POTENTIAL IMPACT OF DOE'S PERFORMANCE OBJECTIVE FOR PROTECTION OF INADVERTENT INTRUDERS ON LOW-LEVEL WASTE DISPOSALS AT OAK RIDGE NATIONAL LABORATORY*

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ABSTRACT

Performance objectives for disposal of low-level radioactive waste at Department of Energy (DOE) sites include limits on radiation dose to inadvertent intruders. This paper investigates the potential impact of DOE's performance objective for protection of inadvertent intruders on the acceptability of low-level waste disposals at Oak Ridge National Laboratory (ORNL). The analysis is based on waste volumes and radionuclide inventories for recent disposals and estimated doses to an inadvertent intruder for assumed exposure scenarios. The analysis indicates that more than 99% of the total volume of waste in recent disposals meets the performance objective for inadvertent intruders, and the volume of waste found to be unacceptable for disposal is only about 16 m^3. Therefore, DOE's performance objective for protection of inadvertent intruders probably will not have unreasonably adverse impacts on acceptable waste disposals at ORNL.

INTRODUCTION

Department of Energy (DOE) Order 5820.2A, Chapter III, specifies performance objectives for disposal of low-level radioactive waste at all DOE sites (1). For protection of inadvertent intruders onto disposal sites at any time after loss of active institutional control, which is assumed to occur at 100 years after facility closure, the DOE Order specifies that effective dose equivalents should not exceed 0.1 rem (1 mSv) per year for chronic exposure scenarios or 0.5 rem (5 mSv) for scenarios involving a single acute exposure. This performance objective is used to determine limits on concentrations of radionuclides that would be acceptable for disposal, based on a site-specific analysis of assumed exposure scenarios for inadvertent intruders.

This paper presents an analysis of the potential impact of DOE's performance objective for inadvertent intruders on the acceptability of low-level waste disposals in Solid Waste Storage Area (SWSA) 6 at Oak Ridge National Laboratory (ORNL). The amount of waste that would be unacceptable for disposal is estimated on the basis of reported waste volumes and radionuclide inventories for recent disposals in SWSA 6 and calculated doses to an inadvertent intruder. This analysis is of interest because the DOE's performance objective for inadvertent intruders is expected to result in concentration limits for disposal of radionuclides at most DOE sites that are considerably lower than the concentration limits for near-surface disposal of civilian low-level waste – the so-called Class-C limits – established by the Nuclear Regulatory Commission (NRC) in 10 CFR Part 61 (2); e.g., see Refs. 3 and 4. Thus, there is concern that DOE's performance objective may cause significant volumes of defense low-level waste to be declared unacceptable for disposal at some sites, particularly when the radionuclide concentrations may be considerably less than the NRC's Class-C limits.

DISPOSAL UNITS AND WASTES

This section describes the different disposal units for low-level waste in SWSA 6 at ORNL (5) and presents data on waste volumes and radionuclide inventories for recent disposals (6).

Types of Disposal Units

Tumulus I and II are above-grade units intended for disposal of contact-handled waste packages with an exposure rate at the surface less than 200 mR/h. Waste packages are placed in concrete box-like casks which are backfilled with concrete. The casks are stacked on a concrete pad and capped with natural materials.

Low-level silos are below-grade units also used for disposal of contact-handled waste packages. These units consist of clusters of two concentric steel pipes placed vertically in a trench. Waste packages are stacked inside the inner steel pipe which is backfilled with concrete. The annular space between the two pipes is filled with concrete, and the top and bottom of the silos are capped with concrete.

High-level silos are constructed in the same manner as the low-level silos. These units are used for disposal of remoted-handled waste packages with an exposure rate at the surface between 200 mR/h and 1 R/h.

High-level wells are below-grade units used for disposal of remote-handled waste packages with an exposure rate at the surface greater than 1 R/h. In these units, several iron pipes are placed vertically inside cylindrical concrete containment tiles, and the space between the pipes and the inner surface of the containment tile is filled with concrete. Waste packages are stacked inside the iron pipes, and the top and bottom of the wells are capped with concrete.

Fissile wells are used for disposal of remote-handled waste packages containing more than 1 g of U-235. The disposal units consist of vertical auger holes lined with steel pipe, and waste packages are stacked inside the pipes. The space

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outside the pipes is backfilled with dirt, and the top and bottom of the wells are capped with concrete.

Asbestos silos are constructed in the same manner as the low-level silos. These units are used for disposal of low-level waste contaminated with asbestos. The exposure rate at the surface of waste packages usually is much less than 10 mR/h.

