PRELIMINARY COMPARATIVE RISK ASSESSMENT FOR HANFORD WASTE SITES

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ABSTRACT

Assessment of HLW repository performance imply both the ability to meet quantitative standards and an assessment of uncertainties. Indeed, the various standards themselves appear to be based on qualitative assessment of the risks associated with a repository, from which follows limits on cumulative releases of radionuclides to the accessible environment during the first 10,000 years following repository closure, limits on radionuclide concentrations in groundwater for the first 1000 years after closure, and limits on radiation dose equivalents to individuals from all potential pathways. An additional dimension may be added by comparing the potential repository risk to risks from existing similar facilities. The Hanford reservation offered a unique opportunity for such comparisons. This discussion is a preliminary comparison of the risks posed by these inventories with the risk posed by the potential repository. This preliminary assessment is presented in terms of comparative radiotoxicity, which may be thought of as a "time independent" risk.

INTRODUCTION

Commercial high-level waste repository performance assessment standards have been set by three regulatory directives: general siting guidelines issued under the Nuclear Waste Policy Act of 1982 (1), the U. S. Environmental Protection Agency's standards(2), and technical criteria for disposal in geologic repositories (3). All set quantitative standards and implicitly require assessment of uncertainties.

The key stipulations of the various standards appear to be based on qualitative assessment of the risks associated with a repository. These stipulations generally include limits on cumulative releases of radionuclides to the accessible environment during the first 10,000 years following repository closure, limits on radionuclide concentrations in groundwater for the first 1000 years after closure, and limits on radiation dose equivalents to individuals from all potential pathways.

Specific performance standards are related to quantitative assessment of risk, and require a probability of less than 0.1 of exceeding cumulative radionuclide release limits, and of less than 0.001 of exceeding ten times those limits. Their statement in probabilistic terms implies the need to estimate uncertainties, which exist because adequate empirical data are not available. The phenomena of interest occur over an extremely long time period, and cannot be fully assessed even in the preoperational period, because of extensive spatial variability and anisotropy in the geologic structures (e. g., hydraulic conductivity) and insufficient measurements (4,5). Attempting to fulfill the analytical mandates of the regulations in the face of data insufficiencies demands modeling approaches. Because many of the concerns about repository performance, as well as certain explicit provisions of the regulations, involve radionuclide transport in groundwater, there is a heavy effort at present in hydrogeological modeling.

Moreover, assessment of compliance with these regulations depends on constructed scenarios of processes and events which can impair performance. Because of the collective inexperience with such processes and events, scenario development introduces another source of uncertainty to the analysis.

One component of risk assessment is estimation of uncertainties. Different analysts recognize the sources of uncertainty in slightly different forms (4,6,7) but the general consensus is that the major sources to analyze are un- certainties in scenario development, model uncertainties, and model parameter uncertainties. Many analytical techniques have been applied to estimate the latter two types of uncertainty. Freeze et al.(8) focused on the 1000-year groundwater travel time criterion and on hydraulic conductivity. According to these observers, uncertainty stems ultimately from the attempt to use methods developed originally to assess response in near-surface unconsolidated aquifers over limited distances and short time frames with relatively abundant data. Quite the opposite of these conditions prevails in nuclear waste repository cases.

The authors considered the limitations of the Bayesian approach in detail and identified four issues of special significance: appropriateness of the Bayesian approach, application of the particular simulation method used, identification of trends and zonations in hydraulic conductivity, and problems associated with small-sample statistics. This evaluation does not include consideration of such processes as chemical reactions and diffusion to the advective groundwater transport, or uncertainties in parameters other than hydraulic conductivity.

Development of scenarios for processes and events that might interfere with repository performance has also received attention from risk analysts. Hunter (9) developed a methodology for scenario development and has done the most complete preliminary work in this area relative to the Hanford Basalt Waste Isolation Project (BWIP). She constructed 318 scenarios in the following categories:

- Normal water flow
- Tectonic disturbances
- Faulting
- Glaciation
- Fluvial erosion
- Thermomechanical disturbances
- Subsidence
- Seal failure
- Drilling

Each category had a series of subtrees, and each potential occurrence was assigned an estimated probability on a decimal scale ranging from 10-8 to 1/year. The unit value was assigned in every case where little or no information existed to make any other assignment. Each scenario was considered at four time points ranging from 100 to 100,000 years after repository closure. In all, 1272 cases were analyzed for Hanford, 84 of which resulted in probabilities of 1. The principal benefit of this early analysis was to identify the greatest needs for information and modeling, which were found to lie in the areas of thermal effects on groundwater flow and glaciation.

