SHALLOW-LAND BURIAL OF LOW-LEVEL RADIOACTIVE WASTES: PRELIMINARY SIMULATIONS OF LONG-TERM HEALTH RISKS*

by

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INTRODUCTION

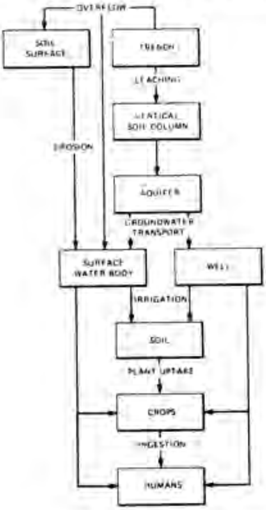
PRESTO (Prediction of Radiation Exposures from Shallow Trench Operations) is a computer code developed under United States Environmental Protection Agency funding to evaluate possible health effects from radionuclide releases from shallow, radioactive-waste disposal trenches and from associated areas contaminated by operational spillage. This model is designed to simulate transport of radionuclides from the disposal site and to predict radionuclide exposures and cancer risks for the 1000 y period following the end of burial operations. PRESTO is a versatile methodology for calculating risks to local and intermediate range populations resulting from water borne and air borne transport (Little, et al., 1981 and Fields, Little and Emerson, 1981). The DARTAB code (Begovich, et al., 1981) is used by PRESTO as a subroutine to combine simulated radionuclide exposure values with dose and health risk factors to produce tabulations of dose and health risk.

Our model development contract with the Environmental Protection Agency specifies that certain test runs must be performed for three existing low-level waste burial areas. We have prepared the first of the required data sets and have simulated radionuclide release and transport and the accompanying exposure and health risk for some of the at-risk populations. Whereas these results should be regarded as preliminary in nature, they demonstrate that the model is performing in a reasonable manner, and allow certain conclusions to be drawn regarding site suitability and relative radionuclide impact.

MODEL CONSIDERATIONS

The computer code used in these simulations is modular and organized according to transport pathways to permit future expansion and refinement. Figure 1 denotes the major pathways of hydrologic transport considered in this model. Near-surface transport mechanisms considered are trench cap failure, cap erosion, farming or reclamation practices, human intrusion, chemical exchange within an active soil layer, contamination from trench overflow, and dilution by surface streams. Subsurface processes include infiltration and drainage into the trench, the ensuing dissolution of radionuclides, and chemical exchange between trench water and buried solids. Mechanisms leading to contaminated water outflow include trench overflow and downward vertical percolation. If the latter outflow reaches an aquifer, the model considers radiological exposure resulting from drinking contaminated water and from irrigation and subsequent ingestion.

Wind-driven human exposure pathways are schematized in Fig. 2. Atmospheric transport of contaminant deposited in normal operations or carried to the surface bv trench overflow is handled either by an internal Gaussian plume approach based on the DWNWND model (Fields and Miller,



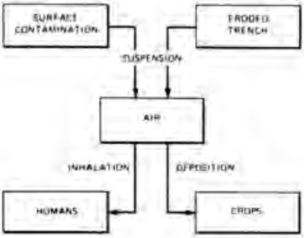


Fig. 1. (Left) Shown here are the major pathways of hydrologic routing considered in the PRESTO model. Sources of radionuclides are the trench contents and the surrounding soil surface, assumed to be contaminated during trench filling and covering operations, and by trench water overflow.

Fig. 2. (Right) Soil surface contaminant may be suspended by winds or mechanical disturbances and transported downwind. Human exposure may result either by inhaling the suspended solids or by consuming food on which the radionuclides have been deposited.

1980) that considers exposed individuals to be located at the population centroid, or by an externally computed and user input exposure term. This exposure term should be calculated using the actual population distribution.

SIMPLIFYING MODEL ASSUMPTIONS

The transport-related computations are simplified by several assumptions. First, daughter nuclide ingrowth resulting from radioactive decay is not calculated because, for the most part, the inventory of commercial low-level waste burial grounds includes few radionuclides that yield long chains. We assume that for those radionuclides not having significant daughter ingrowth, secular equilibrium has been attained by the time of site closure. Daughters, if any, must be assumed present initially. Chemical reactions are not considered explicitly. Instead, they are parameterized using element-specific chemical solubilities or chemical distribution coefficients Kd. Different values of exchange coefficients may be specified for different physical regions (surface soil, trench, sub-trench soil, and aquifer material) of the transport pathway. Waste material in the trench is considered uncontained and homogeneous. Perhaps the most useful simplification consists of expressing as many mechanisms as possible in "unit response" form, so that a single sub-model run yields results applicable in each of 1000 model iterations. This approach permits the model to run fairly inexpensively.

