SUMMARY OF EPA'S RISK ASSESSMENT RESULTS FROM THE ANALYSIS OF ALTERNATIVE METHODS OF LOW-LEVEL WASTE DISPOSAL

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ABSTRACT

Evaluation of the potential health risk and individual exposure from a broad number of disposal alternatives is an important part of EPA's program to develop generally applicable environmental standards for the land disposal of low-level radioactive wastes (LLW). The Agency has completed an analysis of the potential population health risks and maximum individual exposures from ten disposal methods under three different hydrogeological and climatic settings. This paper briefly describes the general input and analysis procedures used in the risk assessment for LLW disposal and presents their preliminary results. Some important lessons learned from simulating LLW disposal under a large variety of methods and conditions are identified.

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is developing generally applicable environmental standards for the land disposal of low-level radioactive wastes (LLW) (1). Comparing the potential risks and costs from LLW disposal under a broad range of disposal alternatives and regional conditions is an important element in developing these standards, as these standards will apply to LLW facilities throughout the United States. To meet these needs, the Agency has evaluated combinations of ten different disposal methods, three general hydrogeologic and climatic settings, twenty-six waste streams, four waste forms, and a variety of other variables. In these assessments, the potential population health risks and critical population group annual whole body doses from all pathways were evaluated using EPA's risk assessment methodology.

The EPA has now completed its risk assessments, and is currently using the results to conduct a cost-benefit analysis of the disposal alternatives. This paper briefly describes the general input and analysis procedures used in the LLW assessments and presents preliminary results. Details of the risk assessments will be published in a Background Information Document (BID) similar to the draft BID prepared in 1985 for review by EPA's Science Advisory Board (2). Summary results of the cost-benefit analysis of the LLW disposal alternatives have been presented by Foutes (3). Details of the cost-benefit analysis will be presented later with the proposed LLW Standard in an Economic Impact Assessment.

INPUT DATA AND BASIC ASSUMPTIONS

LLW Source Term

The LLW source term used in these assessments consisted of 26 waste streams, with each stream defined by the origin or source of the wastes, and their general physical, chemical and radiological characteristics. The 26 waste streams include all commercial LLW waste streams identified by the Nuclear Regulatory Commission (NRC) in their 1985-86 reevaluation of LLW generated in the United States (4) and, in addition, two waste streams containing naturally occurring and accelerator-produced radioactive materials (NARM) (5).

Thirty-four radionuclides which commonly occur in these waste streams and which have been identified as being potentially important in commercial LLW and NARM wastes are listed in Table I, together with their projected activities for 1985-2004. The volume and activity projections are based on work by Gruhlke (6).

TABLE I

Estimated Total Activity (in curies) of Major Radionuclides In Commercial LLW, 1985-2004

Nuclide	Activity	Nuclide	Activity
H-3	1.8 E+6	Po-210	6.8 E+2
C-14	5.9 E+3	Pb-210	6.8 E+2
Fe-55	4.0 E+6	Bi-214	6.8 E+2
Ni-59	2.7 E+3	Pb-214	6.8 E+2
Co-60	3.4 E+6	Ra-226	7.4 E+2
Ni-63	3.6 E+5	U-234	8.2 E+1
Sr-90	7.3 E+5	U-235	2.9 E+0
Nb-96	2.7 E+1	Np-237	1.6 E-4
Tc-99	2.5 E+1	U-238	3.4 E+1
Ru-106	4.0 E+3	Pu-238	1.1 E+3
Sb-125	5.7 E+3	Pu-239	4.1 E+2
I -129	7.0 E+1	Pu-241	1.8 E+4
Cs-134	6.6 E+5	Am-241	1.7 E+3
Cs-135	2.5 E+1	Pu-242	8.6 E-1
Cs-137	9.7 E+5	Am-243	2.5 E+1
Ba-137m	9.7 E+5	Cm-243	2.6 E+1
Eu-154	5.7 E+2	Cm-244	3.3 E+2

The potential impact of LLW produced by Federal defense and research activities is also included in our overall risk assessments. The specific radionuclides present, as well as their concentrations and their physical and chemical characteristics, have been assumed to be approximately the same as those found in commercial LLW, based on advice from the Department of Energy (DOE) (7,8). In this paper, however, the risk assessment is based on commercial LLW only. This is because these risk assessment data are companion data to Foutes's economic analyses (3), which use only commercial LLW. In the overall risk assessment, the activities and volumes of each commercial waste stream have been increased proportionate to the volume of the comparable Federal LLW stream to obtain the combined EPA source term, which includes commercial and Federal LLW.