Radiological risk is based on dose, and routine and regular operation of a facility implies a different dose than an accidental release. Routine doses from an expected exposure during plant activities are continuous, while the major portion of a dose from an accident is received at the time of the accident. Yet both are considered as "risk" and both are measured in the same units, man-rem/year.

RISKS FROM EXISTING FACILITIES

Existing Risk Assessments

The assessments of repository risk discussed above still encompass a certain air of unreality, since they are based entirely on potential faults and weaknesses of a potential facility. An additional dimension may be added by comparing the potential repository risk to risks from existing similar facilities. The Hanford reservation offered a unique opportunity for comparison with existing inventories of radioactive waste of various types: defense high-level waste, TRU waste, low-level waste, etc. The following discussion is a preliminary comparison of the risks posed by these inventories with the risk posed by the potential repository. Risks are also posed by the normal operation of various other facilities on the Hanford site, and probabilistic risk assessments have been made for various postulated abnormal events. Listing these here is beyond the scope of this paper; the present work concerns itself only with the risks posed by the waste inventories.

Several discussions of risk to the general public from waste storage and generation at the Hanford reservation exist (10, 11). These documents are also the sources of the data base of radiologically and chemically hazardous constituents of the defense waste inventory.

Calculation of Future Risk to the General Public

Risk to the general public from defense waste storage may be calculated as follows:

- Scenarios may be constructed which would lead to various releases, or releases from various sources.
- For each scenario, release rates from 1%/year to 50%/year may be postulated, in terms of percent of the indicated radionuclide inventory.
- For each release rate, dose to the general public may be calculated.
- A range of probabilities may be considered for sets of scenarios. While probabilities of mutually exclusive events must add up to 1, events which are independent of each other, relative probabilities can be as- signed which do not add up to 1. The probability assignments of Hunter (9) yield:

Probability = 1.0: the event is very likely, or uncertain, or unknown

Probability = 0.1: the event is less than certain, but reasonably likely

Probability = 0.01: the event is not likely, but cannot be ruled out

Probability = 10-3: available data, which may be questionable, show that the event will not occur

Probability = 10-4: reliable data show that the event is unlikely

Probability = 10-5: reliable data show that the event is extremely unlikely

Probability = 10-6: the event is physically possible, but almost certain not to occur

Probability = 0: currently available data indicate that the event is physically impossible

These probabilities are independent of the projected radiation dose, and are assigned to give some indication of the relative probabilities of the scenarios.

This type of risk assessment was planned for Phase II of the socioeconomic impact study of Hanford. The 1987 amendments to the Nuclear Waste Policy Act resulted in the termination of funding for this project. A preliminary assessment of the radiotoxicity of the waste inventory is presented here, and compared to an assessment of the radiotoxicity of a proposed repository. This comparative radiotoxicity may be thought of as a "time independent" risk. The result for the defense waste inventory at Hanford is shown in Table I. Neither pathways to the accessible environment nor travel along those pathways are considered in this assessment. The calculations for Table I were made as follows:

1. The data in the second column - the radionuclide spectrum of the waste - were taken from the compilations in the Draft EIS on Defense Waste (10).
2. The third column lists the dose in rem/curie for each particular nuclide. Determination of rem/curie for any nuclide involves a number of factors, including

   - the chemical nature of the nuclide
   - the nature and energy of its emissions
   - physiological retention and physiological half-life
   - bioconcentration and partitioning among organs

Four different studies have developed values of the rem/curie for each nuclide (13, 14, 15, 16). The data cited in Exhibit 4-4 uses the largest (most conservative) value of the four; the study used by USEPA (Smith, 1982) was generally the most conservative. Values for ingestion, including drinking water, were used for two reasons: these are available for almost all of the nuclides in question, while inhalation values are not, and it is generally agreed (17) that, over the long term, ingestion doses will far exceed inhalation and immersion doses.

