# PERFORMANCE ASSESSMENT OF LOW-LEVEL RADIOACTIVE WASTE DISPOSAL AT OAK RIDGE NATIONAL LABORATORY

D. W. Lee
Energy Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee

D. C. Kocher
Health and Safety Research Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee

## ABSTRACT

A site-specific, long-term performance assessment is being conducted for the currently operating low-level waste disposal facility at Oak Ridge National Laboratory. Disposal facilities must comply with performance objectives for low-level waste disposal specified in DOE Order 5820.2A. This paper describes (1) the assumptions used in the draft performance assessment, (2) the results of the analysis in regard to compliance of disposal facilities with the requirements for protection of off-site members of the public, inadvertent intruders, and groundwater resources, and (3) modifications of the performance assessment and waste operations that are being developed for demonstrating compliance with the performance objectives with reasonable assurance.

## INTRODUCTION

DOE Order 5820.2A requires each DOE site operating a low-level waste disposal facility prepare a site-specific radiological performance assessment for the purpose of demonstrating compliance with the performance objectives specified in the Order (1). The performance objectives, which define acceptable performance of the facility and apply to wastes disposed of after September 26, 1988, include the following:

1. Protect public health and safety in accordance with standards specified in Environmental Health (EH) Orders and other DOE Orders.
2. Assure that external exposure to the waste and concentrations of radioactive material which may be released into surface water, groundwater, soil, plants and animals results in an effective dose equivalent that does not exceed 25 mrem/yr to a member of the public. Releases to the atmosphere shall meet the requirements of 40 CFR Pt.61. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as reasonable achievable.
3. Assure that the committed effective dose equivalents received by individuals who inadvertently intrude into the facility after the loss of active institutional control (100 years) will not exceed 100 mrem/yr for continuous exposure or 500 mrem for acute exposure.
4. Protect groundwater resources, consistent with Federal, State and local requirements.

A draft performance assessment has been prepared for disposal of low-level radioactive waste at Solid Waste Storage Area 6 (SWSA 6) disposal facility at Oak Ridge National Laboratory (ORNL). The draft performance assessment (2) has been given an initial review by the DOE Peer Review Panel. The draft performance assessment was prepared with the guidance provided by the Peer Review Panel that outlines the format and content for radiological performance assessments (3). Current activities are directed towards the preparation of a final performance assessment for SWSA 6 that is responsive to the recommendations of the Peer Review Panel and additional guidance provided for the preparation of performance assessments (4).

SWSA 6 is located about 3 km (1.9 miles) south of Oak Ridge National Laboratory on the DOE Oak Ridge Reservation (ORR). The facility is located on a 27.5 ha (68 acre) tract of land with rolling terrain. Approximately 12 ha (30 acres) of the site is suitable for disposal operations. The majority of the disposal capacity was used before September 26, 1988. The facility is projected to continue operations until 1996 when the remaining disposal capacity will be exhausted. Those portions of the facility where disposal operations occurred prior to September 26, 1988 are presently subject to closure under the Resource Conservation and Recovery Act of 1976 and the Comprehensive Environmental Response, Compensation, and Liability Act of 1980. Following the implementation guidance for DOE Order 5820.2A, the performance assessment for continuing operations has been prepared without consideration of disposal operations performed prior to issuance of the Order. The performance assessment considers five different types of disposal structures: concrete silos, tumuli, double-walled pipe wells, lined auger holes, and unlined trenches. Each type of disposal unit and the wastes expected to be emplaced therein are considered separately in the performance assessment. In addition, the assessment assumes normal or expected disposal unit performance. Accidental releases or abnormal operations are considered in the safety documentation for the facility and are not part of the performance assessment. Recommended changes in facility design and operations are currently being developed as part of the final performance assessment. These changes are intended to provide reasonable assurance that compliance the performance objectives can be demonstrated.