SITE CHARACTERIZATION

Sites chosen for simulations were located near Barnwell, South Carolina, Beatty, Nevada and West Valley, New York. The sites were characterized as to location, meteorology, soil characteristics, and geography. Initial trench inventories were obtained from the Barnwell staff for the South Carolina site and from the Environmental Protection Agency (Giardina, et al., 1977) for West Valley. For simulation purposes, we estimate the Beatty site inventory by taking, for each radionuclide, the larger of the inventory values for the Barnwell and West Valley sites. We have in the absence of actual data, arbitrarily assumed that surface contamination exists due to operational spillage during normal operations in an amount of 1×10^{-8} of the initial trench inventory. Initial trench inventories for the Barnwell and West Valley sites are shown for comparison purposes in Fig. 3.

Site data for surface and subsurface environmental variables were taken from United States Geological Survey data, site operator literature, and other literature, as summarized in the interim model report (Little, et al., 1981).

AT-RISK POPULATIONS

The PRESTO model is designed to consider three basic activities that may place humans at risk. These are (1) normal operations, which may lead to surface contamination from operational spillage and to

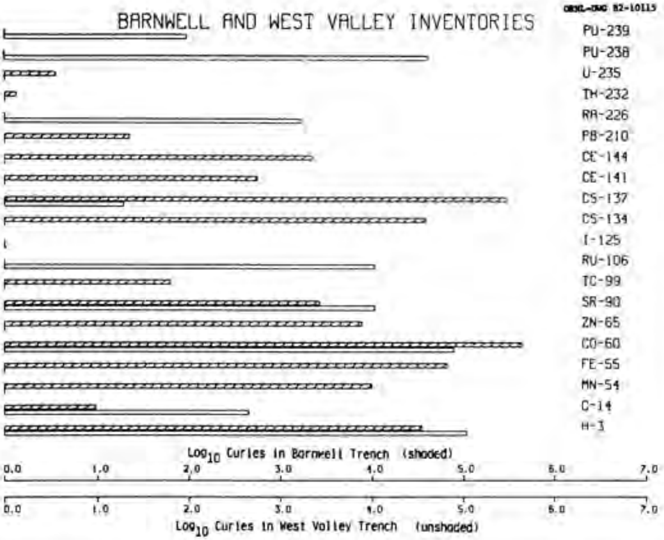


Fig. 3. Barnwell and West Valley trench partial inventories at the close of normal operations are shown here. This is the time at which the transport simulation is begun. The surface radionuclide inventory is for each radionuclide assumed to be 1 x 10^{-8} of the amount in the trench (see text). In these and in subsequent plots, values less than or equal to the minimum scale value are plotted at the minimum value.

ultimate long-term exposure resulting from atmospheric and hydrologic processes; (2) human intrusion, which includes as exposure modes drinking water pumped from below the trench and living in a basement extending into the buried material; and (3) site reclamation and farming.

The initial simulation results described here are presented on a per individual basis. Populations at risk from buried wastes are assumed to breathe air at a distance corresponding to the location of the nearest existing population center. Thus, the distance from the radionuclide burial area was chosen to be 8000 m for the Barnwell site, 6500 m for the West Valley site and 16800 m for the Beatty site.

Water for the Barnwell population was assumed taken from a well located 914 m from the site boundary. We consider this to be a very conservative, although not a worst case, assumption.

RESULTS

The Barnwell site is characterized by a high annual rainfall rate and highly permeable soils. As a result, the pathway of maximum risk is expected to be water-mediated radionuclide migration downward to the aquifer and subsequent horizontal transport to wells or surface seepage points. This expectation is confirmed in Figs. 4 and 5, which compare the 1000-yr average simulated radionuclide concentrations in local stream water and in local downwind atmosphere with levels appearing in well water, also used for irrigation in these simulations. Of interest is the significant concentration of Tc-99 in well water. Radionuclides other than Tc-99, C-14 and H-3 appear in relatively more significant levels in stream water and in downwind atmosphere than in well water, a result of the operational spillage source term.