3. Dose in rem = (curie/nuclide)(rem/curie)
4. The column entitled "organ affected" names the organ which would receive the largest dose from the particular nuclide.
5. The risk per curie intake was taken from the work of Smith,et al (15). "Risk" in this context is synonymous with fatal cancer, but this equivalence has no intrinsic significance. Fatal cancers are used as a measure of risk because there is a body of epidemiological data on which such a measure is based and because fatal cancers are used as this measure throughout the literature.
6. Risk = (curies/nuclide)(risk/curie intake)

It should be understood that the results of this calculation are, in ab- solute terms, totally unrealistic. The calculation was made only to obtain numbers that were capable of comparison, and comparison of doses alone is misleading.

As may be seen from Table I, 99% of the dose and 95% of the risk are accounted for by the Sr-90 and Cs-137 inventory. About 0.04% of the dose and about 4.4% of the risk is accounted for by the plutonium isotopes, and about 0.01% of the dose and 0.1% of the risk, by Am-241. Secure isolation of the encapsulated strontium and cesium from the accessible environment would appear to be an efficient and effective mitigation measure.

A similar calculation may be made for the radionuclides now in the commercial low-level waste site. The results are shown in Table II. The risk estimate was made only for the site's present inventory; assessing future risk from the site depends on various scenarios for waste sources, decommissioning options, the future of the low-level waste compacts, and changes in industrial and institutional use of low-level waste. The total dose from the material in the low-level site is about six orders of magnitude less than the putative dose from a repository (shown in Table III), and about five orders of magnitude less than the defense waste inventory. These ratios may change for various disposal scenarios.

An important factor in interpreting these results is to recognize that these risks are present over the effective lifetime of the particular nuclide. In this instance, these effective lifetimes would appear to be:

- For strontium and cesium, 36.5 half-lives, or 1095 years.
- For Pu-238, 30 half-lives, or 2650 years.
- For Pu-239, 30 half-lives, or 740,000 years.
- For Pu-241, 30 half-lives, or 432 years.
- For Am-241, 30 half-lives, or 13,000 years.
- For Np-237, 20 half-lives, or 65,000,000 years.

In each case, after the effective life has passed, the risk has been reduced to fewer than 10 fatal cancers.

TABLE I

Dose and Risk Associated With the Defense Waste Inventory

C-14	5.1E+03	1.9E+03	9.7E+06	whole body	4.7E-01	2.4E+03	(15)
CE-144	1.0E+08	2.0E+04	2.0E+12	GI-LLI	4.8E-04	4.8E+04	10CFR20, SM-151
CO-60	1.5E+04	1.4E+04	2.1E+08	whole body	4.5E-01	6.8E+03	10CFR20, NI-63
CS-135	1.4E+02	6.5E+04	9.1E+06	whole body	3.1E+00	4.3E+02	(17)
CS-137	2.3E+08	4.4E+06	1.0E+15	whole body	9.3E+01	2.1E+10	(13, 15)
H-3	6.0E+04	9.5E+02	5.7E+07	whole body	2.3E-01	1.4E+04	10CFR20, C-14
I-129	5.2E+01	1.3E+07	6.7E+08	thyroid	4.8E+01	2.5E+03	(15)
NI-63	3.2E+04	1.3E+04	4.1E+08	bone	5.6E-01	1.8E+04	(15)
SM-151	1.2E+06	1.2E+04	1.4E+10	thyroid	5.3E+00	6.4E+06	(16)
SN-126	8.0E+02	8.6E+04	6.9E+07	bone,marrow	2.5E+03	2.0E+06	(13, 15)
SR-90	2.0E+08	3.9E+06	7.8E+14	bone	4.8E+02	9.6E+10	(14)
TC-99	3.5E+04	1.4E+04	4.9E+08	thyroid	6.6E+00	2.3E+05	(13)
ZR-93	4.2E+03	1.4E+03	5.9E+06	liver	2.7E+01	1.1E+05	(15)
AM-241	3.7E+04	3.9E+07	1.4E+12	bone	3.3E+04	1.2E+09	(16)
AM-243	4.0E+01	3.9E+07	1.6E+09	bone	3.2E+04	1.3E+06	(16)
NP-237	6.0E+01	7.1E+08	4.3E+10	bone	2.5E+04	1.5E+06	(15)
PU-238	3.3E+04	1.9E+07	6.2E+11	bone	3.1E+04	1.0E+09	(15)
PU-239	9.4E+04	5.7E+05	5.4E+10	bone	3.1E+04	2.9E+09	(15)
PU-240	2.0E+04	7.6E+05	1.5E+10	bone	3.1E+04	6.2E+08	(16)
PU-241	7.9E+04	1.6E+04	1.3E+09	bone	1.2E+04	9.4E+08	(16)
PU-242	2.4E+00	5.4E+04	1.3E+05	bone	3.0E+04	7.2E+04	(15)
RA-226	3.2E-07	3.7E+08	1.2E+02	bone	4.7E+04	1.5E-02	(14)
U-233	7.1E+01	7.9E+06	5.6E+08	bone	2.4E+04	1.7E+06	(13)
U-234	7.3E+01	2.0E+07	1.5E+09	bone	2.1E+04	1.5E+06	(15)
U-235	2.2E+01	7.1E+06	1.6E+08	bone	2.0E+04	4.5E+05	(13)
U-238	5.6E+02	7.0E+06	3.9E+09	bone	2.1E+04	1.2E+07	(13)
TOTAL			1.8E+15			1.2E+11	