## DISPOSAL FACILITY DESCRIPTION

SWSA 6 is located on the southeastern slope of a knob in Melton Valley adjacent to White Oak Lake. The average annual precipitation in the vicinity of the facility is 137 cm (54 in). Topographic relief at the facility is about 30 m (98 ft) with slopes ranging from less than 5% to greater than 25%. Surface runoff from the facility drains to three small tributaries that discharge to White Oak Lake. Two of these streams originate within SWSA 6. Figure 1 shows the location of SWSA 6 in proximity to White Oak Lake which is adjacent to the facility. The facility is underlain by sedimentary bedrock of Paleozoic Age which generally dips to the southeast at an attitude of 10-15 degrees in an imbricate pattern formed during the Appalachian Orogeny some 300 million years ago. Geologic structures present on the ORR include regional thrust faults, local faults having various orientations, local folds, and numerous sets of local joints and fractures. The underlying formations are composed of bedded limestones, shales and siltstones of variable thicknesses, with the bed orientations generally parallel to the trend of the valley. Soils underlying the facility are residual products derived from weathering and leaching of the underlying bedrock. Soils are of irregular thickness, being thinnest at creeks and thickest beneath upland terrain. Soil thicknesses range from less than 0.5 m (1.5 ft) to more than 10 m (33 ft). Groundwater occurs in a continuous saturated zone below the water table surface. Most wells in the area have a low yield with most of the flow occurring parallel to geologic strike. Variations in hydraulic conductivity are typically two to three orders of magnitude, gradually declining with depth. The water table is a subdued replica of the land surface that is generally near the bedrock weathering interface with seasonal depths fluctuating from less than 1.5 m (5 ft) to more than 3 m (10 ft). All monitoring data to date indicate that groundwater inside the facility boundary discharges to the ephemeral creeks within or immediately adjacent to the facility.

SWSA 6 receives 1,400-2,300 $m^3$/yr (50,000-80,000 $ft^3$/yr) of low-level radioactive waste generated at ORNL. The majority of the waste is contact-handled ( < 200 mR/hr exposure rate at the surface). This type of waste includes debris from ORNL operations, research and development activities, and decommissioning and demolition activities. Compactible and noncompactible waste are managed separately. Contact-handled waste is disposed of in concrete silos and tumulus disposal units. Remote-handled waste ( > 200 mR/hr exposure rate at the surface) includes debris from reactors and hot-cell operations. Remote-handled waste with < 1 R/hr surface exposure rate is disposed of in concrete silos. Waste with a surface dose rate of > 1 R/hr is disposed of in double-walled pipe wells and wells in concrete silos. Fissile waste, consisting of debris generated from research and development activities using enriched uranium, is disposed of separately in lined auger holes or wells. Biological waste consists of contaminated excrement and animal carcasses from biological research. The activity of this waste is very low, and the waste is disposed of in unlined trenches. Asbestos waste, consisting of debris generated during maintenance and demolition of contaminated facilities, is disposed of in concrete silos. Future disposal operations also will include the continuation of current operations and the construction of a large tumulus disposal unit (Interim Waste Management Disposal Facility), which will serve as a prototype for future disposal operations to be performed at a new site.

Wastes generated at ORNL are certified prior to disposal. The current waste certification program has been in place since 1986 and requires the waste generator to characterize and certify that the waste meets the acceptance criteria for transport to treatment, storage, assay and disposal facilities. Methods of characterization include measurement and process knowledge. The characterization data are recorded prior to storage, treatment and disposal. Treatment processes include waste compaction and waste grouting. Waste is packaged in 55-gal drums, 4 x 4 x 6-ft metal boxes, 4-mil plastic bags, or 1-, 2-, 5-, 10-, or 20-gal metal cans prior to disposal.

## ANALYSIS OF PERFORMANCE

Waste characteristics used for assessing the performance of SWSA 6 were defined using the existing data from the waste data management program. While the data from these records are imperfect and may not be accurate representations of future waste generated at ORNL, they are the most reasonable representation of present and future waste streams. Most of the isotopes considered in detail in the performance assessment were identified in the scoping analysis prepared prior to the draft performance assessment (5). Other isotopes were considered on the basis of inventory data, the potential for human exposures or the potential for groundwater contamination. For each isotope considered in detail, the release of contamination from the individual disposal units was estimated using the computer codes NEWBOX and FLOWTHRU. These codes estimate the release rate of contamination by considering the percentage of waste wetted by infiltration of water into the waste and the subsequent leaching and diffusion through the contaminated waste form and the surrounding uncontaminated waste containment. The complex waste forms and concrete barriers were approximated as simple slabs and cylinders. The source-term model did not consider the effects of concrete degradation and cracking, or the performance of steel box liners and drums. As a result, the chemical and physical properties of the wastes and concretes were assumed constant over the period of analysis. The release of contamination was estimated for 500 years and analyzed for its transport in the shallow subsurface and groundwater. Contamination that was not released from the disposal unit was assumed to be available in the event of inadvertent intrusion.