Disposal Alternatives

In our analyses to support the LLW standards, we considered ten methods for disposing of various types and levels of radioactive wastes (9) ranging from sanitary landfill, through current practice (10 CFR 61), to deep geologic disposal. Also included are more recent disposal methods such as concrete canister and earth-mounded concrete bunker disposal (10). Conceptual designs for these disposal methods were defined in sufficient detail to be able to estimate disposal costs and to estimate potential health impacts from their use.

In addition to different waste emplacement and site engineering systems, important factors for disposal alternatives include: the form of the waste at time of disposal, the pre-disposal conditioning, processing and volume reduction of the waste, and any special packaging, such as "high integrity containers." Table II lists the disposal methods and waste form and packaging alternatives considered in our risk assessments. More detailed descriptions are available in the draft BID (2).

TABLE II

Input Data For EPA's 1986 Risk Assessments: Disposal Options and Pretreatment

DISPOSAL

DISPOSAL OPTION	ACRONYM
Regulated Sanitary Landfill	SLF
Shallow Land Disposal	SLD
Improved Shallow Land Disposal	ISD
Current Disposal Practice (Combination of SLD and ISD)	10CFR61
Intermediate Depth Disposal	IDD
Hydrofracture	HF
Deep Well Injection	DWI
Deep Geological Disposal	DGD
Concrete Canister	CC
Earth Mounded Concrete Bunker	EMCB

PRETREATMENT

WASTE FORM OPTION	ACRONYM
Packaged as Generated	AG
Solidified	S
Incinerated, Then Solidified	I/S
Packaged in a High Integrity Container	HIC

Hydrogeologic/Climatic/Demographic Conditions

The hydrogeologic and climatic conditions at a site can directly affect and change the importance of pathways and impacts of releases therefrom. Because the LLW Standards will be applied to LLW facilities throughout the United States, they must be applicable under a wide range of conditions. Therefore, we have conducted all of our routine risk assessments under three very different regional hydrogeologic/climatic scenarios.

The three hydrogeologic/climatic scenarios used are for sites in humid permeable, humid low-permeable, and arid permeable regions. Realistic site data which are believed to be typical for these scenarios were obtained from U.S. Geological Survey (USGS) studies. Population distributions and water usage patterns typical for these three climatic settings were also used. We believe these scenarios span the range of conditions under which a disposal facility would normally be *sited in* the continental United States.

Figure 1 illustrates the difference that these three hydrogeologic/climatic settings have on the relative importance of release pathways. In general, the groundwater pathway is more important when the facility is underlain by a permeable disposal medium, with the impact being less, and occurring later at sites in drier permeable regions. If, however, the underlying disposal medium is of low permeability, the surface pathways dominate. More detailed discussions of the relative importance of pathways in different hydrogeologic settings are given in the draft BID (2) and sensitivity studies of the PRESTO-EPA codes (11).

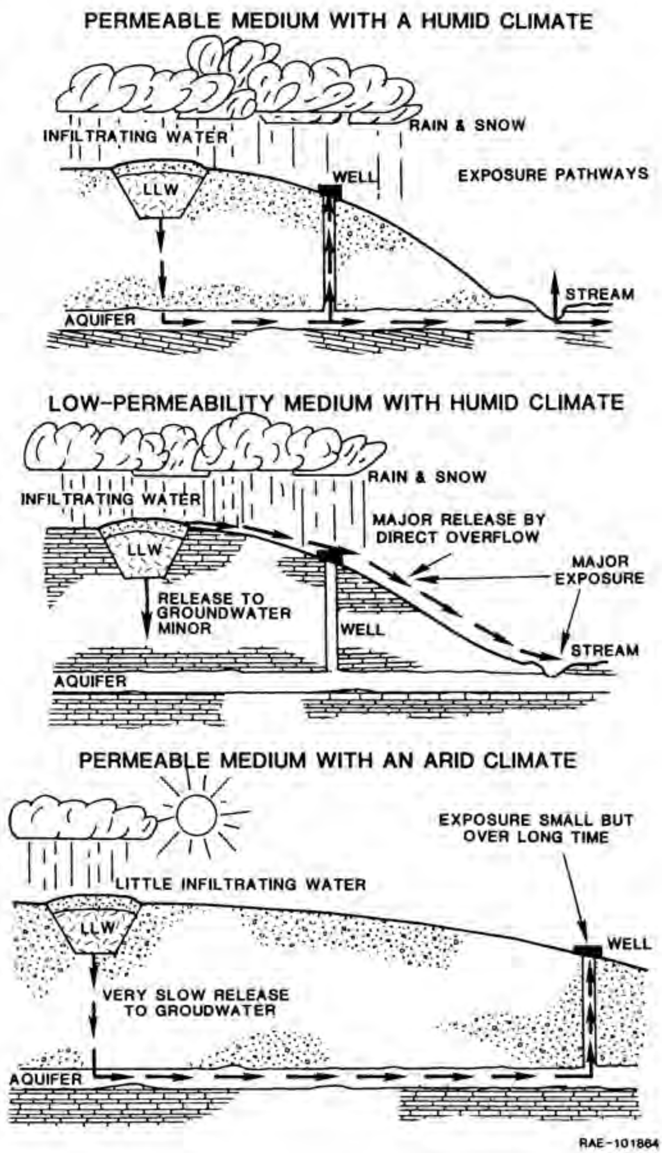

Fig. 1. Relative Importance of Environmental Pathways For a LLW Facility in Various Settings.