[a] "Risk" is synonymous with fatal cancers (see text).

TABLE II

Calculated Time-Independent Risk From the LLW Repository Inventory

Nuclide	Curies/ Nuclide	Rems/Curie Ingested[a]	Dose (Rems)	Organ Affected	Risk/Ci Intake[b]	Risk[c]	Reference
C-14	3.4E+02	1.9E+03	6.6E+05	whole body	4.6E-01	1.6E+02	(15)
CO-60	6.9E+03	1.4E+05	9.7E+08	whole body	4.5E-01	3.1E+03	10CFR20, NI-63
CS-134	6.8E+02	7.9E+05	5.4E+08	whole body	7.0E+01	4.8E+04	10CFR20, CS-137
CS-137	2.0E+03	4.4E+06	9.1E+09	whole body	9.3E+01	1.9E+05	(15)
EU-152	2.0E+00	8.9E+04	1.8E+05	whole body	6.3E+02	1.3E+03	10CFR20, SB-125
FE-55	1.7E+02	8.9E+03	1.5E+06	marrow	2.2E-02	3.7E+00	10CFR20, NI-63
H-3	6.9E+03	9.5E+02	6.5E+06	whole body	2.3E-01	1.6E+03	10CFR20, C-14
NI-63	3.8E+02	1.3E+04	4.9E+06	bone	5.6E-01	2.1E+02	(15)
PM-147	2.0E+02	3.6E+04	7.1E+06	whole body	2.0E+02	4.0E+04	10CFR20, SB-125
SB-125	2.3E+01	8.6E+04	2.0E+06	bone, marrow	2.5E+03	5.8E+04	(15)
SR-90	1.3E+02	3.9E+06	5.1E+08	bone	4.8E+02	6.2E+04	(14, 15)
TC-99	7.0E+00	1.4E+04	9.8E+04	thyroid	6.6E+00	4.6E+01	(13, 15)
TH-232	1.0E+00	3.6E+06	3.6E+06	bone	1.0E+03	1.0E+03	10CFR20, U-238
TH(nat)	1.0E+01	3.6E+06	3.6E+07	bone	1.3E+03	1.3E+04	10CFR20, U-238
U-238	3.4E+02	7.0E+06	2.4E+09	bone	2.1E+04	7.1E+06	(13)
U(nat)	4.0E+00	2.4E+05	9.6E+05	bone	2.1E+04	8.4E+04	10CFR20, U-238
TOTAL			1.3E+10			7.6E+06	

[a] For CO-60, CS-134, EU-152, Fe-55, PM-147, TH-232, natural TH and natural U, the dose per Curie was taken from 10 CFR 20, Appendix B, Table II, assuming that the doses for Table II were 100 mrem/7 days.

[b] For CO-60, CS-134, EU-152, Fe-55, PM-147, TH-232, natural TH and natural U the risk was calculated from that for a nuclide having similar chemical and biochemical behavior, together with the data from 10 CFR 20 Appendix B, Table II.

[c] "Risk" means fatal cancers.

The actual leakage of the defense waste has been about 0.002% per year on the average, over the past 40 years (10). If this leak rate is assumed to continue, the inventory would leak to the environment over 50,000 years, the primary risk would be due to Np-237 and Pu-239, and would be approximately 1500 fatal cancers per year.

Time-independent dose and risk associated with the proposed repository may be estimated in the same manner that dose and risk associated with the defense waste inventory, for purposes of comparison (to the defense waste inventory, for example). This estimate clearly does not consider actual mechanisms of release from the repository, and is, again, in the nature of a radiotoxicity assessment. The results are given in Table III.

