SITE SELECTION CRITERIA FOR SHALLOW LAND BURIAL OF LOW-LEVEL RADIOACTIVE WASTE

Kathleen L. Falconer, Laurence C. Hull, and Steve A. Mizell

EG&G Idaho, Inc.
Idaho National Engineering Laboratory
Idaho Falls, Idaho 83415

INTRODUCTION

The land disposal of low-level waste must be accomplished in a manner that protects public health and safety. This can be attained by selecting, designing, operating, and closing sites such that contaminants never leave the site boundary in concentrations greater than prescribed limits. Site design, operation, and closure are all functions of the characteristics of the site selected. The site selection process is the most effective means for optimizing safe, efficient, and economical low-level waste disposal.

The Department of Energy's Low-Level Waste Management Program initiated an effort in the fall of 1980 to develop criteria pertinent to the shallow land burial of low-level radioactive waste. The authors, together with a technical review committee, developed the site selection criteria that are presented in this paper. Members of the committee were John Cherry, University of Waterloo; Alan Grey, EG&G Idaho; John Robertson, U.S. Geological Survey; Tsuneo Tamura, Oak Ridge National Laboratory; and Merlin Wheeler, Los Alamos National Laboratory. An extensive review of existing work covering the disposal of radioactive wastes [1, 2, 3, 4] was made and applicability of this work to shallow land burial was evaluated. The criteria presented here are considered preliminary and do not necessarily represent the position of the Department of Energy's Low-Level Waste Management Program.

PERFORMANCE OBJECTIVES

A shallow land burial site must meet specific ground rules or performance objectives. The performance objectives are based on the regulatory limits that govern contaminant release to the accessible environment. They are specified as the maximum radiological dose permissible for individuals outside the site for the entire time frame over which the waste remains hazardous and for the inadvertent intruder into the waste after access to the site is decontrolled.

- o The annual dose from radionuclides released from any shallow land burial site to persons outside the site boundary shall not exceed 25 mrem/yr--whole body, 75 mrem/yr--thyroid, 25 mrem/yr--any organ, for a performance period of 500 years.

- o Waste shall not be disposed of in a shallow land burial site that would result in an unexceptable dose to an inadvertant intruder after an institutional control period of 100 years has ended.

Time periods set for the performance objectives are the key to determining what wastes are acceptable for land disposal. These time periods in conjunction with nuclide half-life can be used to determine a concentration limit for each radionuclide accepted for burial at low-level waste disposal sites.

SITE SELECTION CRITERIA

Criteria are standard rules by which the ability of a potential site to meet performance objectives may be judged. They are comprehensive, qualitative, and applicable in any geologic environment. The twelve criteria presented in this paper provide the framework for identifying sites that are suitable for land disposal of low-level radioactive waste. They ensure that all factors important to the containment and isolation capabilities and environmental acceptability of candidate sites are considered in the siting process. Each criterion presented is supplemented by an explanation of the pertinent factors that should be examined to evaluate compliance. However, listings of all possible combinations of site characteristics that would result in acceptable site performance are not provided. The criteria are purposely general to allow for an analysis of the interrelationships of all site characteristics.

In developing site selection criteria, it was necessary to make certain assumptions about the low-level waste management system in which selected sites will be operated. The following assumptions were made:

- o The site will be selected, designed, operated and closed to meet performance objectives. Zero release is not achievable.
- o Performance objectives can be met by utilizing both natural and engineered barriers.
- o After the institutional control period, the site will be suitable for normal surface use but will not be designed to prevent human excavations into the waste.
- o Waste form will not jeopardize site performance.

1. The site should be of sufficient area and depth to accommodate the projected volume of waste and a three dimensional buffer zone.

To meet site performance objectives for low-level radioactive waste disposal, the site and its operation must not limit the activity of man beyond site boundaries. A three-dimensional buffer zone will allow waste attenuation within the site boundary such that performance objectives are met. The essential information required to determine outer boundaries of the site (i.e., the buffer zone) includes the rate of change of radionuclide concentration as a function of distance from the disposal facility along all migration pathways and the concentration and quantity of radionuclides in the waste source. The depth to which the buffer zone extends depends on the hydrologic, geologic, and climatic setting of the disposal facility and whether waste is buried in unsaturated or saturated materials.

