RADIOLOGICAL ASSESSMENTS OF CONCEPTUAL LOW-LEVEL RADIOACTIVE WASTE DISPOSAL FACILITIES FOR THE STATE OF TEXAS

R. Shuman, V. C. Rogers, R. D. Baird
Rogers & Associates Engineering Corporation
P.O. Box 330
Salt Lake City, UT 84110

ABSTRACT

The Texas Low-Level Radioactive Waste Disposal Authority is in the process of estimating the relative preformance of three alternative waste disposal facilities; above-ground vaults, below-ground modular concrete canisters with below-ground vault, and above/below-ground modular concrete canisters with below-ground vault. As a part of this process radiological assessments were performed for each facility. Intruder exposures and exposures to an off-site farmer were modeled for 1,000 yr following site closure. For concrete service lifetimes of 500 yr (200 yr for the below-ground vaults of the modular concrete canister disposal facilities) above-ground vault disposal results in doses three or more times greater than the modular concrete canister facilities. However, maximum intruder doses for all three alternative facilities are substantially lower than both the maximum intruder dose for shallow land disposal and the 500 mrem/yr regulatory limit. Doses to the adjacent farmer for the above/below-ground modular concrete canister and above-ground vault facilities exceed those for shallow land disposal, with the latter resulting in a dose rate substantially higher than 25 mrem/yr. Performance of the above-ground vault disposal facility is most critically affected by reductions in concrete service life, exceeding acceptable performance criteria at 100 yr for the Intruder-Explorer scenario. While the performance of the modular concrete canister facilities is also impacted by service life, intruder doses do not exceed the maximum intruder dose projected for shallow land disposal.

INTRODUCTION

The Texas Low-Level Radioactive Waste Disposal Authority is in the process of estimating the relative performance of three alternative waste disposal facilities. The disposal facilities under consideration are:

- Above-Ground Vaults
- Below-Ground Modular Concrete Canisters with Below-Ground Vault
- Above/Below-Ground Modular Concrete Canisters with Below-Ground Vault

As a part of this process, radiological performance assessments were performed for each facility. This paper details the approach taken in these assessments and summarizes the results therefrom.

METHODOLOGY

Disposal Technology Assumptions

Detailed design specifications of the three alternative disposal facilities are provided elsewhere(1). Above-ground vaults were assumed to have a concrete service life of 500 yr. Similarly, the above/below-ground and below-ground modular concrete canister facilities were assumed to remain intact for 500 yr, except for the below-ground vault. This latter structure was assumed to lose structural integrity at 200 yr following site closure. In all cases, concrete and grout were assumed to revert to their original constituents at the time of failure.

In addition to these facilities, pathway analysis of a shallow land burial facility was performed to provide a basis for comparison of the assessment results. The layout of the shallow land disposal facility was assumed to be similar to that of the modular concrete canister technology. There are 16 waste trenches; 13 for Class A and B wastes and 3 for Class C waste. The Class A and B trenches are 7 m deep, corresponding to 5 m of waste and a 2 m cover. Class C trenches contain approximately 1.8 m of waste overlain by a 5 m cover.

Source term configurations, and the volumes of the waste streams thereof, were based on Ref. 2. Isotopic concentrations of the identified waste streams were taken from the Nuclear Regulatory Commission's Final Environmental Impact Statement on 10 CFR Part 61(3). For the modular concrete canister facilities only the non-fuel reactor component waste stream was assumed to be placed in the below-ground vaults. All other waste streams were placed in the disposal unit according to their waste class designation. Assessments of modular concrete canister disposal took into account placement of compacted and uncompacted waste, whereas those of the other facilities did not.

Uncompacted waste densities were calculated to be 1200 kg/m^3 for Class A and 1800 kg/m^3 for Classes B and C. Compaction was assumed to result in a Class A density of 1800 kg/m^3, with Class B and C being unaffected. Waste reserved for disposal in the below-ground vault was assumed to have a density of 3500 kg/m^3.

Exposure Scenarios

The radionuclide releases and human exposures that determine the magnitude of external and internal doses are dependent upon human use of the disposal site environment. Patterns of human use may be specified by using a collection of appropriate exposure pathways. This set of selected pathways is termed an exposure scenario. The exposure scenarios considered for the present analyses include:

- Intruder-Explorer
- Intruder-Construction
- Intruder-Agriculture
- Adjacent Farm

For the Intruder-Explorer scenario it was assumed that a person arrives at the waste site following the institutional control period and spends 1,000 hr over the course of a year exploring or wandering about the site surface. No attempt to dig into the waste site is made during this time, thus limiting exposures to those due to direct radiation from 1) buried waste while the facility is intact, and 2) exposed waste following failure of the facility. Following failure, the possibility for inhalation of contaminated particulates exists as well.

