EXPOSURE AND RISK CALCULATIONS FOR DISPOSAL OF WASTES HAVING MINIMAL RADIOACTIVITY

David E. Fields

Health and Safety Research Division
Oak Ridge National Laboratory*
Oak Ridge, Tennessee 37830

ABSTRACT

The U.S. Nuclear Regulatory Commission is currently considering revision of rules 10 CFR 20 and 10 CFR 61, which cover disposal of solid wastes containing minimal activity radioactivity. In support of these revised rules, we have evaluated the consequences of disposing of four waste streams at four types of disposal areas located in three different geographic regions. Consequences are expressed in terms of human exposures and associated health effects. Each geographic region has its own climate and geology. Example waste streams, waste disposal methods, and geographic regions chosen for this study are clearly specified.

The PRESTO-II methodology was used to evaluate radionuclide transport and health effects. This methodology was developed to assess radiological impacts to a static local population for a 1000-year period following disposal. The modeling of pathways and processes of migration from the trench to exposed populations included the following considerations: groundwater transport, overland flow, erosion, surface water dilution, resuspension, atmospheric transport, deposition, inhalation, and ingestion of contaminated beef, milk, crops, and water.

INTRODUCTION

The U.S. Nuclear Regulatory Commission is currently considering revisions of rules 10 CFR 20[1] and 10 CFR 61,[2] which cover disposal of solid wastes, including wastes containing minimal radioactivity. Wastes containing minimal levels of activity are expected to be disposed of without special attention to post-burial radionuclide releases. Quantitative definition of minimal levels of activity may be included in a revision to the aforementioned rules.

In order to establish the maximum radionuclide concentrations and/or amounts that low-level wastes may contain and still be considered minimal activity, it is necessary to consider the consequences of waste disposal for example situations. An example situation is defined as the combination of a well-characterized waste stream, a specific disposal site and disposal mode, a sample set of site parameters which is used to simulate transport from the disposal site to at-risk population, and a data base of exposure and health risk parameters which is used to evaluate consequences to the population(s) of interest.

This study describes the evaluation of human exposures and health risks for 48 example cases. These cases consist of the combinations of four waste streams, four types of disposal methodologies, and three different geographic regions. Each waste stream is specified as to the concentration of each of 23 radionuclides contained in it. Each waste stream is a generalized industrial waste product. The streams considered in this study are (1) dewatered pressurized water reactor (PWR) ion exchange resins, (2) PWR compressible trash, (3) boiling water reactor (BWR) compressible trash, and (4) institutional liquid scintillation waste. The four types of disposal methodologies are (1) burial at a (low-level) radionuclide waste disposal facility; (2) burial at a reactor site; (3) burial at a municipal waste disposal facility; and (4) dispersal into the general environment. The geographic regions in this study were considered to have geoclimatology similar to, for region A, Barnwell, South Carolina; for region B, Beatty, Nevada; and for region C, West Valley, New York, since data for these sites are available.

A version of the PRESTO-II[3] (Prediction of Radiation Exposures from Shallow Trench Operations) model was chosen for evaluation of radionuclide transport and health effects.

METHODOLOGY

The PRESTO-II code[3] is an extension of the PRESTO-EPA model, which was developed under U. S. 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-year period following the end of burial operations. PRESTO is a versatile methodology for calculating risks to local and intermediate-range populations from waterborne and airborne transport.[4,5] The DARTAB code[6] is used by PRESTO-II as a subroutine to combine simulated radionuclide exposure values with dose and health risk factors to produce tabulations of dose and health risk.

The computer code used in these simulations is modular and organized according to transport pathways. 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

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*Operated by Union Carbide Corporation with the U.S. Department of Energy under contract W-7405-eng-26.