Risk Assessment Codes

The PRESTO-EPA codes were used to estimate the health impacts from the disposal of LLW. The original PRESTO-EPA model was developed jointly by EPA and Oak Ridge National Laboratory for use in the LLW Standard development effort (12). This model, which was completed in 1983, was expanded by EPA and Rogers and Associates Engineering Company into a family of risk assessment codes in order to estimate the health impacts from the disposal of LLW under various conditions (13).

The use of the codes to estimate the impact from the disposal of LLW in various types of regulated disposal alternatives has been described elsewhere (14). The results of the analyses for regulated disposal alternatives are summarized in this paper. The potential impact from the unregulated disposal of candidate BRC wastes have been summarized by Holcomb (15).

Types of Alternatives Evaluated

The main thrust of our assessments was to analyze the potential risk from disposal methods which could be used without further development and could generally be used for all types of LLW. Five disposal methods, including the sanitary landfill, shallow land disposal (as practiced from 1963-1982), improved shallow land disposal (as practiced under 10 CFR 61), intermediate depth disposal, and concrete canister methods, were selected for detailed evaluation under these criteria. Both the health risk to local and regional general populations and dose rate to individuals in critical population groups were calculated. The basic risk assessment was done using a LLW disposal site which contained the combined waste stream volumes which would be found in a model 250,000 m^3 site. A fully loaded site consisted of the estimated waste volume for each waste stream, with the appropriate waste forms and types of containers.

Although the earth-mounded concrete bunker and deep geologic disposal methods could be used for all types of wastes, we included them in our special or limited analyses rather than in our mainstream analyses because of their significantly greater costs. Other special disposal methods and management alternatives tested or evaluated included: deep well injection (liquid waste only); hydrofracture (liquid and finely granular waste only); effects of different regional compact waste volumes and characteristics; effects of site size; and effects of special waste management and treatment options (use of incineration, solidification, or high integrity containers).

The effective annual whole body dose equivalent to an individual in the critical population group and the health effects to the general population due to the disposal of 250,000 m^3 of a US average mix of LLW at a standard or reference site were analyzed for 145 scenarios. Detailed results are presented in the LLW BID and are summarized below.

SUMMARY RESULTS OF RISK ASSESSMENTS

The EPA has taken great care to use as realistic input data as possible and risk assessment codes which it believes are "state-of-the- art" for its purpose! The purpose should clearly be understood to be as realistic as possible a comparison (not conservative) of disposal alternatives which could be used later in cost-benefit and cost-effectiveness analyses. None of the predicted population health effects or CPG doses in the following sections should be taken to be predicted impacts from any existing site or future site. Any site specific predictions would require a site specific assessment code, site specific engineering, site specific hydrogeologic/climatic data, and site specific waste data. Remember, the numbers that follow are for EPA to compare disposal alternatives!

Health Effects to the General Population

Figure 2 summarizes the health effects to a general population from disposing of 250,000 m^3 of an average US mix of LLW by seven different alternatives in three different hydrogeologic/climatic settings. These alternatives included disposal of LLW by the sanitary landfill (SLF), shallow land disposal (SLD), improved shallow land disposal (ISD), intermediate depth disposal (IDD) and concrete canister (CC) methods. Also included were various combinations of "as generated" or solidified waste forms.

In the humid permeable setting, estimated total health effects (fatal cancers and genetic effects) ranged from 7.1 for sanitary landfill, the least stringent disposal method, to 1.9 for concrete canister disposal, the most highly engineered method, with 4.4 health effects for 10 CFR 61 disposal. These health effects were incurred primarily by the regional population via the groundwater pathway, and usually occurred within the first 500 hundred years.

In the humid impermeable setting, estimated total health effects ranged from 47 for sanitary landfill to 0.3 for concrete canister disposal, with 2.5 health effects for 10 CFR 61 disposal. Again, the majority of the health effects were incurred by the regional population. However, the major release pathway shifted from the groundwater pathway to surface water by direct overflow to land surface because of the "bathtub" effect (16). In the direct overflow case, because of the impermeable disposal medium, both mobile and less mobile radionuclides were released more quickly than would have been expected based upon k_d values alone.