In the Intruder-Construction scenario it was assumed that a person constructs a house on the waste disposal site. A basement 100 m^2 in area is excavated to a depth of 3 m below ground surface and a well is drilled through the waste. Excavated material brought to the surface is mixed with surface soil. During construction the individual is assumed to spend 500 hr (over a three month period) on the site. Exposures include gamma radiation from the excavated waste and inhalation of contaminated dust suspended during construction activities. This scenario is assumed to take place at the end of the institutional control period for the shallow land disposal facility. For the remaining three facilities the time of occurrence is delayed until the concrete structures have failed.

In modeling the Intruder-Agriculture scenario, it was assumed that an intruder resides on the waste disposal site and plants food crops which supply 50 percent of his annual food requirements. Exposures include gamma radiation, inhalation of suspended contaminants, and ingestion of contaminated water and foodstuffs. This scenario is assumed to occur at the end of institutional control for shallow land disposal and after the failure of the concrete structures for the other facilities. For the above-ground vault facility it was assumed that soil conditions would not be capable of supporting agricultural activities. As such, contaminant doses due to food chain transport were not considered for this technology.

In the Adjacent Farm scenario it was assumed that an individual builds a house 1,000 m from the disposal units. A well is drilled and food crops are planted which provide 50 percent of the individual's annual food requirements. Contaminants from the facilities were assumed to be transported to the farm via surface water and groundwater. In modeling surface water transport it was conservatively assumed that a volume of water equal to annual site infiltration contacts that waste situated above-grade and becomes surface runoff. Exposures include direct radiation, inhalation of suspended contaminants, and ingestion of contaminated water and foodstuffs.

Modeling Approach

Exposures resulting from each of the scenarios above were modeled for a period of 1,000 yr following site closure. Groundwater simulations were carried out for longer periods of time to adequately assess the potential for contamination of irrigation and drinking water supplies. The disposal site was *initially* modeled without any facility present to determine the protection provided water resources by the natural geohydrologic characteristics of the site itself. Additional analyses considered the impact of concrete structures on groundwater flow patterns.

Two computer codes were used in modeling all of the disposal facilities. The majority of the transport pathways, including atmospheric transport and dispersion, food chain transfer, and surface water transport, were modeled using PATHRAE(4), a code developed for the U.S. Environmental Protection Agency for performance assessment of low-level waste disposal technologies. Groundwater flow in the unsaturated zone beneath the site was simulated using the UNSAT code, developed for the U.S. Nuclear Regulatory Commission(5). An additional code, ISOSHLD(6), was used in the assessment of the above-ground vault facility to calculate direct radiation exposure rates for geometries of exposure not readily addressed with PATHRAE.

The service lifetimes of concrete canisters and vaults and their affect on projected doses was investigated. These analyses assumed structural failure at 100-year intervals from 100 to 500 yr following site closure.

RESULTS AND DISCUSSION

The dose summaries for shallow land disposal and the three alternative facilities are listed in Table I. Maximum doses for the intruder scenarios for shallow land disposal all occur at the end of institutional control, 100 yr after site closure. Of these, the dose to the on-site resident farmer is greatest, amounting to approximately 120 mrem/yr. Doses for the remaining intruder scenarios for shallow land disposal are smaller by a factor of nine or more.

The predicted maximum intruder doses for the three conceptual disposal facilities assessed in this report were all less than the predicted maximum intruder dose for shallow land disposal. In all cases, the intruder dose for above-ground vault disposal exceeded intruder doses calculated for the modular concrete canister disposal facilities.

For shallow land disposal and below-ground modular concrete canister disposal, no dose to the adjacent farmer occurs in the 1,000-year simulation period of this assessment. This is due to the fact that transport of contaminants from these facilities occurs through groundwater pathways only. Given the extremely long groundwater travel times at the site, discussed below, no exposures are projected.

The above-ground vault and the above/below-ground modular concrete canister facilities result in doses to the adjacent farmer as a result of surface water transport of contaminants. For the above/below-ground modular concrete canister facility the projected dose is less than 0.3 mrem/yr, rising to 240 mrem/yr for above-ground vaults.