Biological trenches are unlined, below-grade excavations used for disposal of wastes generated when radionuclides are used in biological research. The exposure rate at the surface of waste packages usually is much less than 10 mR/h.

Data on Recent Disposals

More than 30 radionuclides with half-lives sufficiently long that they could be of concern in a dose analysis for inadvertent intruders at times beyond 100 years after disposal have been reported in recent low-level waste disposals in SWSA 6 (6). However, on the basis of the preliminary dose analysis presented in this paper, only a few of these radionuclides appear to occur in concentrations sufficiently high that the estimated doses to an inadvertent intruder would exceed a small fraction of the dose limits in the performance objective. Data on waste volumes for the different disposal units in SWSA 6 and inventories in disposed waste of the important radionuclides for an intruder dose analysis are summarized in Table I.

TABLE I
Data on Recent Disposals of Low-level Waste in Different Disposal Units in SWSA 6 at ORNL[a]

Disposal Units	Volume (m^3)	Nuclide[b]	Activity (Ci)
Tumulus I and II	1,134	Sr-90	11
		Tc-99	0.019
		Cs-137	27
		Ra-226	0.0017
		Th-232	0.00067
		Pu-239	0.022
		Am-241	0.035
Low-Level Silos	594	Sr-90	2.7
		Cs-137	3.2
		Th-232	0.0011
		Am-243	0.0062
High-Level Silos	286	Sr-90	23
		Cs-137	26
		Th-232	0.00014
High-Level Wells	15.6	Sr-90	1,400
		Tc-99	0.40
		Cs-137	1,400
		Eu-152	1,100
		Eu-154	580
		Th-229	0.0075
		Th-232	0.000037
Fissile Wells	0.54	Cs-137	43
		U-235	0.00088
		U-238	0.048
Asbestos Silos	108	Sr-90	0.042
		Tc-99	0.0012
		Cs-137	0.057
		Th-232	0.000043
Biological Trenches	208	Sr-90	0.010
		Cs-137	0.0022

[a] Data obtained from ref. (6) apply to reported disposals between September 26, 1988, which is implementation date for DOE Order 5820.2A (1), and April 7, 1992.
[b] Only those radionuclides in different disposal units that contribute most of the estimated dose to an inadvertent intruder are listed.

SCENARIOS FOR INADVERTENT INTRUSION

Three exposure scenarios for inadvertent intruders were assumed in the draft performance assessment for SWSA 6 — the so-called agriculture, discovery, and post-drilling scenarios (7). This section briefly describes these exposure scenarios and summarizes the factors used to obtain the preliminary estimates of dose for each scenario.

Agriculture Scenario

In the agriculture scenario, an inadvertent intruder is assumed to excavate into waste while constructing a foundation for a home at the location of disposal units, and some of the exhumed waste is assumed to be mixed with native soil in the intruder's vegetable garden. The following exposure pathways then are assumed to occur: ingestion of contaminated vegetables from the garden, ingestion of contaminated soil from the garden in conjunction with vegetable intakes, external exposure to contaminated soil while working in the garden or residing in the home on top of the disposal units, and inhalation of radionuclides suspended into air while working in the garden or residing in the home. The agriculture scenario results in chronic exposures and, thus, is subject to a dose limit of 0.1 rem (1 mSv) per year.

For disposal units constructed using engineered barriers (i.e., concrete casks or caps), direct intrusion into waste using normal excavation procedures is assumed to be precluded during the period of time that the engineered barriers remain intact. In the preliminary dose analysis, all engineered barriers were assumed to remain intact for 300 years after disposal (7). Thus, the agriculture scenario is assumed to occur at 300 years after disposal for all disposal units, except the scenario is assumed to occur at 100 years after disposal for the biological trenches because these units do not include engineered barriers.

Discovery Scenario

In the discovery scenario, an inadvertent intruder is assumed to excavate at the location of disposal units in constructing a foundation for a home, as in the agriculture scenario. However, for all disposal units except the biological trenches, which do not include engineered barriers, the intruder is assumed to encounter an intact engineered barrier that cannot be penetrated by normal excavation procedures.

Then, shortly after encountering the engineered barrier, the intruder abandons excavation at that location and moves elsewhere. The only exposure pathway for this scenario is external exposure to photon-emitting radionuclides in the waste during the time the intruder works at the site. The discovery scenario results in a single acute exposure and, thus, is subject to a dose limit of 0.5 rem (5 mSv).

The discovery scenario is assumed to occur at any time after loss of active institutional control at 100 years after disposal. However, this scenario is not relevant in the dose analysis for the biological trenches, because these units are constructed without engineered barriers and the agriculture scenario is assumed to occur at 100 years after disposal.