Three general environments can be described for burial in the unsaturated zone. In areas where precipitation infiltrates to the saturated zone (Fig. 1a), contaminants leached from buried waste can be transported to the zone of saturation. While material leached from upper soil horizons may accumulate in lower horizons during dry periods, this material may be remobilized by infiltration during recharge periods. Such an

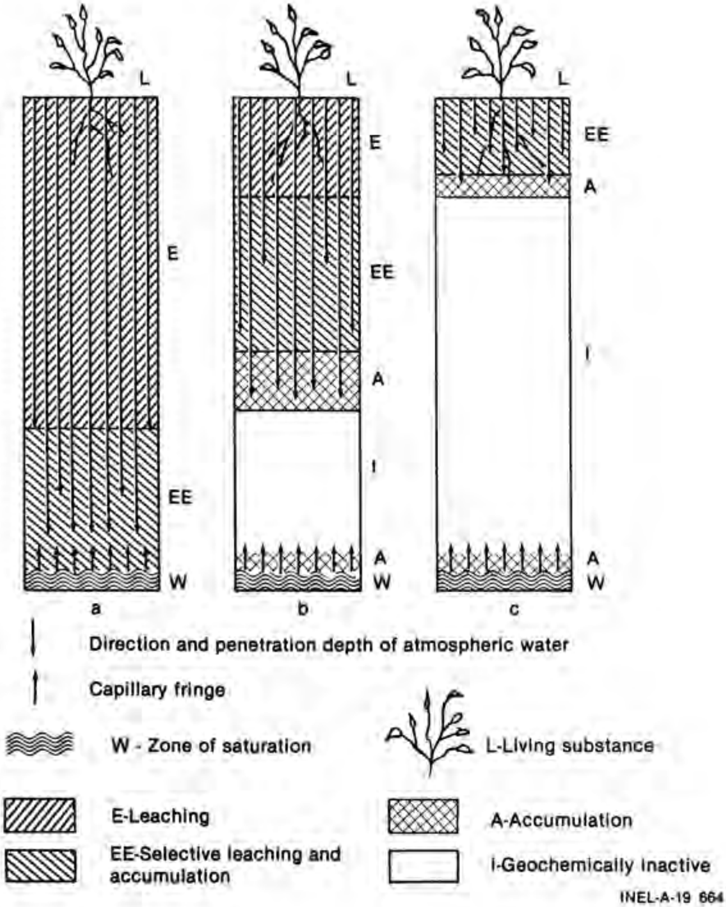

Fig. 1. Subsurface Geochemical Environments Associated with Three Typical Soil-water Regimes.

environment could exist in a humid climate where soil materials were permeable. The suitability of such a site, for burial activities above the water table, would depend on the attenuation capabilities of the unsaturated zone, the waste form to be disposed, and the site design features used to minimize contact of water with the waste.

In environments where infiltration does not reach the zone of saturation (Fig. 1b), such as areas where evapotranspiration plus runoff equal or exceed precipitation, solutes dissolved from upper soil horizons are deposited in a zone of accumulation. Material leached from the waste would be deposited in the zone of accumulation and would not reach the saturated zone. Between the zone of accumulation and the capillary fringe is a zone of low geochemical activity. The buffer zone boundary could be in this inactive zone if sufficient leaway is allowed for potential climatic changes or enhanced infiltration through the disposal trenches.

In very arid climates, little or no water is available for leaching, and a thick zone of low geochemical activity separates buried waste from an underlying saturated zone (Fig. 1c). This environment would present a minimal probability of release by ground-water pathways, and the lower buffer zone boundary could be placed at a moderate distance below the disposal horizon. The extent of the buffer zone for burial above the water table is depicted in Fig. 2a.

Burial below the water table must be carried out in a more restricted hydrogeologic environment than burial in the unsaturated zone. Where waste is placed in the saturated zone, material must be fine grained and of very low hydraulic conductivity to ensure that moisture fluxes are such that molecular diffusion is the primary mechanism for transport of radioactive contamination. The upper portion of the saturated zone, even in low-permeability materials, commonly exhibits higher permeabilities due to weathering and fractures.[5] The upper limit of the buffer zone should be below this zone of increased permeability (Fig. 2b) for burial in saturated materials.