In an arid permeable setting, estimated total health effects ranged from 4.4 for sanitary landfill to 0.4 health effects for concrete canister disposal, with 2.6 health effects for 10 CFR 61 disposal. As in the case of the humid permeable setting, essentially all of the health effects were incurred by the regional population via the groundwater pathway. However, in the arid setting, they occurred during the second thousand years, rather than the first 500 years, because of the much lower rainfall and, therefore, much smaller flux of water entering the trench to leach the wastes. This caused a much smaller flux of water to leave the trench and a much thicker unsaturated zone between the trench bottom and the aquifer. However, once the contaminant reached the aquifer, it moved at the same rate as the groundwater, less any retardation from ion-exchange with geologic media.

Exposure of Critical Population Groups

Figure 3 summarizes the estimated maximum annual effective whole body doses to a critical population group living within a few tens of meters of a reference disposal facility containing 250,000 m^3 of a US average mix of LLW. Potential exposures were calculated for the same seven disposal methods and waste form combinations as for the preceding health effects assessments. Analyses were terminated at

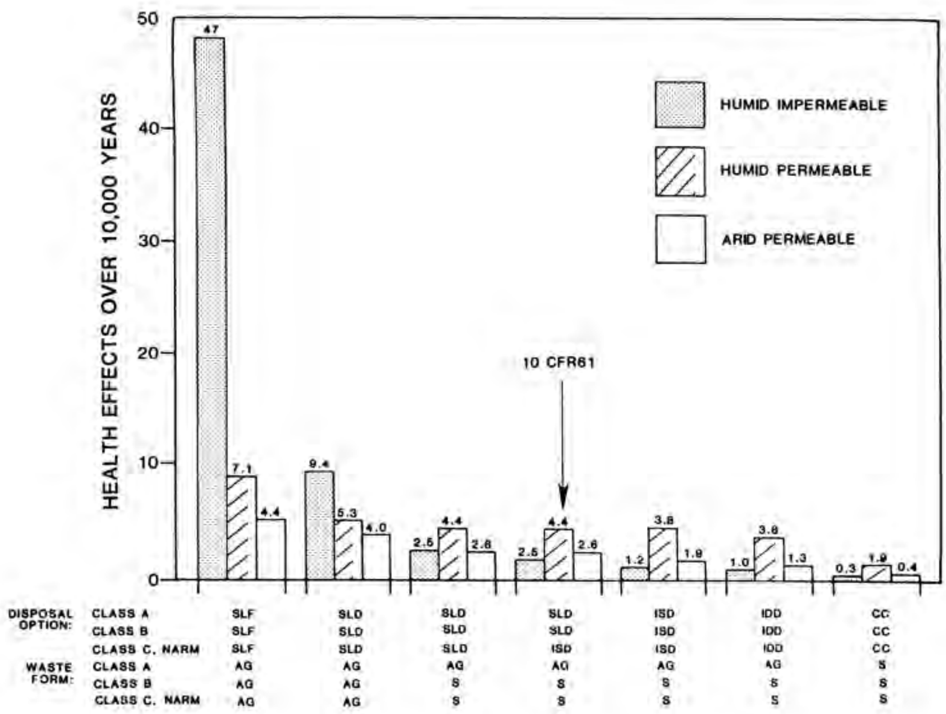

Fig. 2. Comparison of Population Health Effects Over 10,000 Years By Disposal Options For a Reference Disposal Facility Containing 250,000 m^3 of U.S. Average Mix of Low-Level Radioactive Waste.