In considering groundwater-borne radionuclide reaching a surface-accessible point such as a well or seepage area, quantities of interest include both the radionuclide concentration and its temporal profile. Concentrations at wells or surface seepage points may be characterized as to the breakthrough time, at which the leading edge of the subsurface

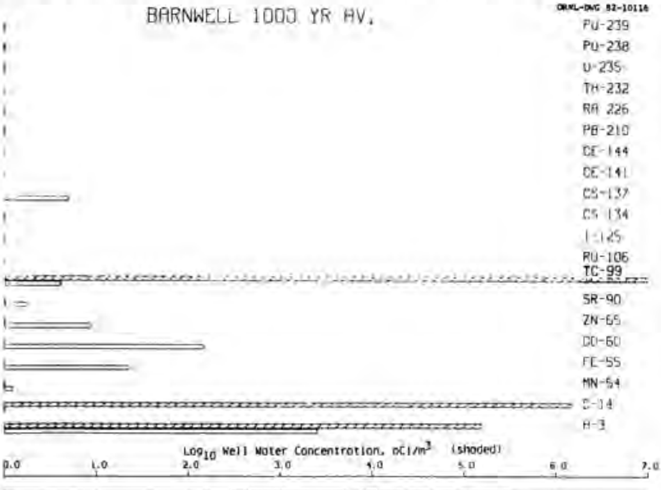


Fig. 4. The 1000 y average radionuclide concentration in the surface stream, following dilution, is compared to the corresponding value for a hypothetical well located 914 m from the Barnwell site boundary.

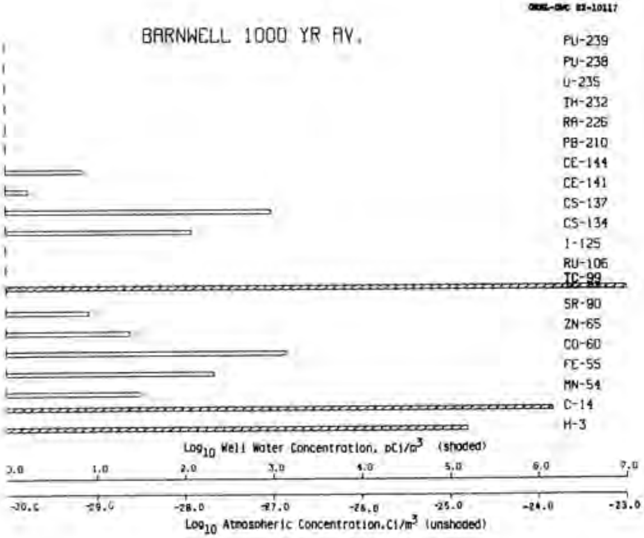


Fig. 5. The 1000 y average radionuclide concentration in the atmosphere 8000 m from the site boundary, is compared to the 1000 y average concentration at a hypothetical well located 914 m from the Barnwell site boundary.

contaminated water profile reaches the point of interest. As a result of the element-specific chemical exchange between solid and water, the breakthrough time is different for different radionuclides. Simulated breakthrough times for a surface seepage point or well located 914 meters from the edge of the burial site at Barnwell are shown in Fig. 6. Nuclides having high concentration at the outflow, such as Tc-99, will usually have low chemical distribution coefficients and short breakthrough times. Figure 6 indicates that some elements have breakthrough times less than the simulation period, in this case 1000 years. It is these elements for which a non-zero risk may be computed for the subsurface pathway.

Radionuclide exposure results from inhalation and ingestion of transported material, and 1000 y average values for ingestion and inhalation for the Barnwell site are shown in Fig. 7. Tc-99, C-14 and H-3, all of low chemical distribution coefficient, are transported via the subsurface pathway and contribute strongly to the ingestion intake. Much lower intakes, but not necessarily smaller health impacts, result