2. <u>The site should allow waste to be buried either completely above or below the transition zone between the unsaturated and saturated zones.</u>

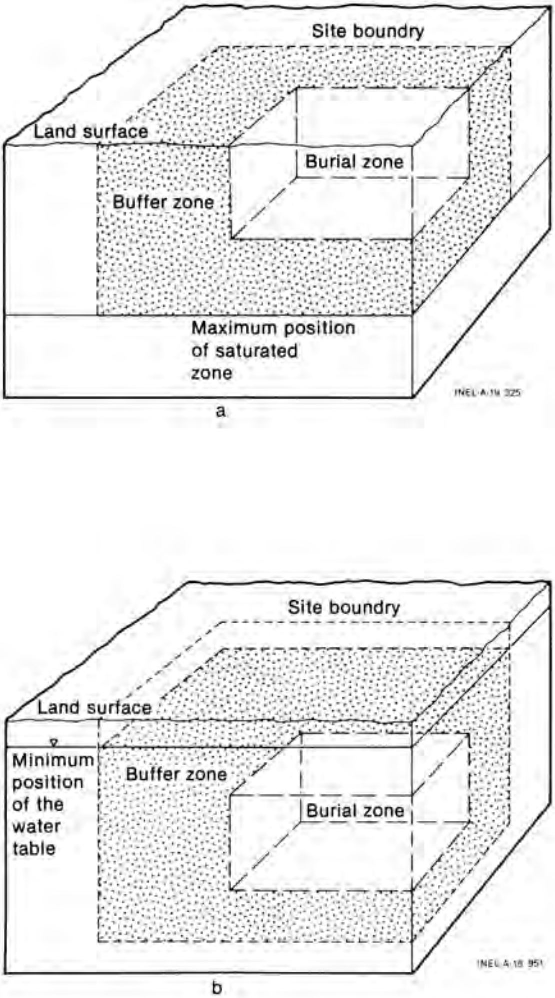

Fig. 2. Schematic Illustration of Waste Burial Above (a) and Below (b) the Unsaturated/Saturated Transition Zone.

The reliability of performance prediction may be significantly decreased by burial of waste in the transition zone and greater radionuclide release rates may result from the increased geochemical activity associated with this zone.[6] To determine compliance with this criterion, it is necessary to examine the water table elevation, the range of both seasonal and long-term water table fluctuations, height of the capillary fringe, thickness of excavatable material, and, if waste is buried below the transition zone, the hydraulic characteristics of earth materials in the saturated zone.

The transition from saturated to unsaturated moisture conditions does not occur abruptly but over a zonal interface defined by fluctuations of the water table and capillary fringe. The position of the transition zone changes with time in response to varying soil moisture, recharge, and saturated zone flow conditions. Because moisture contents may be very close to saturation just above the capillary fringe, a small amount of percolation can produce a large change in the position of the water table. It is thus necessary to monitor the location of the water table and capillary fringe for a period of time sufficient to identify seasonal maximum and minimum positions and predict long term fluctuations.

The height of capillary rise in an unsaturated soil is determined by moisture content and pore size of the soil or rock material. The capillary fringe and adjacent nearly saturated material will comprise a smaller segment of the moisture profile in coarse-grained material than in fine-grained material. In fine-grained material, pore spaces are small and easily bridged by water under surface tension. Large increases in height of the capillary fringe and water table may occur as a result of minimal percolation into fine-grain materials. This phenomenon also creates a situation in which lateral water movement in the capillary fringe becomes significant. Hydrologic models of lateral flow systems with shallow water tables demonstrate that a significant portion of the net flux occurs in the capillary fringe under some flow system configurations.[7]

3. <u>The site should be located where flooding will not jeopardize performance.</u>

Where burial occurs above the water table, flood waters can transport waste material and/or saturate the waste, increasing leachate formation and accelerating subsurface water flow. Flooding can also interfere with site operations irrespective of the zone of burial. Locating burial sites outside areas that require extensive engineered protection will ensure that no increase in the probability of flooding occurs during the performance period of the site because of failure of engineered barriers.

Site selection is the most effective way to minimize the possibility of flooding. Locating the site in a flood plain, regulatory floodway, topographic depression, coastal low-lying area, or within the influence of an existing or potential dam would enhance the possibility of flooding. The probability of recurrence of river and stream flooding and of extreme meteorological events, which might cause flooding of depressions or coastal low lands, can be determined and used as an indication of potential flooding in an area. The concern for flooding from dams has two aspects: the probability of dam failure with downstream flooding, and inundation or subsurface water-level rise upstream of future dams.