Post-Drilling Scenario

In the post-drilling scenario, an inadvertent intruder is assumed to drill through disposal units, e.g., for the purpose of constructing a well, and all drilling waste is assumed to be mixed with native soil in the intruder's vegetable garden. The following exposure pathways then are assumed to occur: ingestion of contaminated vegetables from the garden, ingestion of contaminated soil from the garden in conjunction with vegetable intakes, external exposure to contaminated soil while working in the garden, and inhalation of radionuclides suspended into air while working in the garden. These pathways are the same as some of those assumed for the agriculture scenario, except the volume of waste mixed with garden soil is assumed to be a factor of 10 greater for the agriculture scenario than for the post-drilling scenario (7). The post-drilling scenario results in chronic exposures and, thus, is subject to a dose limit of 0.1 rem (1 mSv) per year.

Normal drilling procedures at ORNL can easily penetrate through hard rock. Therefore, drilling through disposal units is assumed to be credible even when all engineered barriers are intact, and the post-drilling scenario is assumed to occur at any time after loss of active institutional control at 100 years after disposal. However, the post-drilling scenario is not relevant in the dose analysis for the biological trenches, because the more restrictive agriculture scenario (3,4) is assumed to occur at 100 years after disposal for these units.

Summary of Dose Analyses for Intruder Scenarios

The preliminary dose analyses for the three exposure scenarios for inadvertent intruders assumed in the draft performance assessment for SWSA 6 are summarized in Table II. Results are given only for those radionuclides listed in Table I, because the other radionuclides reported in the waste are not important in the intruder dose analysis for any disposal units. The dose analyses are summarized in Table II in the form of so-called scenario dose conversion factors (SDCFs), which are doses per unit concentration of radionuclides. The SCDFs are applied, as described below, to the concentrations of radionuclides in disposal units at the time an intrusion scenario is assumed to occur to obtain the preliminary estimates of dose to inadvertent intruders.

RESULTS OF DOSE ANALYSIS FOR INADVERTENT INTRUDERS

In the dose analysis for inadvertent intruders in SWSA 6, a separate analysis is performed for each type of disposal unit described previously. For an assumed exposure scenario and particular type of disposal unit, the effective dose equivalent

TABLE II

Scenario Dose Conversion Factors for Assumed Exposure Scenarios for Inadvertent Intruders in Performance Assessment for SWSA 6 at ORNL[a]

Nuclide	Scenario dose conversion factor[b]		
	Agriculture	Discovery	Post-drilling
Sr-90	2.7E-4	-	2.7E-5
Tc-99	8.4E-5	-	8.4E-6
Cs-137	1.0E-3	4.5E-6	1.1E-6
Eu-152	2.0E-3	1.1E-5	9.6E-7
Eu-154	2.2E-3	1.2E-5	1.1E-6
Ra-226	4.2E-3	1.8E-5	1.1E-4
Th-229	7.3E-4	1.5E-6	1.7E-5
Th-232	4.9E-3	2.7E-5	6.0E-5
U-235	1.9E-4	2.5E-7	4.2E-7
U-238	4.2E-5	1.4E-7	3.4E-7
Pu-239	6.8E-5	-	3.3E-6
Am-241	7.7E-5	3.6E-10	3.1E-6
Am-243	2.9E-4	3.4E-7	3.2E-6

[a]Values obtained from Tables 4.17, 4.18, and 4.19 of draft performance assessment report (7) give doses per unit concentration of radionuclides.

[b]Values are in units of rem/y per $\mu Ci/m^3$ for agriculture and post-drilling scenarios and rem per $\mu Ci/m^3$ for discovery scenario.

to an inadvertent intruder from a given radionuclide is estimated by

$$H = C_0 \times SDCF \times G \times \exp(-\lambda t), \quad \text{(Eq. 1)}$$

where H is the effective dose equivalent in rem per year for the chronic agriculture and post-drilling scenarios or in rem for the acute discovery scenario, C_0 is the average radionuclide concentration in the waste at the time of disposal in $\mu Ci/m^3$, SDCF is the scenario dose conversion factor for the radionuclide in rem/y per $\mu Ci/m^3$ for the chronic exposure scenarios or in rem per $\mu Ci/m^3$ for the acute exposure scenario, G is a geometrical correction factor for the particular type of disposal unit described below, λ is the radionuclide decay constant in y^{-1}, and t is the assumed time between disposal and occurrence of the exposure scenario in years. The average initial concentrations of radionuclides, C_0, for the different disposal units in SWSA 6 are obtained from the data in Table I, and the SDCFs for each exposure scenario and radionuclide are given in Table II. As described previously, the agriculture scenario is assumed to occur at 100 years after disposal for the biological trenches or at 300 years for all other disposal units; and, the discovery and post-drilling scenarios are assumed to occur at 100 years for all disposal units, except these scenarios are not relevant for the biological trenches which do not include engineered barriers.