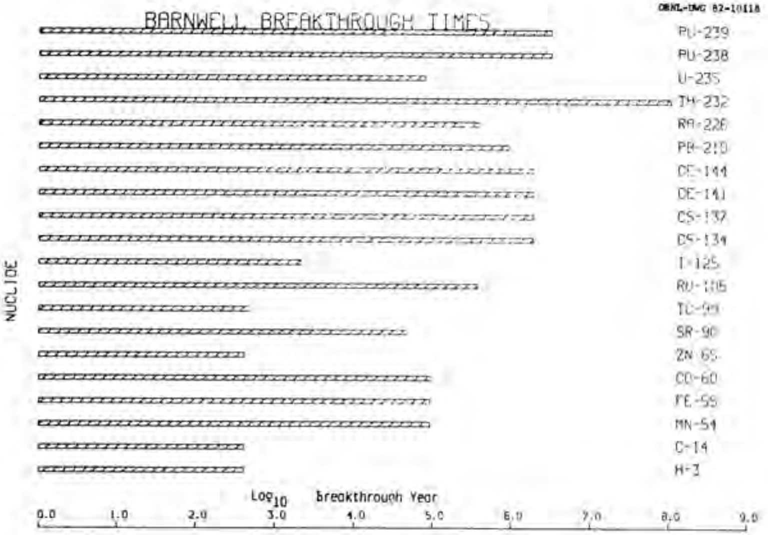


Fig. 6. The breakthrough time for a radionuclide undergoing hydrologic transport through an aquifer depends on the chemical distribution coefficient Kd for the radionuclide, the flow length, the hydrologic flow rate, the aquifer bulk density and the aquifer porosity. Values for the Barnwell site indicate that, for a 1000 y simulation, the radionuclides H-3, C-14, Zn-65 and Tc-99 will reach the assumed outflow point 914 m distant from the site boundary.

from radionuclides transported by winds, and levels of the wind-transported radionuclides reflect the initial inventory of radionuclides stored at the Barnwell site, shown in Fig. 3, as modified by radioactive decay.

When Fig. 7 is considered with Fig. 8, which compares simulated health risks (cancers) per person-year to the initial radionuclide trench inventory, one observes that some radionuclides of highest risk, such as Tc-99, are transported chiefly through the subsurface pathway, while others, having a higher chemical distribution coefficient, are primarily transported by air. That Cs-137, Cs-134 and Co-60 generate no health risk for 1000 y of subsurface transport is suggested by consideration of the breakthrough times shown in Fig. 6.

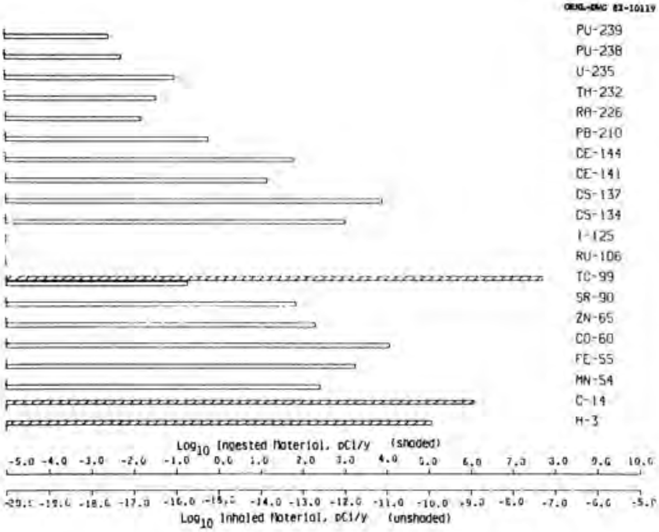


Fig. 7. Simulated average human radionuclide intakes for the Barnwell site are compared for the ingestion and inhalation pathways. Whereas all radionuclides present in the surface contaminant inventory give some, albeit small, intake via inhalation, the major intakes result from ingestion of Tc-99, C-14 and H-3, which are transported via subsurface hydrologic flow.

Also of interest for this site is the simulated release to the surface of the trench contents due to erosion of the trench cap, a process simulated to occur for this site at a rate of about 1 mm/year. This release occurs after most of the radionuclide inventory has decayed, but nevertheless it is a major contributor to the surface contaminant inventory.

Simulation results for the West Valley, New York site predict that health risks are incurred for both the airborne pathway and the surface water-mediated transport pathway. The source term for atmospheric transport is due to both operational spillage and to contaminant transported to the surface during trench overflow. Irrigation with well water contributes little to risk since, due to the impermeable soil and deep water table, a radionuclide concentration of zero was simulated for a well located 100 m from the West Valley site boundary. Health risks due to ingestion depended greatly on whether crops were irrigated and, if so, if the source of water was a deep (uncontaminated) well or a surface stream. The major radionuclide contributors to risk for the West Valley site are Co-60, Pu-238 and Ru-106.

Our initial simulations for the Beatty, Nevada site indicate comparatively little health risk ensues from downward-migrating radionuclides. This result follows from the low annual precipitation and deep water table at this site. The primary exposure pathway at Beatty is via suspended airborne particulates which were contaminated by spillage during normal operations. The major radionuclide contributors to risk appear to include Tc-99, Am-241, Cs-137 and Co-60.

DISCUSSION AND CONCLUSIONS

Preliminary simulations have been performed for several release scenarios at three specific sites having different waste inventories, geophysical characteristics and population distributions. Doses and health risks to nearby populations have been discussed.