4. The site should be located where erosion will not jeopardize performance.

During the required performance period of the site, erosion by wind and water must not cause intrusion on the buffer zone and/or waste cover such that it (a) uncovers the waste, (b) increases surface radiation levels above regulatory limits, and/or (c) significantly shortens radionuclide release pathways. Waste that is uncovered is susceptible to transport from the site, but erosion does not have to uncover the waste to significantly shorten migration pathways. During closure, certain engineered structures, such as trench caps, will likely be emplaced to improve waste containment. Erosion of these emplaced structures could decrease the performance capabilities of the site. Allowances for predicted rates of erosion during the site performance period should be incorporated into site design, operating, and closure criteria.

Plant cover and moisture availability are the most important factors governing the rate of erosion by both wind and water. Where average annual precipitation is very low, natural vegetation may be sparse or absent, allowing high wind erosion rates and high water erosion rates whenever precipitation does occur. As the quantity of precipitation increases, plant cover becomes thicker, decreasing the amount of wind erosion and slowing the rate of erosion by water. Where plant cover is prevented from growing or has been temporarily removed, wind and water erosion rates are much higher than under natural conditions.

Processes responsible for erosion by water are: raindrop impact, sheet and rill erosion, gully erosion, and migration of streams or shorelines. Factors that govern erosion by these processes include: (a) character of geologic material, (b) topography, (c) land use, (d) volume of precipitation and runoff, and (e) intensity of wave action[8,9]. Raindrop impact and sheet and rill erosion result from the impact of raindrops on exposed soil surfaces, loosening soil particles that are subsequently transported by overland flow in thin sheets (sheet flow) or in small rills. Rates of erosion by gullies and migration of channels and shorelines are generally evaluated by reference to historical data.

Factors governing the erodability of a soil by wind are: (a) wind velocity, (b) soil moisture content, (c) presence of barriers (topographic or vegetative) to slow or divert wind, (d) the amount of vegetation cover, and (e) surface roughness.[10,11] Wind velocities on the order of 5 meters/sec are necessary to initiate soil movement.[10] At speeds above that, the quantity of soil transported increases with the cube of velocity. Wind transport generally does not occur until soil moisture levels have dropped to or below the wilting point of the vegetation present.[11] Vegetation decreases wind erosion by adding roughness, creating barriers, and holding soil together with roots. Evaluation of the interrelations among these factors is necessary to determine the susceptability of a site to wind erosion.

5. The site should be located in areas where hydrogeologic conditions allow reliable performance prediction.

Confident characterization of the hydrogeologic system in which a waste disposal site is located enables determination of potential migration pathways, estimation of radioactive contaminant movement rates in the subsurface environment, and design of a monitor network to collect data that can be used to confirm performance predictions of radionuclide transport. Major hydrologic characteristics of the site that must be examined include: subsurface geology, hydrologic budget, direction and magnitude of ground-water flow, permeability type, and diffusion and dispersion properties of the system.

The most critical determination that must be made to comply with this criterion is the characterization of the permeability control of the hydrogeologic system. Although there have been efforts to analyze fracture-flow systems, such problems as non-Darcian flow in fractures and variable hydraulic conductivity, which may be dependent upon expansion and contraction of fracture apertures, make analysis of fracture-flow systems extremely difficult.[12] Because of these problems and the fact that most analysis techniques are designed for intergranular permeable flow, prediction of fracture-flow systems cannot be achieved with a high level of confidence. Thus, hydrogeologic systems dominated by fractured, jointed, or cavernous flow should be excluded from shallow land burial site consideration. Within the context of an intergranular permeable hydrogeologic system, a thorough understanding of the three-dimensional geology will indicate the complexity of the hydrogeologic system and suggest the level of confidence with which predictions can be viewed.

It may be possible to show that the hydrogeologic system at a particular site is not capable of transporting significant quantities of radioactive contaminant; such a situation might exist at a site having an exceptionally thick unsaturated zone and little infiltration, or at a site with sufficiently low hydraulic conductivity so there is negligible fluid movement. In such situations, it will only be necessary to demonstrate that the ground-water movement at the site is so slow that contaminant transport is dominated by molecular diffusion.

6. The site should be located where geologic hazards will not jeopardize performance.

Significant land disturbances may destroy site integrity and increase the likelihood of radionuclides entering the biosphere. In addition, site hydrology may be altered to the extent that performance predictions are no longer applicable. Specific geologic events that must be considered include earth movement associated with seismic activity, mass movement, land subsidence, and volcanic activity.[13] The results of these events in the geologic past may so complicate the hydrogeologic system that predictions of site performance cannot be confidently obtained.