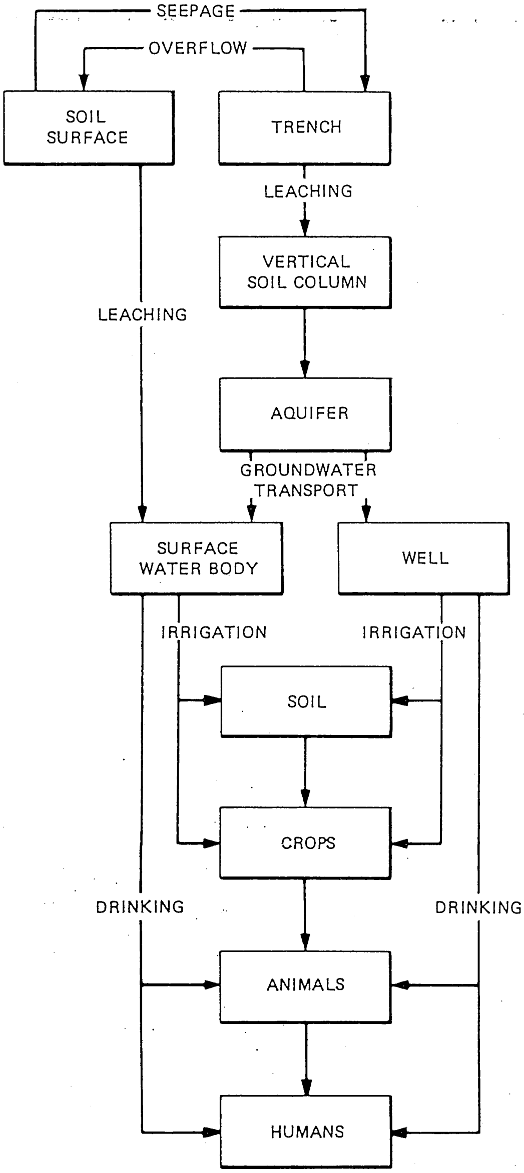

Figure 1. Major pathways of hydrologic routing considered in the PRESTO-II model.

between trench water and buried solids. Mechanisms leading to contaminated water outflow include trench overflow and downward vertical percolation. The model considers radiological exposures resulting from drinking contaminated aquifer and stream water and from irrigation and subsequent ingestion of crops.

Wind-driven human exposure pathways are shown in Fig. 2. Atmospheric transport of contaminant deposited in normal disposal operations or carried to the surface by trench overflow is handled either by an internal Gaussian plume approach based on the DWNWND model^7 that considers exposed individuals to be located at the population centroid, or by an externally computed and user input exposure term.

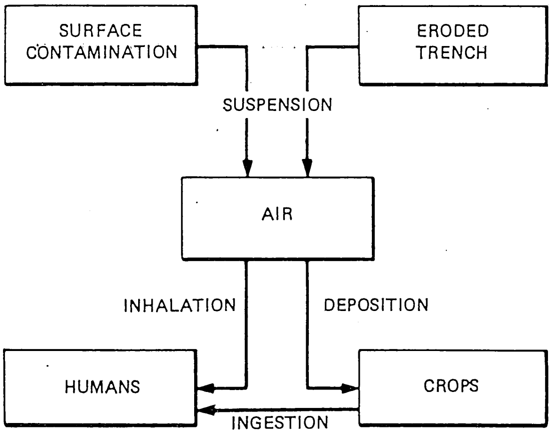

Figure 2. Major pathways of atmospheric routing considered in the PRESTO-II model.

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 decay chains. We assume that for those radionuclides that do have 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 explicitly considered. Instead, they are parameterized using element-specific chemical solubilities or chemical distribution coefficients, k_d. Different values of the exchange coefficient may be specified for different physical regions (surface soil, trench, sub-trench soil, and aquifer material). Waste material in the trench is considered uncontained and homogeneous.

CHARACTERIZATION OF WASTE STREAMS

Radionuclide concentrations for four example waste streams used in the minimal activity study simulations were specified by the NRC. The radionuclide composition was based on previous NRC work in support of rule 10 CFR 61^2. These waste streams were characterized as (1) resins from PWR's with condensate polishing systems (PIXRESIN); (2) PWR compactible trash (PCOTRASH); (3) BWR compactible trash (BCOTRASH); and (4) institutional liquid scintillation waste (ILQSCNVL). Table I summarizes the radionuclide concentrations in these waste streams for 23 radionuclides. Also provided by the NRC were expected yearly production volumes and activities, for a 1000 MW(e) plant, for the first three waste streams. A volume and activity of ILQSCNVL were also provided, but these amounts were for an anticipated production of ten years for the entire United States, presumed to be packaged for shipment to and disposal at a single waste disposal site. Values used in the exposure and risk calculations are for PIXRESIN, 9.06 m^3 and 0.304 Ci; for PCOTRASH, 215 m^3 and 4.9 Ci; for BCOTRASH, 221 m^3 and 5.2 Ci (these three values corresponding to a generation period of one year for a 1000 MW(e) plant) ; and for ILQSCNVL, 1.67×10^4 m^3 and 53.8 Ci (the last value corresponding to a generation period of ten years). The radionuclide volumes were used to estimate the areas used for radionulide disposal.