The sum of all nuclide specific risks shown in Fig. 8, yields an estimated initial annual risk for a unit local population from waste buried at the Barnwell disposal facility of 7.8×10^{-7}. If the local population is assumed to be stable at the current value of 7033 persons, the corresponding estimated risk value is 8.5×10^{-9}. For an average lifetime of 70.7 years, the probability of an average individual (from a population of 7033) dying of cancer induced by radionuclides disposed of at this site is therefore 6×10^{-7}. The radionuclide is of course assumed to be distributed between trench and surface, and transported, as previously described. In comparison, the current annual death rate due to cancer for the United States population is 183.5 per 100000 persons (Lane, 1981), so the unit probability of dying by cancer, excepting that associated with the Barnwell wastes, is 1.8×10^{-3}. This exceeds the yearly death probability for average local individuals due to the Barnwell wastes by a factor of 21000. The fraction of deaths in the general population due to cancer is .21 (Lane, 1981), so the fraction of deaths that are radionuclide-linked over the 1000 y period considered here is given by 874 per 100000, divided into 8.5×10^{-9}, which yields a value of 9.7×10^{-7}, or about one in one million deaths. Most risk is due to Tc-99, which is primarily transported by the subsurface pathway, and which has a maximum impact several hundred years (based on computed breakthrough times and concentration time profiles) after site closure.

The risk per individual per unit radioactivity associated with burial operations at the Beatty site is lower than for the Barnwell site, although uncertainties in our data for the Beatty inventory make comparisons of simulated risks between these sites less meaningful.

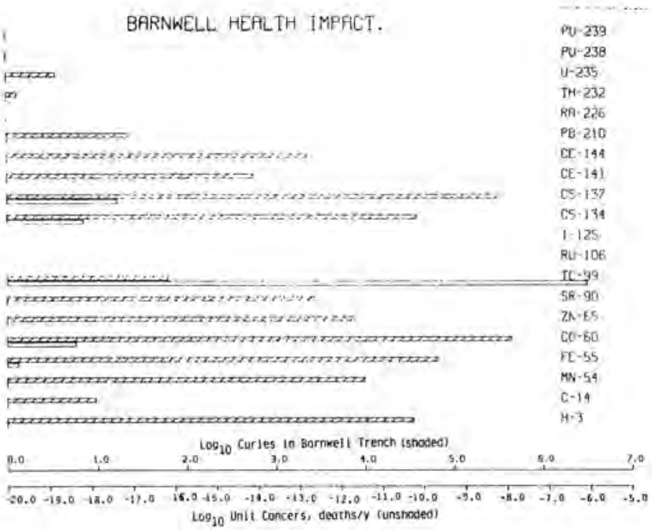


Fig. 8. The simulated 1000 y average health impact for one individual breathing air 8000 m downwind and drinking and irrigating with well water pumped 914 m "downstream" from the Barnwell site aquifer are compared with the initial trench inventory. The major contributors to risk are Tc-99, Cs-137, Cs-134 and Co-60. The sum of all health impacts shown above is approximately four orders of magnitude below the "background" death rate. When a representative local population of 7033 is assumed, the unit death rate is about 6 orders of magnitude below the background death rate.

Initial results therefore tend, in general, to support the disposal option of shallow-land burial for some short-lived radionuclides. The dominance of one exposure mode over others for certain combinations of site and radionuclide characteristics is also apparent. Still other results, including consideration of breakthrough times, suggest that undesirable health consequences might be reduced by adapting a time-varying containment/isolation strategy. For example, contamination of well waters fed by aquifers flowing "downstream" from disposal areas may be measurably above background only in certain relatively short periods. Awareness of the existence of these periods may allow use of alternate wells to reduce exposure levels.

Major determinants of health risk include trench inventory, disposal practices, site geology, local meteorology, local population (including number and distribution), and their life style (e.g., whether individuals are considered farming or non-farming, etc.).

Low-probability release events, such as meteors and trench fires, were not considered in our simulations. This omission may be particularly significant for the Beatty site, where buried wastes appear to have, under non-catastrophic circumstances and among considered sites the least potential for environmental transport. Our results indicate that hydrologically inactive sites such as Beatty may be preferred over sites where hydrologic transport, either through subsurface transport, erosion, or trench overflow, is an important factor in radionuclide movement.

Simulation results presented here must be regarded as initial estimates only. Uncertainties associated with our results may be large. We have proposed to evaluate the uncertainties associated with predictions of the PRESTO model, as functions of the precision with which input variables are known. Determination of the sensitivity of model results to variations in model input values would indicate where efforts to gather data would be most gainfully applied. Measurements of the levels of ground surface contamination need to be made at each of the existing shallow-land burial sites. Such information and data would be of great value when decisions are to be made regarding disposal of low-level radioactive wastes.

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