Table III uses representative nuclides, rather than the entire repository inventory. However, the assumption that it represents the repository inventory quite accurately and that any additional radionuclides are negligible is a fair one. The major sources of dose and risk are:

	Dose	Risk
SR-90 and CS-137	92%	26%
Plutonium	6%	67%
Americium	1%	4%

The total time independent dose from the repository is approximately 35 times that of the defense waste inventory. The radiotoxicity of the repository, however, is about two orders of magnitude greater than that of the defense waste; the difference lies with the plutonium content of the repository. Both in this case and with the defense waste inventory, the risk from any given nuclide varies over time; e.g., after 100,000 years the risk from strontium and cesium is virtually gone, and the major risk is from Neptunium-237 (17).

DISCUSSION

Several preliminary observations can perhaps be made:

- The long-term radiological risk posed, at any given site, by the waste stored in the commercial HLW repository could be reduced by reprocessing spent

TABLE III

Risks Associated With the HLW Repository Inventory.

Nuclide	Curies/ Nuclide	Rems/Ci Ingested	Dose (rems)	Organ Affected	Risk/Curie Intake	Risk[a]	Reference
C-14	2.8E+04	1.9E+03	5.3E+07	whole body	4.6E-01	1.3E+04	(15)
CS-135	2.2E+04	6.5E+04	1.4E+09	whole body	3.1E+00	6.8E+04	(17)
CS-137	8.6E+09	4.4E+06	3.8E+16	whole body	9.3E+01	8.0E+11	(15)
I-129	3.8E+03	1.3E+07	4.9E+10	thyroid	4.8E+01	1.8E+05	(15)
SN-126	5.6E+04	8.6E+04	4.8E+09	bone, marrow	2.5E+03	1.4E+08	(15)
SR-90	6.0E+09	3.9E+06	2.3E+16	bone	4.8E+02	2.9E+12	(14)
TC-99	1.4E+06	1.4E+04	2.0E+10	thyroid	6.6E+00	9.2E+06	(13, 15)
ZR-93	1.9E+05	1.4E+03	2.7E+08	liver	2.7E+01	5.2E+06	(15)
AM-241	1.7E+07	3.9E+07	6.6E+14	bone	3.3E+04	5.6E+11	(16)
AM-243	1.7E+06	3.9E+07	6.6E+13	bone	3.2E+04	5.5E+10	(16)
NP-237	3.3E+04	7.1E+08	2.3E+13	bone	2.5E+04	8.4E+08	(16)
PU-238	2.2E+08	1.9E+07	4.2E+15	bone	3.1E+04	6.9E+12	(15)
PU-239	3.3E+07	5.7E+05	1.9E+13	bone	3.1E+04	1.0E+12	(15)
PU-240	4.9E+07	7.6E+05	3.7E+13	bone	3.1E+04	1.5E+12	(16)
PU-242	1.7E+05	5.4E+04	9.2E+09	bone	3.0E+04	5.0E+09	(15)
U-234	1.9E+05	2.0E+07	3.8E+12	bone	2.1E+04	3.9E+09	(15)
TOTAL			6.6E+16			1.4E+13	

[a] "Risk" is here synonymous with fatal cancers.