Observations at existing disposal sites over the past few decades suggest that emission of radionuclides directly to the atmosphere in gaseous form is not an important release mechanism at SWSA 6. Suspension of particulates by natural processes has not been identified as an important pathway for the transport of contamination and can be precluded as long as a minimal amount of overlying, uncontaminated soil exists at the disposal facility. As a result, the pathways analyzed in detail were surface water and groundwater. The release of contamination from waste disposal units was assumed to occur primarily into groundwater or to surface water from shallow subsurface flow during storm events. Transport of contamination in surface water and groundwater took into account precipitation, storm hydrology, streamflow, infiltration, percolation, recharge, adsorption, and radioactive decay. Some contaminants were adsorbed from groundwater to the soil. Highly sorbed radionuclides released from the facilities were not included in the dose analysis of intruders or off-site individuals. Two models were used for analyzing transport in the shallow subsurface and the saturated zones: the Unified Transport Model code for the shallow subsurface and the U.S. Geological Survey Method of Characteristics Code for the saturated zone. Both of these codes are well documented but

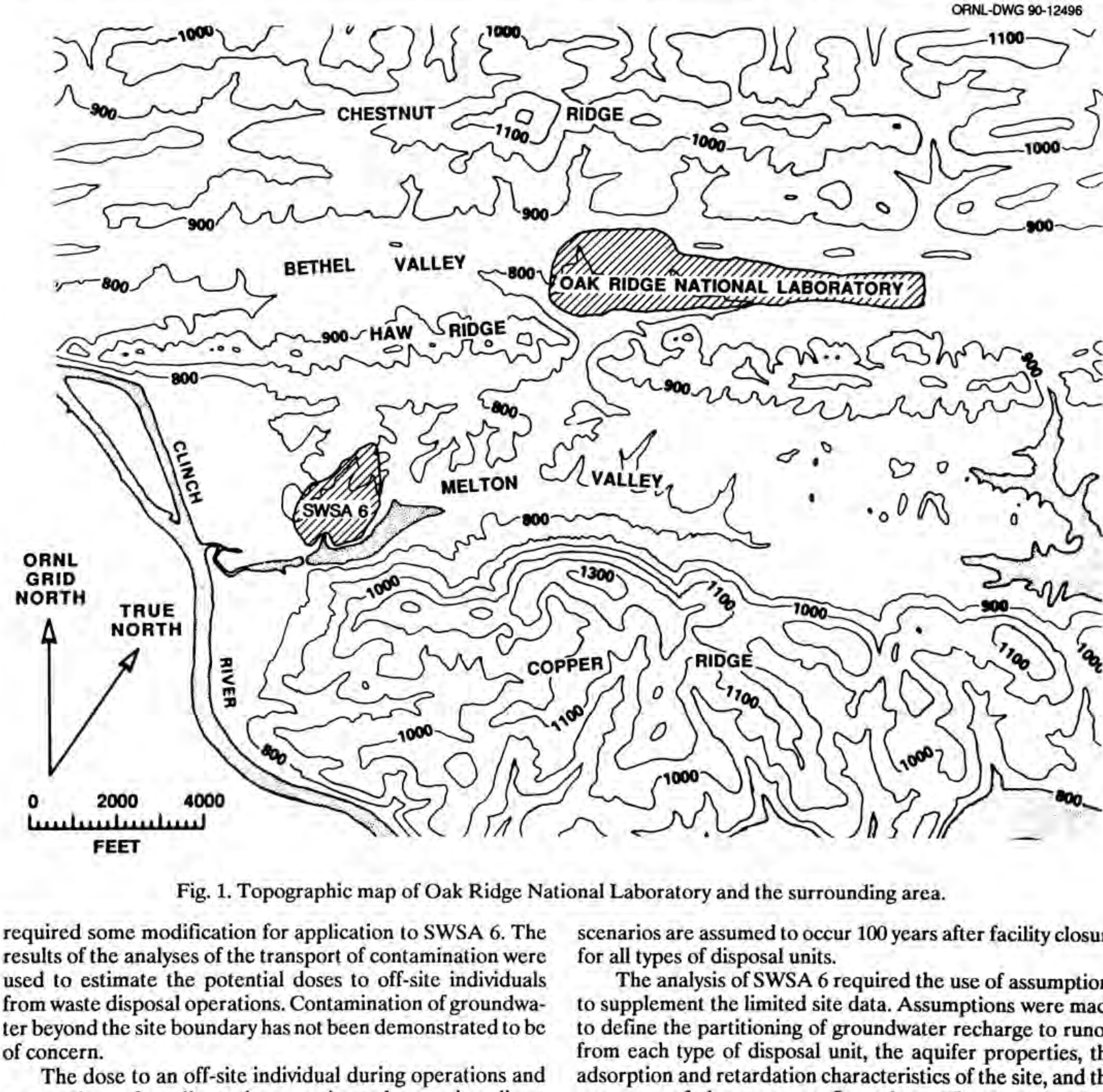


Fig. 1. Topographic map of Oak Ridge National Laboratory and the surrounding area.

required some modification for application to SWSA 6. The results of the analyses of the transport of contamination were used to estimate the potential doses to off-site individuals from waste disposal operations. Contamination of groundwater beyond the site boundary has not been demonstrated to be of concern.