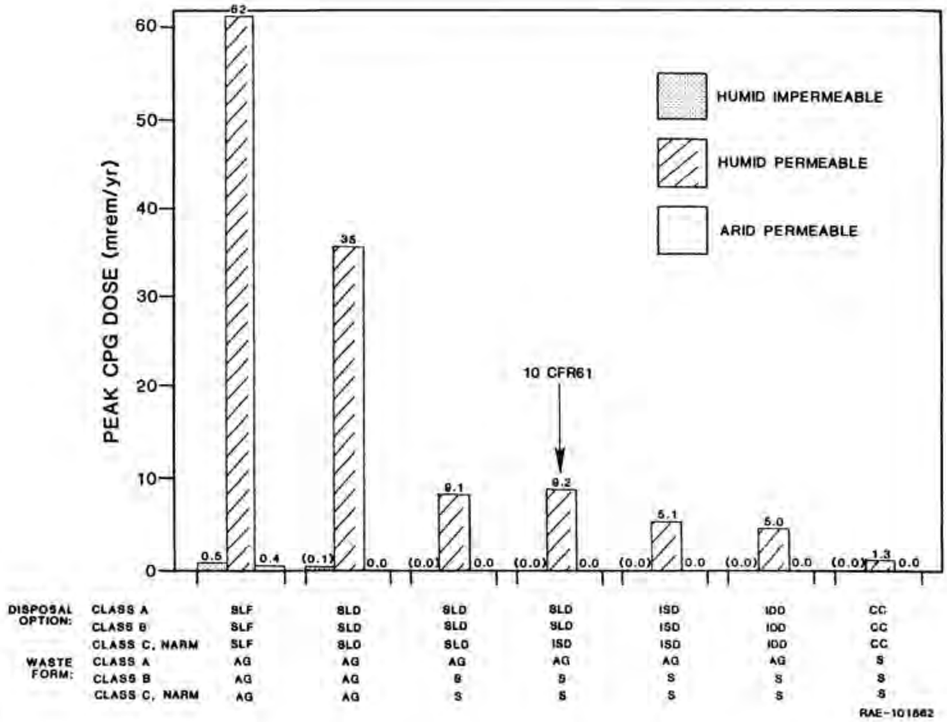

Fig. 3. Comparison of Effective Whole Body Doses to a Critical Population Group By Disposal Options For A Reference Disposal Facility Containing 250,000 m^3 of U.S. Average Mix of Low-Level Waste.

1,000 years for all of the standard CPG assessments, although in some sensitivity runs, analyses were extended to 10,000 years to look for possible significant exposures beyond 1,000 years. No significant increase in exposures were identified during these longer time periods.

In the humid permeable setting, estimated exposures ranged from 62 mrem/yr for sanitary landfill to 1.3 mrem/yr for concrete canister disposal, with 9.2 mrem/yr for 10 CFR 61 disposal. These exposures were incurred via the groundwater pathway in 60 years from sanitary landfill, in 780 years from 10 CFR 61 disposal, and in 1,000 years from concrete canister disposal. In Fig. 3, one can see the significant reduction in individual exposure which can be obtained from solidification of selected waste streams.

In the humid impermeable setting, estimated exposures were all less than 1 mrem/yr, ranging from 0.5 to 0.001 mrem/yr for sanitary landfill and concrete cannister disposal, respectively, with 0.03 mrem/yr for 10 CFR 61 disposal. Exposures were due to releases to the land surface and subsequently to surface waters, due to the "bathtub" effect caused by the low permeability disposal medium. The year of maximum exposure occured at 24 years for sanitary landfill, 190 years for 10 CFR 61 disposal, and at 250 years for concrete canister disposal. These 190 to 250 year periods for 10 CFR 61 and concrete canister disposal included 100 years of institutional control, during which it was assumed that the trench covers were maintained intact, with the balance of the time for the caps to fail and the trenches to fill and overflow. No active maintenance on the cover was assumed for sanitary landfill.

The estimated maximum exposures were all less than 1 mrem/yr for the arid permeable setting. They ranged from 0.4 mrem/yr for sanitary landfill to less than 0.001 mrem/yr for concrete canister disposal (calculations terminated at 1,000 years) with 0.007 mrem/yr for 10 CFR 61 disposal.

As for the case of population health effects estimates, these results should not be considered as applying to any specific facility either present or future. They are only applicable to generic comparisons of methods. Also, the absolute values have considerable uncertainty associated with them even within the context of a generic analysis, and we would consider a factor of two variability in the scale not to be unreasonable.

LESSONS LEARNED FROM ASSESSMENTS

The analyses described in the preceding sections were necessary for the development of the EPA LLW Standard. In addition, they provided a great deal of general information relating to LLW disposal. A brief discussion of highlights follows.

Which are the predominant radionuclides? Whether a specific radionuclide is important depends on (1) how much is present, (2) its environmental mobility, and (3) if it has a high dose conversion (risk) factor. Whether is a key word because in all of our many analyses, we did not find one radionuclide which was important in all disposal situations. We did find, however, several radionuclides which consistently tended to be troublesome.

The "unit curie response" analysis, wherein the impact of disposing of one curie of each radionuclide of interest from disposal by a specific disposal method, waste form, and hydrogeologic/climatic combination is modeled, was very useful for identifying potentially important radionuclides. However, we found that the relative importance of radionuclides changed, depending on hydrogeologic/ climatic setting, the form of the waste, and release, transport, and exposure modes available.