Table I Radionuclide concentrations ($\mu Ci/cm^3$) in example waste streams.

Nuclide	PIXRESIN[a]	PCOTRASH[b]	BCOTRASH[c]	ILQSCNVL[d]
H-3	2.66E-3	3.04E-4	6.75E-5	1.67E-3
C-14	9.74E-5	1.12E-5	4.17E-6	8.37E-5
FE-55	2.34E-3	5.97E-3	6.01E-3	0.0
NI-59	2.79E-6	7.11E-6	6.21E-6	0.0
CO-60	4.53E-3	1.15E-2	1.01E-2	0.0
NI-63	8.61E-4	2.19E-3	1.36E-4	0.0
NB-94	8.84E-8	2.25E-7	1.96E-7	0.0
SR-90	1.94E-4	2.22E-5	1.27E-5	1.45E-3
TC-99	8.23E-7	9.42E-8	2.68E-7	0.0
I-129	2.44E-6	2.78E-7	7.14E-7	0.0
CS-134	8.23E-7	9.42E-8	2.68E-7	0.0
CS-137	2.19E-2	2.51E-3	7.14E-3	0.0
U-235	4.71E-8	7.89E-9	1.22E-9	0.0
U-238	3.71E-7	6.22E-8	9.60E-9	0.0
NP-237	9.06E-12	1.52E-12	2.35E-13	0.0
PU-238	2.60E-5	5.97E-6	2.30E-6	0.0
PU-239	1.82E-5	5.53E-6	1.16E-6	0.0
PU-241	7.94E-4	2.41E-4	5.63E-5	0.0
PU-242	3.99E-8	1.21E-8	2.53E-9	0.0
AM-241	1.87E-5	3.96E-6	9.67E-7	0.0
AM-243	1.26E-6	2.67E-7	6.52E-8	0.0
CM-243	9.92E-9	2.74E-9	1.93E-9	0.0
CM-244	1.38E-5	2.61E-6	1.49E-6	0.0

[a] Resins from pressurized water reactors with condensate polishing systems

[b] Pressurized water reactor compactible trash.

[c] Boiling water reactor compactible trash.

[d] Institutional liquid scintillation waste.

Table II. Classification of sites considered in minimal activity study.

Site Classification	Assumptions for Initial Simulations
Burial at Low-level Waste Disposal Site (L)	Site-specific climatological, geological, and demographic data are used. Low level waste disposal sites considered are Barnwell SC, Beatty NV and West Valley NY. The ground surface is assumed contaminated by operational spillage present in an amount per radionuclide of 10^{-6} of the buried amount. Water use for ingestion and farm use is 0.5 from well and 0.5 from stream. Ratio of trench cap to undisturbed site infiltration is 0.5.
Burial at Reactor Site (R)	Site similar to type (L) site, except that reactor is assumed near stream, and water table is 0.5 m below the bottom of the trench. Stream is assumed located 50 m downslope of disposal area. For initial runs, well position is same as for type (L).
Burial at Municipal Site (M)	Similar to type (L), except that well distance = 500 m for all sites. Dilution of radionuclide wastes by nonnuclear wastes accounted for by assuming large trench area. Ratio of trench cap to undisturbed site infiltration is assumed to be 1.0
Disposal in General Environment (G)	A stream dump of the waste stream is assumed. Site climate and demographics are identical to type (L) but water use is assumed totally from stream

In addition to the specified disposal inventory, we have assumed that an additional surface contamination results from spillage during normal operations. In the absence of actual measurements of the amount of such spillage, we have arbitrarily assumed this amount to be 1×10^{-6} of the initial trench inventory. It may be that the spillage would be greater at municipal facilities. This might result from more extensive and less carefully managed spreading and crushing operations. In the absence of actual data, however, and in keeping with the simplifications made in dealing with generic site data, the spillage source terms have been assumed to be identical for each of the sites.

CHARACTERIZATION OF DISPOSAL SITES AND CLIMATES

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, demography, soil characteristics, and geography. Sites considered here are generic, and should not be assumed to correspond to any single, actual low-level waste, reactor, or municipal site.