TABLE IV

Leak Rates (in Curies) for Various Leak Scenarios for the Single-Shell Tanks

Leak Rate (%/Year) Number of Leaky Tanks	1%	5%	10%	280%		33.3%	50%
1.0E+00	1.4E+06	7.1E+06	1.4E+07	2.9E+07	3.6E+07	4.8E+07	7.1E+07
2.0E+00	2.9E+06	1.4E+07	2.8E+07	5.8E+07	7.2E+07	9.6E+07	1.4E+08
3.0E+00	4.3E+06	2.1E+07	4.2E+07	8.7E+07	1.1E+08	1.4E+08	2.1E+08
4.0E+00	5.7E+06	2.8E+07	5.6E+07	1.2E+08	1.4E+08	1.9E+08	2.8E+08
5.0E+00	7.1E+06	3.5E+07	7.0E+07	1.4E+08	1.8E+08	2.4E+08	3.5E+08
6.0E+00	8.6E+06	4.3E+07	8.4E+07	1.7E+08	2.2E+08	2.9E+08	4.3E+08
7.0E+00	1.0E+07	5.0E+07	9.8E+07	2.0E+08	2.5E+08	3.4E+08	5.0E+08
8.0E+00	1.1E+07	5.7E+07	1.1E+08	2.3E+08	2.9E+08	3.8E+08	5.7E+08
9.0E+00	1.3E+07	6.4E+07	1.3E+08	2.6E+08	3.2E+08	4.3E+08	6.4E+08
1.0E+01	1.4E+07	7.1E+07	1.4E+08	2.9E+08	3.6E+08	4.8E+08	7.1E+08
1.5E+01	2.1E+07	1.1E+08	2.1E+08	4.3E+08	5.4E+08	7.2E+08	1.1E+09
2.0E+01	2.9E+07	1.4E+08	2.8E+08	5.8E+08	7.2E+08	9.6E+08	1.4E+09
2.5E+01	3.6E+07	1.8E+08	3.5E+08	7.2E+08	9.0E+08	1.2E+09	1.8E+09
3.0E+01	4.3E+07	2.1E+08	4.2E+08	8.7E+08	1.1E+09	1.4E+09	2.1E+09
3.5E+01	5.0E+07	2.5E+08	4.9E+08	1.0E+09	1.3E+09	1.7E+09	2.5E+09
4.0E+01	5.7E+07	2.8E+08	5.6E+08	1.2E+09	1.4E+09	1.9E+09	2.8E+09
4.5E+01	6.4E+07	3.2E+08	6.3E+08	1.3E+09	1.6E+09	2.2E+09	3.2E+09
5.0E+01	7.1E+07	3.5E+08	7.0E+08	1.4E+09	1.8E+09	2.4E+09	3.5E+09
6.0E+01	8.6E+07	4.3E+08	8.4E+08	1.7E+09	2.2E+09	2.9E+09	4.3E+09
7.0E+01	1.0E+08	5.0E+08	9.8E+08	2.0E+09	2.5E+09	3.4E+09	5.0E+09
8.0E+01	1.1E+08	5.7E+08	1.1E+09	2.3E+09	2.9E+09	3.8E+09	5.7E+09
9.0E+01	1.3E+08	6.4E+08	1.3E+09	2.6E+09	3.2E+09	4.3E+09	6.4E+09
1.0E+02	1.4E+08	7.1E+08	1.4E+09	2.9E+09	3.6E+09	4.8E+09	7.1E+09
1.1E+02	1.6E+08	7.8E+08	1.5E+09	3.2E+09	4.0E+09	5.3E+09	7.8E+09
1.2E+02	1.7E+08	8.5E+08	1.7E+09	3.5E+09	4.3E+09	5.8E+09	8.5E+09
1.3E+02	1.9E+08	9.2E+08	1.8E+09	3.8E+09	4.7E+09	6.2E+09	9.2E+09
1.4E+02	2.0E+08	9.9E+08	2.0E+09	4.1E+09	5.0E+09	6.7E+09	9.9E+09
1.5E+02	2.1E+08	1.1E+09	2.1E+09	4.3E+09	5.4E+09	7.2E+09	1.1E+10

nuclear fuel and reclaiming plutonium, and the short term risk could be reduced markedly by removing and encapsulating SR-90 and CS-137. Moreover, reprocessing poses a considerable occupational risk and creates both chemical and radioactive waste (like the PUREX process) which may be less tractable than spent fuel.

- The riskiest component of defense waste - encapsulated SR-90 and CS-137 - is not truly "waste" and is packaged for ultimate use. These radionuclides - plutonium on the one hand, and strontium and cesium on the other - are still risky to store. However, at the present time almost all of the CS-137 and some of the SR-90 are shipped off-site for use. The capsules remaining on site are not waste but are used for research and development at on-site facilities.

It should be re-emphasized that the comparisons of risk made here do not include anything in the way of leak rates, leak scenarios, etc. The only utility which these analyses have is for comparison with each other. In order to assess the risk from the repository adequately, scenarios for repository leaks must be drawn and the leak rates calculated for various scenarios. The matrices shown in Tables IV summarizes leak rates for possible leakage scenarios for the single-shell defense waste storage tanks. A first-cut risk assessment for the defense waste will depend on these leak rates, and will again assume that everything that leaks is ingested. Subsequent refinements of the risk analyses will model ingestion and absorption pathways.

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