Where groundwater pathways are important, the majority of the impacts are contributed by long-lived, mobile radionuclides with high risk factors, such as C-14, Tc-99, and I-129. Less mobile radionuclides, such as Np-237 and Am-241, became important in cases where the trenches overflow and these radionuclides can be discharged directly onto the land surface and subsequently into surface waters, after being retarded by the soils. For ground surface exposure pathways, gamma-emitting radionuclides such as Co-60, Cs-134 and Cs-137 can become important, while the mobile radionuclides become much less so. Figure 4 shows the relative importance, on a per curie basis, of selected radionuclides in each hydrogeologic region as derived from a "unit curie response" analysis.

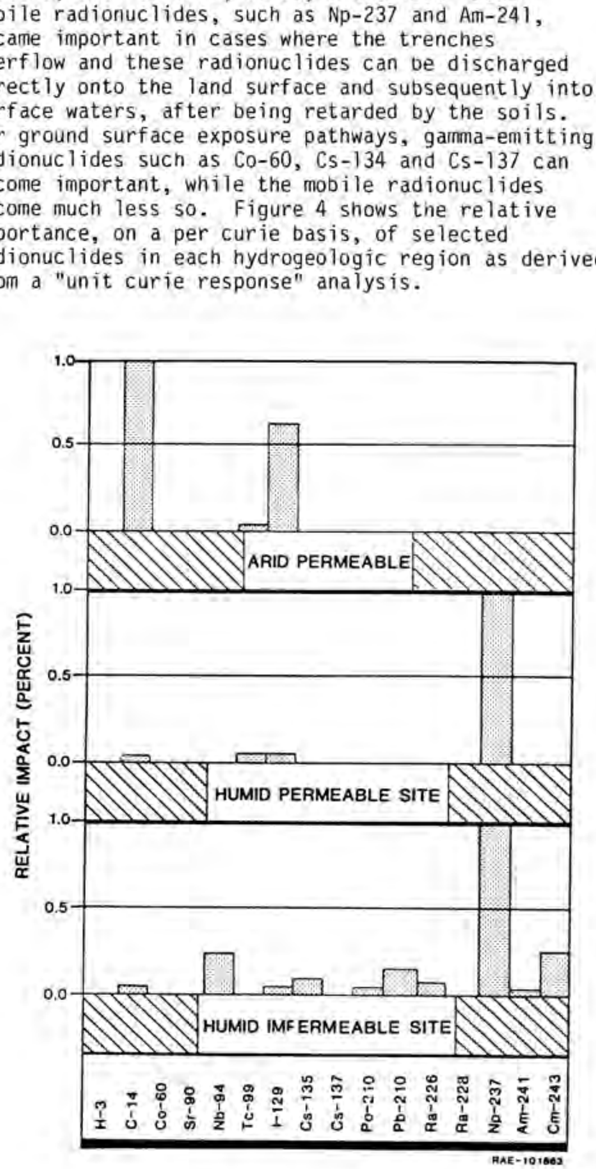

Fig. 4. Relative Impact from the Disposal of One Curie of Various Radionuclides by Setting.

In addition, a radionuclide's contribution to health effects depends to a great degree, on whether it is present in sufficient concentration in the waste. The "unit volume response" analysis, on a waste stream by waste stream basis, together with an analysis of the site fully loaded with the anticipated volumes of each waste stream, is very useful for identifying potentially important waste streams and radionuclides. In the "unit volume response" calculation, one cubic meter of waste is loaded with an appropriate concentration of each radionuclide and the impact of its disposal, by a specific disposal method, waste form, and hydrogeologic/climatic combination is modeled.

Based on this analysis, we can identify the important radionuclides on a per waste stream basis. Specific radionuclides can shift in importance, depending on the hydrogeologic/climatic setting and radionuclides which were important on a per curie basis, can become much less important on a waste stream basis. Neptunium-237 is an excellent example. In our "unit curie response" analysis Np-237 was identified as potentially the most critical radionuclide because of its high mobility in water pathways, its high toxicity, and its long half-life. Fortunately, we found only negligible concentrations of Np-237 in our examination of commercial LLW and, thus Np-237 was not important. However, more Np-237 in the LLW source term could change this.

Beyond the above general points, discussion of a radionuclide's importance becomes almost antidotal. No one radionuclide was found always to be important, but a number of specific factors were identified which could bring to the fore different important radionuclides or suites of radionuclides.

Which is the important receptor, the population or the critical individual? Review of Figs. 2 and 3 clearly shows that, when the disposal conditions and the radionuclides released remain the same, the relative impact to the general population and critical population groups can change when hydrogeologic/climatic conditions change. In general, however, the potential impact of a LLW disposal facility on the general population is low, unless there is an unusually large quantity of a long-lived, mobile radionuclide in the source term. However, the facility's impact on the CPG or individuals can be significant.