Table II summarizes the classes of disposal sites considered in this study. These classes will be described in more detail in the following paragraphs.

The first class of disposal site to be discussed will be the low-level waste disposal site. One site was located in each of the three geographical regions considered in this study. Low-level waste disposal site input parameters were based on values described in the PRESTO-II document.[3] For each waste form, the trench area was calculated by dividing the yearly waste volume for the waste stream being considered by 2 m (an approach consistent with an assumed waste layer thickness of 2 m). The cross slope extent of the spillage was assumed to be the square root of the trench area. This choice of cross slope extent ties the parameter value to the length of one side of a square trench and makes the value responsive to the actual waste volume. For low-level disposal simulations as well as for simulations for other modes of disposal considered in this study, it was assumed that some of water use was from a well drilled into an aquifer and 50% was from surface waters. This assumption introduces more uncertainty in model predictions for arid sites than for humid sites, since water sources in arid regions are more likely to include distant reservoirs and surface waters are less likely to serve as a source of potable water. Predicted human exposures and health risk are highly dependent on sources of water, however, for the generic simulations described here, it was decided to use the same water use factors for all sites.

Simulations of consequences from burial at a reactor site were consistent with the location of a reactor in the same geographical region as the low-level waste disposal site, but with location near a surface water body (assumed to be a river). The distance to the stream was assumed to be only 50 m (downslope) and the water table was assumed to be only 0.5 m beneath the bottom of the trench.

Simulations of consequences from burial at a municipal site were consistent with location of the municipal site in the same geographical region as the low-level waste disposal site, but with the horizontal distance from the primary water supply (well) to the point below the disposal area set to 500 m for all runs. For the municipal site, significant dilution of the radionuclide wastes by nonradioactive wastes was assumed. The radionuclide waste thickness was assumed to be only 0.05 m, so the trench area was the yearly waste stream volume divided by 0.05 m.

Simulations of disposal of radionuclide waste streams in the general environment were based on dumping the waste stream into surface waters. Populations at risk from buried wastes are assumed to breathe air at a distance corresponding to the location of the nearest existing population center. 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.

RESULTS AND DISCUSSION

Average individual doses associated with disposal of the example waste streams are summarized in Table III.

Table III. Summary of average individual doses to the public for the example waste streams. These values may be compared to the proposed limit of 0.1 mrem/y for minimal activity wastes.

	Low level	Reactor	Municipal	General
	PIXRESIN average individual dose (rem/y)			
Barnwell	9.48E-09	9.86E-09	9.90E-09	1.46E-02
West Valley	5.58E-14	5.58E-14	5.59E-14	4.72E-04
Beatty	2.14E-08	2.18E-08	4.83E-08	6.50E-02
	PCOTRASH average individual dose (rem/y)			
Barnwell	2.67E-08	2.67E-08	2.68E-08	6.70E-02
West Valley	3.04E-13	3.04E-13	3.04E-13	2.09E-03
Beatty	5.77E-08	5.88-086	1.32E-07	2.17E-01
	BCOTRASH average individual dose (rem/y)			
Barnwell	5.73E-08	5.73E-08	5.73E-08	1.13E-01
West Valley	4.82E-13	4.82E-13	4.82E-13	3.79E-03
Beatty	1.12E-07	1.13E-07	2.52E-07	5.63E-01
	ILQSCNVL average individual dose (rem/y)			
Barnwell	3.42E-06	3.44E-06	3.51E-06	2.71E+00
West Valley	2.67E-11	2.67E-11	2.59E-11	6.86E-02
Beatty	1.00E-05	1.05E-05	2.48E-05	4.38E+00

Relative human radiological impacts for these waste streams were found to rank according to the relative gross radioactivity of the streams. This conclusion might be modified if account were taken of the (unknown) chemical composition of the waste streams.

Because some assumptions describing release scenarios have been arbitrary, it may be misleading to generalize about the relative consequences of burying wastes in different geographic regions. Nevertheless, lower radiological impact was predicted for region C (West Valley, New York), relative to regions A (Barnwell, North Carolina) and B (Beatty, Nevada). In the absence of water buildup in trenches and resultant overflow, the wastes are better isolated from aquifers in region C. If the region B site had not been assumed to be irrigated, predicted consequences for this site would have been considerably lower.