The geometrical correction factor, G, for particular disposal units in Eq. (1) takes into account that, for some exposure scenarios, the average concentrations of radionuclides to which an intruder would be exposed are less than the average concentrations in disposed waste, because a substantial fraction of the area encompassed by an envelope around all disposal units of the same type contains uncontaminated material (e.g., soil, waste containers, backfill). This correction factor particularly applies to the agriculture and discovery scenarios, because an intruder is assumed to excavate over an area considerably larger than the area occupied by individual casks, silos, wells, or trenches. Therefore, for each type of disposal unit, the average radionuclide concentrations to which an intruder would be exposed are the average concentrations in disposed waste multiplied by the fraction of the land area encompassed by all such disposal units that contains waste. The latter term is the geometrical correction factor for particular disposal units.

For the agriculture and discovery scenarios, the assumed geometrical correction factor is 0.4 for Tumulus I and II, 0.25 for the low-level silos, high-level silos, fissile wells, asbestos silos, and biological trenches, and 0.075 for the high-level wells. These values are based on current designs or operating practices for the different types of disposal units (5).

For the post-drilling scenario, the geometrical correction factor is assumed to be unity for all disposal units; i.e., an intruder is assumed to drill only through contaminated regions in disposal units. Any uncontaminated material exhumed by drilling is taken into account in the dilution factor for mixing of drilling waste with native soil in the intruder's vegetable garden.

The use of average concentrations of radionuclides in disposed waste and the geometrical correction factor described above is based on the reasonable assumption that an inadvertent intruder would access disposal units at random locations. By using average concentrations of radionuclides and the geometrical correction factor to determine limits on concentrations that would be acceptable for disposal, acceptable disposals could include a relatively small number of waste packages in which radionuclide concentrations far exceed the allowable average values. However, radionuclide concentrations in individual waste packages at DOE disposal sites cannot exceed the NRC's Class-C limits for civilian waste (1), even if the average concentrations in disposal units would be less than the limits determined by a site-specific dose analysis for inadvertent intruders.

The results of the dose analyses for inadvertent intruders for the different disposal units in SWSA 6 are summarized in Table III. For each exposure scenario, the results are expressed in terms of the ratio of the effective dose equivalent, as estimated from Eq. (1), to the applicable dose limit. Particular disposal units then would be in compliance with the performance objective for protection of inadvertent intruders if, for each scenario, the ratios of the dose from each radionuclide to the dose limit, summed over all radionuclides, are less than unity; this is the so-called sum-of-fractions rule which applies when exposure to all radionuclides occurs at the same time. The results of the dose analyses for the different disposal units in SWSA 6 are described as follows.

For Tumulus I and II, the low-level silos, the asbestos silos, and the biological trenches, the estimated doses to an inadvertent intruder from all radionuclides and for all exposure scenarios are well below the dose limits in the performance objective. The total volume of waste in these units of 2,044 m^3 (see Table I) comprises 87% of the volume of all recent disposals in SWSA 6.

For the high-level silos, the estimated dose to an inadvertent intruder from all radionuclides exceeds the dose limit by a factor of 2 for the post-drilling scenario, but the estimated doses are well below the limits for the agriculture and discovery scenarios. For the post-drilling scenario, the dose is due almost entirely to the inventory of Sr-90. Thus, if this scenario were precluded only for an additional 30 years after loss of active institutional control (e.g., by use of fences and warning signs), the dose would be below the limit. The total volume of waste in the high-level silos of 286 m^3 comprises 12% of the volume of all recent disposals in SWSA 6.

For the high-level wells, the estimated doses to an inadvertent intruder from all radionuclides exceed the dose limits by factors of nearly 100 for the agriculture scenario, nearly 10 for the discovery scenario, and more than 2000 for the post-drilling scenario. For each scenario, the dose is due primarily to the inventories of Sr-90 and/or Cs-137. Thus, the doses for the discovery and post-drilling scenarios would be reduced below the limits if these scenarios were precluded for about 200 years and more than 400 years after disposal, respectively, by such measures as passive institutional controls or engineered barriers. However, the dose at times long after disposal would still exceed the limit by a factor of 2 for the agriculture scenario, due to the inventories of long-lived Tc-99 and Th-229, and it is not reasonable to assume that passive institutional controls or engineered barriers could preclude exposure to these radionuclides. The total volume of waste in the high-level wells of 15.6 m^3 comprises less than 1% of the volume of all recent disposals in SWSA 6.