Is the radionuclide in an available or transportable form? If we review the curie quantity of each radionuclide at time of disposal, Co-60, Sr-90, Cs-134, Cs-137, and Pu-241 all have a high impact potential. However, they have never appeared as critical or important radionuclides in our general population or CPG assessments. This is because, in their normal diposal form, they are generally sufficiently retarded that they never reach the individual or population. However, they can have a potential impact on intruders.

Is the hydrogeologic/climatic setting important? Our analyses show that the hydrogeologic/climatic setting is generally the most important factor in our overall results. Detailed review of output from the assessments show that the hydrogeologic/climatic setting can dramatically affect the mode of release, the environmental pathways to receptors, and who is affected. Review of the disposal options with wastes in an "as generated" form (SLF and SLD) in Figs. 2 and 3 shows how these changes can affect the overall input of a disposal facility.

How does site size affect impact? Because of the disparity in projected volumes in different compacts, we tested the sensitivity of population health effects and individual doses (CPG) to site size, holding the types of waste and disposal method constant. We reviewed the changes in CPG dose from disposing of 100,000, 170,000, 250,000, 370,000, 500,000 and 590,000 m^3 of a US average mix of LLW by the 10 CFR 61 method under three different hydrogeologic/climatic settings. In general, we found that with a linear increase in inventory, we can expect an approximately linear increase in health effects. Furthermore, the CPG doses did not exceed 15 mrem/yr for a 590,000 m^3 capacity site in a humid permeable setting and were always much less in the other settings.

Why did some potentially important radionuclides have no significant impact? From a review of the radionuclide inventory in a US mix of LLW for 1985-2004 (Table I), we can identify at least eleven radionuclides which could potentially have a significant impact on either population health effects or CPG dose because of a large number of curies or their high mobility and long half-life. Of these eleven radionuclides, ten were never dominant. In Table III, we can see that a fortunate combination of (1) large inventory but low mobility, or (2) high mobility and long half-life but small inventory, prevented them from being dominant radionuclides. A significant increase in mobility in the first case, or increase in inventory in the second case could change their relative importance to LLW disposal.

TABLE III

Potentially Important Radionuclides Which Have Minor Impact

Nuclide	Problem	Reason for Minor Impact
H-3	Large inventory, mobile	Low hazard, Short half-life
Fe-55, Co-60	Large inventory	Low mobility, Short half-life
Ni-63, Sr-90, Cs-134/137	Large inventory	Low mobility
Tc-99, Np-237	Hazardous, mobile, long half-life	Small inventory
U-234/238	Hazardous	Low mobility
Pu-238/242	Hazardous, long half-life	Small inventory, Low mobility

SUMMARY

Comparative risk assessments, using the PRESTO-EPA family of models, were performed for ten different disposal methods, three general hydrogeologic and climatic settings, 26 waste streams and four waste forms.

In the humid impermeable setting, health effects cumulated over 10,000 years, ranged from 47 for sanitary landfill to 0.3 for concrete canister disposal, with 2.5 health effects for 10 CFR 61 disposal.

Similar trends occurred for the other two geohydrological settings with 4.4 and 2.6 health effects for 10 CFR 61 disposal in the humid permeable and arid permeable settings, respectively.

Maximum annual individual doses to a critical population group living within a few tens of meters of a reference LLW disposal site, generally occurred within 1,000 years. In the humid permeable setting, estimated doses ranged from 62 mrem/yr for sanitary landfill to 1.3 mrem/yr for concrete canister disposal, with 9.2 mrem/yr for 10 CFR 61 disposal. In the humid impermeable and arid permeable settings the estimated doses were all less than 1 mrem/yr.

In general, where groundwater and surface water pathways are important, the long-lived mobile radionuclides, C-14, Tc-99, and I-129 dominate the impacts. Less mobile nuclides such as Np-237 and Am-241 become important in trench overflow. For ground surface exposure pathways, gamma emitting nuclides such as Co-60, Cs-134, and Cs-137 dominate.

The results do not necessarily apply to any specific site or facility. They are only applicable to generic comparisons of methods, and this is how they have been used at EPA.

REFERENCES

1. Galpin, F.L. and Meyer, G.L., "Overview of EPA's Low-Level Radioactive Waste Standards Development Program, 86," Proceedings of 8th Annual Participants' Information Meeting on DOE Low-Level Waste Management Program, Denver, Colorado, September 22-26, 1986, U.S. Department of Energy, CONF-860990, Idaho Falls, Idaho, 1987.

2. U.S. Environmental Protection Agency, Proposed Low-Level Radioactive Waste Standards (40 CFR 193): Background Information Document, U.S. Environmental Protection Agency, Technical Report EPA 520/1-85, in Press, Washington, D.C.