The projected doses by exposure scenario and disposal facility may be compared to pertinent regulatory limits as a gauge of each facility's performance. Two such regulatory limits are considered, namely, 500 mrem/yr dose rate to an inadvertent intruder at a low-level radioactive waste disposal facility(7) and 25 mrem/yr whole-body equivalent dose rate to a member of the general public exposed to releases from a disposal facility(8).

All intruder doses projected for shallow land disposal and the alternative facilties fall well below the 500 mrem/yr regulatory limit. The projected dose to the adjacent farmer for the above/below-ground modular concrete canister facility similarly falls well below the regulatory limits for exposures to members of the general public. In contrast, the projected dose to an adjacent farmer for the above-ground vault disposal facility is nearly ten times higher than the applicable regulatory limit.

TABLE I

Radionuclide Dose Summaries for Shallow Land Disposal and the Three Alternative Disposal Facilities

Exposure Scenario	Shallow Land Disposal	Above-Ground Vaults	Below-Ground Modular Concrete Canister	Above/Below-Ground Modular Concrete Canister
	Disposal Facility			
Intruder-Explorer				
Peak Year	100	500	100	100
Maximum Dose (mrem/yr)	3.3E-6	3.8E+0	7.7E-7	4.9E-7
Dominant Pathway	Direct Radiation (100%)[a]	Direct Radiation (71%)	Direct Radiation (100%)	Direct Radiation (100%)
Dominant Nuclide	Cs-137 (97%)	Nb-94 (42%)	Cs-137 (96%)	Cs-137 (98%)
Intruder-Construction				
Peak Year	100	500	500	500
Maximum Dose (mrem/yr)	1.3E+1	6.4E+0	4.7E-1	4.3E-1
Dominant Pathway	Direct Radiation (86%)	Inhalation (93%)	Inhalation (89%)	Inhalation (93%)
Dominant Nuclide	Cs-137 (85%)	Am-241 (62%)	Am-241 (52%)	Am-241 (55%)
Intruder-Agriculture				
Peak Year	100	500	500	500
Maximum Dose (mrem/yr)	1.2E+2	4.0E+0	1.5E+0	1.3E+0
Dominant Pathway	Direct Radiation (93%)	Inhalation (77%)	Inhalation (69%)	Inhalation (75%)
Dominant Nuclide	Cs-137 (93%)	Am-241 (57%)	Am-241 (50%)	Am-241 (52%)
Adjacent Farm				
Peak Year	---[b]	500	---[b]	500
Maximum Dose (mrem/yr)	0.0E+0	2.4E+2	0.0E+0	2.2E-1
Dominant Pathway	---	Inhalation (78%)	---	Inhalation (54%)
Dominant Nuclide	---	Am-241 (92%)	---	Am-241 (62%)

[a] Indicates percent of total exposure scenario dose due to respective pathways or nuclides.
[b] Exposure scenario does not result in dose during 1000-year simulation period.

Results for site groundwater simulations indicate an approximate water travel time of 300,000 yr in the absence of any disposal facility. This travel time is similar to that calculated using the maximum vertical water flux for the more permeable upper strata of site soils(9). Given such an extreme travel time as this the impact of concrete structures, with service lives on the order of 500 yr, is minimal. It is evident from these results that the natural geohydrological characteristics of the site, in and of themselves, provide significant protection of the groundwater.

It is clear from the projected groundwater flow rates that contamination of the aquifer below the site is unlikely. Nevertheless, the consequences of a much shorter water travel time to the aquifer, 30,000 yr, were investigated in order to bound the expected impacts via groundwater transport. Even in this case the dose consequences are minimal, amounting to a projected peak dose rate of only 1 mrem/yr approximately 100,000 yr after site closure.

Results from the sensitivity analyses of maximum dose projections as a function of concrete service life are shown in Figs. 1 through 4 for the four exposure scenarios. Included in these figures are the regulatory limits introduced above. Projected doses decrease for all scenarios as the concrete service lifetimes are lengthened, reflecting delayed exposure to the waste.

The maximum intruder dose rates for both modular concrete canister disposal facilities are well below the allowable limit of 500 mrem/yr for all concrete service lives. The worst case of these is the Intruder-Agriculture exposure scenario (Fig. 3) where the maximum intruder dose rate at a concrete service life of 100 yr approaches 100 mrem/yr. In contrast, the maximum intruder dose rate for above-ground vault disposal, seen for the Intruder-Explorer scenario (Fig. 2), exceeds the 500 mrem/yr regulatory limit for a concrete service life of 100 yr. This dose rate drops rapidly below the limit with moderate increases in service life.