The influence of the disposal methodology was also reflected in our results. In order of increasing adverse consequences, these disposal methodologies may be ranked as follows: burial at a low-level waste disposal site, burial at a reactor site, burial at a municipal site, and dispersal in the general environment. Indeed, the last disposal methodology (general environmental dispersal) would be expected to result in consequences higher by 4-10 orders of magnitude than any of the other disposal methodologies.

The differences in predicted consequences of burial using one of the first three methodologies are insignificant within a single geographical region. This somewhat surprising result arises because for most simulations, more than 98% of the radiological impact was due to the isotopes C-14 and I-129. Both of these radionuclides have very low chemical exchange coefficients[8] in soils with low concentrations of organic material, and both were predicted to migrate at close to hydrologic velocities. (It has been suggested[9] that for many soils, the exchange coefficient of iodine may be large).

One version of the proposed NRC radiation protection standard 10 CFR 20[1] defines minimal activity wastes as being those which will result in members of the public receiving individual doses of no more than 0.1 mrem/year from ionizing radiation. Simulated individual doses for the representative waste streams considered in this study were less than this amount for all disposal scenarios, except for dispersion into the general (aquatic) environment. However, for no case of dispersal into the general environment did the predicted dose fall below the proposed limit for minimal activity wastes.

In some cases, minimal adverse radiological impacts would result from disposal of minimal activity wastes. Our results suggest that there would be little difference in the health impacts associated with burying these wastes in a low-level disposal area, or in burying them at a reactor site. Municipal sanitary land fill sites, if long-term security can be guaranteed, might also have low anticipated dose and health consequences. Local disposal would have several advantages. General environmental dispersal would likely have higher adverse consequences.

REFERENCES

1. USNRC, *Nuclear Regulatory Commission (10 CFR Part 20) Standard for Protection Against Radiation - Proposed Rulemaking* (1982).
2. USNRC, "Draft Environmental Impact Statement on 10 CFR Part 61, Licensing Requirements for Land Disposal of Radioactive Waste," NUREG-0782, Vol. 2 U.S. Nuclear Regulatory Commission, Washington, D. C. (1981).
3. FIELDS, D. E., R. O. CHESTER, C. A. LITTLE, G. HIROMOTO, and C. J. EMERSON, "PRESTO-II: A Low-Level Radioactive Waste Environmental Transport and Risk Assessment Code," ORNL-5970, Oak Ridge National Laboratory, Oak Ridge, Tennessee (in preparation).
4. LITTLE, C. A., D. E. FIELDS, C. J. EMERSON, and G. HIROMOTO, "Environmental Assessment Model for Shallow-Land Disposal of Low-Level Radionuclide Wastes: Interim Report," ORNL/TM-7943, Oak Ridge National Laboratory, Oak Ridge, Tennessee (1981).
5. FIELDS, D. E., C. A. LITTLE, and C. J. EMERSON, "A Computerized Methodology for Evaluating the Long-Range Radiological Impact of Shallow-Land Burial," in T. Oakes Ed., *Selected Papers from the 1981 UCCND Environmental Protection Meeting, Barkeley Lodge, Cadiz, Kentucky, April 21-22, 1981*, CONF-810452, Oak Ridge National Laboratory, Oak Ridge, Tennessee.
6. BEGOVICH, C. L., K. F. ECKERMAN, E. C. SCHLATTER, S. Y. OHR, and R. O. CHESTER, "DARTAB: A Program to Combine Airborne Radionuclide Environmental Exposure Data With Dosimetric and Health Effects Data to Generate Tabulations of Predicted Health Impacts," ORNL-5692, Oak Ridge National Laboratory, Oak Ridge, Tennessee (1981).
7. FIELDS, D. E. and C. W. MILLER, "User's Manual for DWNWND -- An Interactive Gaussian Plume Atmospheric Transport Model with Eight Dispersion Parameter Options," ORNL/TM-6874, Oak Ridge National Laboratory, Oak Ridge, Tennessee.
8. BAES, C. F., III, R. D. SHARP, A. L. SJOREEN, and R. W. SHOR, "A Review *and Analysis* of Parameters for Assessing Transport of Environmentally Released Radionuclides Through Agriculture," ORNL-5786, Oak Ridge National Laboratory, Oak Ridge, Tennessee (1982).
9. KOCHER, D. C., "On the Long-Term Behaviour of Iodine-129 in the Terrestrial Environment," *Environmental Migration of Long-Lived Radionuclides*, International Atomic Energy Agency, pp. 669-679 (1982).