3. Foutes, C.E. and Queenan, C.J., "An Economic Evaluation of Alternative LLW Disposal Methods," Proceedings of 8th Annual Participants' Information Meeting on DOE Low-Level Waste Management Program, Denver, Colorado, September 22-26, 1986, U.S. Department of Energy, CONF-860990, Idaho Falls, Idaho, 1987.

4. U.S. Nuclear Regulatory Commission, "Update of Part 61 Impacts Analysis Methodology," NUREG/CR-4370, Washington, D.C., 1986.

5. Bandrowski, M.S. and Gruhlke, J.M., "Inclusion of NARM in the LLW Standard," Proceedings of 8th Annual Participants' Information Meeting on DOE Low-Level Waste Management Program, Denver, Colorado, September 22-26, 1986, U.S. Department of Energy, CONF-860990, Idaho Falls, Idaho, 1987.

6. Gruhlke, J.M., "EPA Source Term for Low-Level Radioactive Waste Risk Assessment," U.S. Office of Radiation Programs, Environmental Protection Agency (draft), Washington, D.C., 1986.

7. Oertel, G.K., U.S. Department of Energy, Letter to T.A. McLaughlin, U.S. Environmental Protection Agency, Washington, D.C., June 11, 1982.

8. Welty, C., U.S. Department of Energy, Telephone conversation with G.L. Meyer, U.S. Environmental Protection Agency, Washington, D.C., January, 1986.

9. Hung, C.Y. et al, "Conceptual Designs and Cost Estimates for Land Disposal Systems Used in Development of EPA's Environmental Standards for Disposal of Low-Level Radioactive Waste," Proceedings of 5th Annual Participants' Information Meeting for DOE Low-Level Waste Management Program, Denver, Colorado, August 30-September 1, 1983, U.S. Department of Energy, CONF-8308106, Idaho Falls, Idaho, 1983.

10. Baird, R.D., Owen, D.H., and Rogers, V.C., "Engineering Cost Analyses for the Earth-mounded Concrete Bunker and Concrete Canister Disposal Methods and for the Engineering Surface Storage Method Applicable to Low-Level Waste Management," prepared for U.S. Environmental Protection Agency by Rogers and Associates Engineering Company, U.S. Environmental Protection Agency, Washington, D.C., 1986.

11. Bandrowski, M.S., Hung, C.Y., and Meyers, G.L., "Sensitivity Analyses of EPA's Codes for Assessing Potential Health Risks from Disposal of Low-Level Wastes," Proceedings of 7th Annual Participants' Information Meeting on DOE Low-Level Waste Management Program, Las Vegas, Nevada, September 10-13, 1985, U.S. Department of Energy, CONF-8509121, Idaho Falls, Idaho, 1985.

12. U.S. Environmental Protection Agency, "PRESTO-EPA: A Low-Level Radioactive Waste Environmental Transport and Risk Assessment Code - Methodology and User's Manual," Prepared by Oak Ridge National Laboratory under Contract No. W-7405-eng-26, Interagency Agreement No. EPA-D--89-F-000-60, U.S. Environmental Protection Agency, Washington, D.C., 1983.

13. Rogers, V.C., Hung, C.Y., Cuny, P.A. and Parraga, F., "An Update on Status of EPA's PRESTO Methodology for Estimating Risks from Disposal of LLW and BRC Wastes," Proceedings of 6th Annual Participants' Information Meeting on DOE Low-Level Waste Management Program, Denver, Colorado, September 11-13, 1984, U.S. Department of Energy, CONF-8409115, Idaho Falls, Idaho, 1984.

14. Hung, C.Y., Meyer, G.L., and Rogers, V.C., "Use of PRESTO-EPA Model in Assessing Health Effects from Land Disposal of LLW to Support EPA's Environmental Standards," Proceedings of 5th Annual Participants' Information Meeting on DOE Low-Level Waste Management Program, Denver, Colorado, August 30, 1983, U.S. Department of Energy, CONF-8308106, Idaho Falls, Idaho, 1983.

15. Holcomb, W.F., and Gruhlke, J.M., "The EPA's Criteria Development for Radioactive Waste that is 'Below Regulatory Concern," Proceedings of 8th Annual Participants' Information Meeting on DOE Low-Level Waste Management Program, Denver, Colorado, September 22-26, 1986, U.S. Department of Energy, CONF-860990, Idaho Falls, Idaho, 1987.

16. Meyer, G.L.," Recent Experience with the Land Burial of Solid Low-Level Radioactive Wastes," Management of Radioactive Wastes From the Nuclear Fuel Cycle - Volume II, IAEA-SM-207/64, pp. 383-394, International Atomic Energy Agency, Vienna, Austria, 1976.