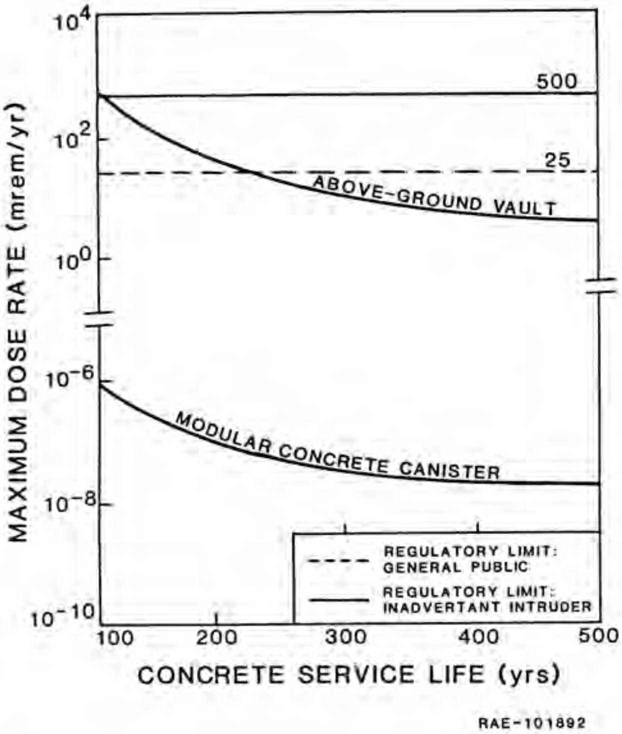

Fig. 1. Sensitivity of Maximum Intruder-Explorer Dose Rates to Variations in Concrete Service Life.

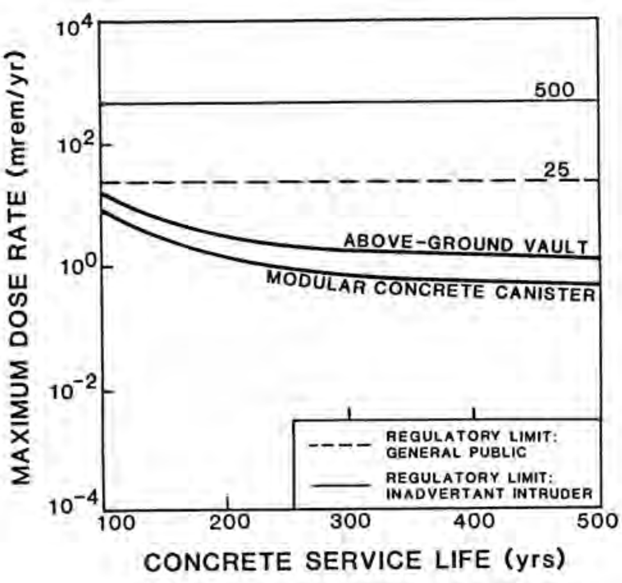

Fig. 2. Sensitivity of Maximum Intruder-Construction Dose Rate to Variations in Concrete Service Life.

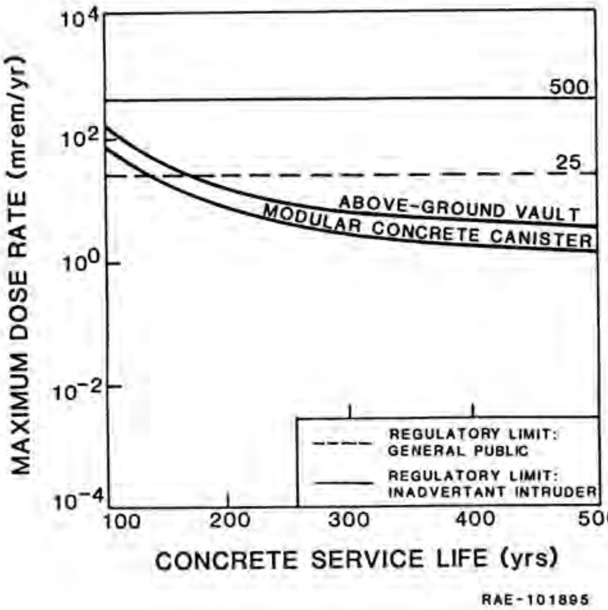

Fig. 3. Sensitivity of Maximum Intruder-Agriculture Dose Rate to Variations in Concrete Service Life.