For the fissile wells, the estimated doses to an inadvertent intruder from all radionuclides exceed the dose limits by factors of 200 for the agriculture scenario, nearly 20 for the discovery scenario, and nearly 100 for the post-drilling scenario. For each scenario, the dose is due primarily to the inventory of Cs-137. Thus, the doses for the discovery and

TABLE III

Ratios of Estimated Doses to Inadvertent Intruders to Dose Limits for Assumed Exposure Scenarios for Different Disposal Units in SWSA 6 at ORNL

		Ratio of dose to dose limit[a]		
Disposal units	Nuclide	Agriculture	Discovery	Post-drilling
Tumulus I and II	Sr-90	0.01		0.23
	Tc-99	0.01		
	Cs-137	0.10	0.01	0.03
	Ra-226	0.03		
	Th-232	0.01		
	Pu-239	0.01		
	Am-241	0.01		
	Sum	0.18	0.01	0.26
Low-Level Silos	Sr-90			0.11
	Cs-137	0.01		0.01
	Th-232	0.02		
	Am-243	0.01		
	Sum	0.04		0.12
High-Level Silos	Sr-90	0.04		1.9
	Cs-137	0.23	0.02	0.10
	Th-232	0.01		
	Sum	0.28	0.02	2.0
High-Level Wells	Sr-90	13		2200
	Tc-99	1.6		0.65
	Cs-137	69	6.1	100
	Eu-152	0.02	0.71	4.1
	Eu-154		0.03	0.16
	Th-229	0.26	0.03	
	Th-232	0.01		
	Sum	84	6.9	2300
Fissile Wells	Cs-137	200	18	88
	U-235	0.77		0.01
	U-238	0.93		0.03
	Sum	200	18	88
Asbestos Silos	Sr-90			0.01
	Sum	<0.01		0.01
Biological Trenches	Sum	<0.01		

[a] Dose limit is 0.1 rem per year for agriculture and post-drilling scenarios and 0.5 rem for discovery scenario (1).

post-drilling scenarios would be reduced below the limits if these scenarios were precluded for more than 200 years and about 300 years after disposal, respectively, by passive institutional controls or engineered barriers. However, as in the case of the high-level wells, the dose at times long after disposal would still exceed the limit by a factor of nearly 2 for the agriculture scenario, due only to the inventories of long-lived U-235 and U-238, and passive controls or engineered barriers could not reasonably preclude exposure to these radionuclides. The total volume of waste in the fissile wells of 0.54 m^3 comprises about 0.02% of the volume of all recent disposals in SWSA 6.

Thus, if drilling into the high-level silos could be precluded for an additional 30 years after loss of active institutional control, which would seem to be a reasonable possibility, the analysis indicates that only disposals in the high-level wells and fissile wells would result in doses to inadvertent intruders that exceed the performance objective. Furthermore, the unacceptability of waste disposals in these units does not depend on assumptions regarding the time after disposal at which the different exposure scenarios would occur (i.e., on the *duration of intact engineered barriers or* passive institutional controls), because the dose for the agriculture scenario in each of these units exceeds the limit at times long after disposal due only to the high concentrations of long-lived radionuclides. The total volume of waste in the high-level wells and fissile wells is about 16 m^3, which is less than 1% of the total volume of all recent disposals in SWSA 6.

SUMMARY AND CONCLUSIONS

This paper has investigated the potential impact of the performance objective for protection of inadvertent intruders in DOE Order 5820.2A (1) on the acceptability of low-level waste disposals in SWSA 6 at ORNL. Estimates of dose to inadvertent intruders, based on assumed exposure scenarios, were obtained from data on radionuclide inventories and waste volumes for recent disposals in SWSA 6 and information on the design of the different disposal units at the site. A separate dose analysis was performed for each type of disposal unit.

The analysis shows that only about 16 m^3, or less than 1%, of the volume of waste in recent disposals in SWSA 6 would be unacceptable in regard to meeting DOE's performance objective for inadvertent intruders. Thus, the impact of the performance objective on acceptable disposals at ORNL does not appear to be severe. However, this conclusion is valid only if substantial volumes of waste generated in the future do not contain average concentrations of longer-lived radionuclides considerably higher than the concentrations reported in recent disposals.

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