The dose to an off-site individual during operations and at any time after disposal was estimated assuming direct ingestion of contaminated water, ingestion of milk and meat from dairy and beef cattle that drink contaminated water, and exposure from swimming in contaminated water released from White Oak Dam. After institutional control has ended, the same exposure scenario is considered for an individual who inadvertently intrudes onto the disposal site, except swimming in surface water could not occur on the site. Additionally, an inadvertent intruder is assumed to engage in direct intrusion into disposal units according to one of three scenarios: the "intruder-agriculture," the "intruder-discovery," or the "intruder-drilling" scenario. The drilling and agriculture scenarios are continuous exposure scenarios, whereas the discovery scenario is acute. The agriculture scenario is assumed to occur at the time of loss of integrity of the waste disposal units. For engineered disposal units, this scenario is assumed to occur 300 years after facility closure and 100 years after facility closure for the biological trenches. The drilling and discovery scenarios are assumed to occur 100 years after facility closure for all types of disposal units.

The analysis of SWSA 6 required the use of assumptions to supplement the limited site data. Assumptions were made to define the partitioning of groundwater recharge to runoff from each type of disposal unit, the aquifer properties, the adsorption and retardation characteristics of the site, and the geometry of the waste configurations. These assumptions were selected to provide a reasonable, yet conservative, representation of facility performance and were based on the limited information available.

The methodology used to analyze the performance of SWSA 6 was based on the available data on the waste disposed at SWSA 6, the disposal methods used at SWSA 6, and the SWSA 6 site characteristics. In analyzing the performance, the results of the source-term modeling, which provide estimates of releases from disposal units, were used as input to the shallow subsurface model. The contamination released from the waste disposal units to the shallow subsurface model was diluted with the upslope shallow subsurface drainage estimated to enter the disposal units. The shallow subsurface model estimates the transport of contamination to surface water and the recharge to the saturated zone. The saturated zone model uses the contaminated and uncontaminated recharge as input to estimate the transport of contamination to a well 100 m (328 ft) from the disposal unit, and to determine the discharge of contaminated groundwater to surface water. The resulting concentrations in groundwater and surface water are used to estimate the dose from domestic use of water resources. Contamination not released from disposal units is presumed to remain in the disposal units and provides the input to the analysis of direct intrusion according to the agriculture, drilling, and discovery scenarios.

## RESULTS OF ANALYSIS

Releases of contamination from disposal units were estimated over a period of 500 years. Mobile isotopes, such as $^{90}$Sr and $^{3}$H, had their maximum leach rates within this time period. About 30% of the mass inventory of $^{90}$Sr was leached by diffusion from the waste form to the environment during the 500-year period. Less mobile isotopes, such as $^{238}$U and $^{238}$Pu, had not reached their maximum leach rates during the 500-year period, and less than 1% of the mass inventory was leached from the waste form during this time. These estimates did not consider concrete degradation or advection of leachate through cracked or degraded concrete.

Shallow subsurface processes dominate hydrologic phenomena on the ORR and are the primary mechanisms for transport of radionuclides. The Unified Transport Model was calibrated to best represent these processes for the facility. The results indicated that the transport of contamination by shallow subsurface processes was rapid and subject to dilution by uncontaminated runoff. Dilution factors on the order of 10 to 100 were typical for the isotopes considered for the various disposal units.

Modeling of contaminant transport in groundwater using the U.S.G.S. Method of Characteristics code was successful in representing the water table data established for the facility and providing conservative yet reasonable representations of the contaminant plumes from each disposal unit. Maximum concentrations were very low for all isotopes, with the highest concentrations on the order of $10^{-12}$ g/m$^3$ for $^3$H and $10^{-14}$ g/m$^3$ for $^{90}$Sr. Groundwater discharges to surface water were summed with discharges from shallow subsurface processes for dose calculations. Time differences in releases were taken into account in the calculations.

The dose analysis for off-site individuals was performed by assuming ingestion of contaminated surface water as a drinking water supply with the withdrawal of surface water occurring at White Oak Dam. The dam is located just downstream of the confluence of the ephemeral creeks that traverse the facility with White Oak Lake. Sufficient dilution is present in the surface water regime that the resulting doses are substantially below the limit prescribed in the performance objectives. The results for the inadvertent intruder, however, exceeded the performance objectives in the following cases: the agriculture scenario for the low-range silos, the drilling scenario for the high-range silos, all scenarios for the double-walled pipe wells and fissile wells, the agriculture and drilling scenarios for the tumuli. Groundwater doses were estimated to be very small, with annual doses that were four orders of magnitude less than a 4-mrem performance objective.