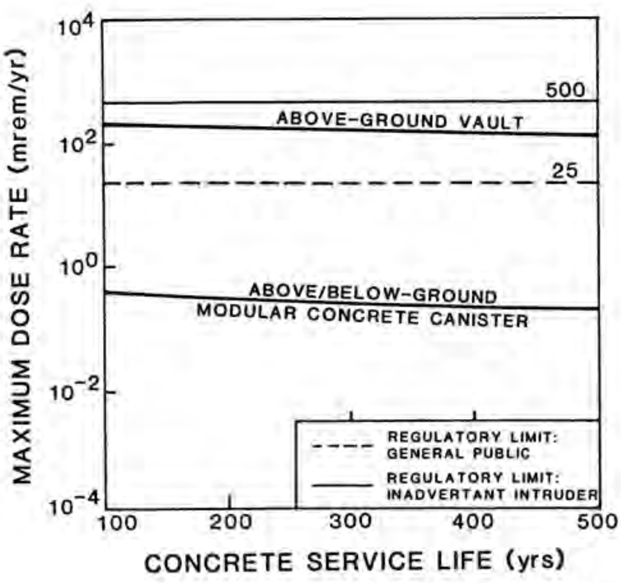

Fig. 4. Sensitivity of Maximum Adjacent Farmer Dose Rate to Variations in Concrete Service Life.

The sensitivity of the maximum adjacent farmer dose rate to changes in concrete service life is portrayed in Figure 4. For the above/below-ground modular concrete canister disposal facility, the maximum dose rates to the adjacent farmer range from about 0.3 to about 0.5 mrem/yr, as the concrete service life decreases from 500 to 100 yr. These dose rates are well below the 25 mrem/yr dose rate allowed for members of the general public. The comparable dose rates for above-ground vault disposal range from about 140 to about 240 mrem/yr, all of which are well in excess of the allowable limit.

In summary, for concrete service lifetimes of 500 yr (200 yr for the below-ground vaults of the modular concrete canister disposal facilities) above-ground vault disposal results in doses three or more times greater than the modular concrete canister facilities. However, maximum intruder doses for all three alternative facilities are substantially lower than both the maximum intruder dose for shallow land disposal and the pertinent regulatory limit. Doses to the adjacent farmer for the above/below-ground modular concrete canister and above-ground vault facilities exceed those for shallow land disposal, with the latter resulting in a dose rate substantially higher than permissible limits.

Performance of the above-ground vault disposal facility is most critically affected by reductions in concrete service life, exceeding acceptable performance criteria at 100 yr for the Intruder-Explorer scenario. While the performance of the modular concrete canister facilities is also impacted by service life, intruder doses do not exceed the maximum intruder dose projected for shallow land disposal.

REFERENCES

1. R. D. BAIRD, et al., "Low-Level Radioactive Waste Disposal Facilities: Conceptual Designs and Assessments Summary Report," Rogers and Associates Engineering Corp., Report RAE-8605-4 Vol. 1, to Texas Low-Level Radioactive Waste Disposal Authority, (1987).

2. "Volumes and Characteristics of Low-Level Radioactive Waste in Texas: 1984," Texas Low-Level Radioactive Waste Disposal Authority, (1984).

3. Final Environmental Impact Statement on 10 CFR Part 61 "Licensing Requirements for Land Disposal of Radioactive Waste," Appendices C-F, U.S. Nuclear Regulatory Commission, NUREG-0945 Vol. 3, (1982).

4. G. B. MERRELL, et al., "The PATHRAE Performance Assessment Code for the Land Disposal of the Radioactive Wastes," Rogers and Associates Engineering Corp., Report RAE-8469/3 to U.S. Environmental Protection Agency, (1985).

5. D. LESTER, et al., "System Analysis of Shallow Land Burial," U.S. Nuclear Regulatory Commission Report, NUREG/CR-1963, (1981).

6. R. L. ENGEL, J. GREENBORG and M. W. HENDRICKSON, "ISOSHLD - A Computer Code for General Purpose Isotope Shielding Analysis," Pacific Northwest Laboratory, BNWL-236, (1966).

7. Draft Environmental Impact Statement on 10 CFR Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Main Report, U.S. Nuclear Regulatory Commission, NUREG-0782 Vol. 2, (1981).

8. U.S. Nuclear Regulatory Commission, "Licensing Requirements for Land Disposal of Radioactive Waste (10 CFR Part 61)," Federal Register, Vol. 47, No. 248, (1982).

9. Texas Bureau of Economic Geology, "Preliminary Geologic and Hydrologic Studies of Selected Areas in Culberson and Hudspeth Counties, Texas," University of Texas at Austin, Austin, Texas, (1986).