meters After 1,000 Years.

CONCLUSION

Based on the mathematical simulation for migration of radionuclides via atmospheric dispersion and groundwater transport, the potential health effects to maximally exposed individuals and the surrounding general public due to radioactive releases from the thorium-contaminated site at Wayne will be insignificant. The addition of a one-meter soil cover can effectively eliminate most radiation doses via atmospheric pathways. If onsite controls are maintained and wells are not allowed in the onsite surficial aquifer downgradient of the burial area, adverse health effects will not occur.

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