The results obtained in the draft performance assessment have significant uncertainties. Also, the models were qualitatively shown to be sensitive to several parameters that were associated with limited available data. The uncertainties associated with the performance of SWSA 6 are likely to overshadow the parameter sensitivity of the models used to analyze the facility as a result of the complex environmental setting, the lack of knowledge regarding future waste characteristics, and the limited understanding of the long-term performance of concrete waste forms. Current activities are directed towards providing a more quantitative understanding of the uncertainties associated with the performance assessment.

## INTERPRETATION OF RESULTS

The results of the analysis indicate that all disposal units are in compliance with the performance objectives for off-site individuals and protection of groundwater resources. However, protection of groundwater resources is uncertain because the analysis of the performance of concrete did not include cracking and concrete degradation. Continued work in developing a more complete representation of the long-term performance of concrete will address this uncertainty. The analysis of direct intrusion gave estimated doses for disposal that exceed the applicable performance objectives for many disposal units. However, these results indicate that only a small faction of the total waste inventory is associated with the estimated exceedance of the performance objectives. $^{232}$Th is responsible for the exceedance of the performance objective for disposal in the low-range silos by a factor of five, and $^{232}$Th, $^{233}$U, and $^{237}$Np are responsible for the exceedance of the performance objectives for the tumulus facilities by nearly a factor of 20. These long-lived isotopes also are associated with uncertain inventory data. Work is continuing to determine the validity of the data used in the analysis of these units. The doses from disposal in the high-range silos exceed the performance objectives by a factor of two for the intruder-drilling scenario as a result of the high inventories of $^{90}$Sr. This result is tempered by the very conservative nature of the drilling scenario that calls for an intruder to drill directly into a waste silo and to penetrate the depth of the silo. The biological trenches and asbestos silos met the performance objectives for direct intrusion. The doses from disposal in the fissile wells and the double-walled pipe wells exceed the performance objectives by a factor of about 500 according to the agriculture scenario and by factors of 20 and 4000 respectively according to the drilling scenario. The high dose estimates are the result of the high concentrations of $^{137}$Cs, $^{235}$U, and $^{238}$U in the fissile wells and $^{90}$Sr, $^{99}$Tc, and $^{137}$Cs and $^{152}$Eu in the double-walled pipe wells. Significant reductions in allowable waste concentrations appear to be necessary for these disposal units to approach compliance with the performance objectives.

## IMPROVEMENTS IN OPERATIONS AND THE PERFORMANCE ASSESSMENT

The results indicate that current and expected disposal operations in the double-walled pipe wells and the fissile wells could result in doses to inadvertent intruders that are substantially above the performance objectives. Design changes to be applied to these units, including the termination of disposal operations, are being evaluated and plans are being developed as part of the preparation of the final performance assessment. The remaining units that exceed the performance objectives for inadvertent intruders are being investigated to determine if the parameter values and uncertainties in the analysis can be reduced to the extent that compliance with the performance objectives can be demonstrated. Analyses are being conducted and procedures are being developed to establish certifiable waste acceptance criteria for the disposal operations in SWSA 6, including improved methods of waste characterization. These criteria are being developed to specify waste concentrations required for compliance with the performance objectives of DOE Order 5820.2A.

Work is ongoing to further evaluate source terms. The time period of concern is being extended beyond 500 years to ensure that the results are representative of the maximum dose to an individual for all isotopes at any time in the future. Additional analyses of the source term will include the consideration of the BARRIER code for modeling the long-term behavior of the disposal facilities in SWSA 6. Additional data being collected at SWSA 6 at the existing silos will be applied to the source-term analysis. This work will be coupled with an examination of the records for the concentration of radionuclides in wastes. Additional work also is directed towards developing a more accurate representation of site performance. This activity is intended to ensure that the potential contamination of groundwater resources is addressed with an acceptably low level of uncertainty in the final performance assessment.

## ACKNOWLEDGMENTS

The authors would like to acknowledge the contributions to the draft performance assessment for SWSA 6 that is the basis for this paper. Major contributions to the performance assessment were made by J.S. Baldwin, J.M. Bownds, R.H. Ketelle, R.J. Luxmoore, J.M. Begovich, H.W. Godbee, J.L. Kasten and C.W. Nestor Jr.

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