Vibration or displacement of the earth's surface during earthquakes could fracture burial trenches or their caps, effectively destroying site integrity and possibly releasing radionuclide contaminants to the general environment. In addition, such movement of the earth's surface might also trigger mass movement of surface material that could impact the disposal site regardless of the direct effect of an earthquake. Changes in the hydrologic properties of geologic material resulting from movement along faults may cause these fault zones to act as either conduits or dams, relative to the surrounding material, for flow of subsurface water.

Mass movement of earth materials in the form of land slides, slumping, and soil creep could adversely affect site performance. The impact of mass movement events is proportional to the velocity and magnitude of such events. A large slump or slide could completely destroy a site located at the head or foot of the material involved. Soil creep and small magnitude slumps or slides might not destroy the site but could have a detrimental impact on trench caps or the local hydrogeologic system, which could adversely affect the ability of the site to contain buried waste.

Effects of volcanic activity may take several forms. If an eruptive volcanic vent formed at the disposal site, radioactive waste material could be dispersed into the atmosphere. Lava flows accompanying volcanic activity could endanger site integrity by damming nearby streams, causing unanticipated flooding or by damaging trench caps, making the waste accessible to animals, plants, and water. Earthquake activity commonly associated with volcanic events could also modify the hydrogeologic system in which the site is situated or destroy engineered features of the site, compromising site integrity.

Land subsidence could affect trench cap integrity, causing caps to crack and open under extreme conditions. The eventual result would be to shorten pathways of contaminant movement to the biosphere. Removal of subsurface material (oil, gas, water, minerals) is a principal cause of subsidence. Additional causes of subsidence include hydrocompaction of surface material, compaction due to earth vibrations, and compaction of fine-grain material due to fluid withdrawal.

7. The site should be selected with consideration given to those characteristics of earth materials and water chemistry that favor increased residence times and/or attenuation of radionuclide concentrations within site boundaries.

Leachate migrating from buried wastes may carry radionuclides and other contaminants picked up from the waste. Slowing the movement of contaminants relative to the movement of water will provide more time for radioactive decay to decrease radionuclide concentrations. Properties of earth materials and water chemistry that favor the removal of radionuclides from solution by sorption or precipitation and that favor retention on or in solid phases, will retard the movement of radionuclides. Nuclide concentrations will decline more rapidly with distance from the waste if geochemical processes actively remove radionuclides from leachate than if only hydrodynamic dispersion is acting.

The decrease in concentrations of radionuclides in leachate migrating from a disposal facility can occur by hydrodynamic and geochemical mechanisms. Hydrodynamic dilution occurs through dispersive mixing caused by ground-water velocity heterogeneity. Geochemical processes depend on the subsurface Eh-pH environment, the leachate composition, the geochemical properties of individual radionuclides, and the characteristics of the geologic materials. Because of the variation in susceptability of radionuclides to geochemical controls and the possible variation in subsurface conditions relating to water chemistry, geochemical mechanisms may not provide quantitative, predictable, and reproducible removal of radionuclides from subsurface waters. Hydrologic predictions that included only advection, dispersion, and radioactive decay would tend to provide worst case estimates of possible contaminant migration. Hydrologic conditions should be used to provide a conservative estimate of expected site confinement capabilities; geochemical controls on migration would then provide a margin of safety. Evaluation of migration of nuclides at Hanford, Washington,[14] the Idaho National Engineering Laboratory,[15] and the Oklo natural reactor[16,17] show geochemical attenuation can be very effective in retarding the movement of certain radionuclides.

8. The site should be selected with consideration given to current and projected population distributions.

The minimum distance a site can be located from a population cluster must be determined by considering the size of the population and the effects of potential accidental and chronic radiation releases during operations. A site located close to population centers could interfere with their expansion, as well as increase the likelihood of human intrusion into the waste after institutional control has ended.

9. The site should be selected with consideration given to current and projected land use and resource development.

Site selection must represent a balanced choice in land use, in that siting represents a commitment in land use to future generations. Historical, current, and potential land uses at the site and the adjacent areas should be prime considerations in complying with this criterion. Land uses which represent a higher priority in comparison to low-level waste disposal should be evaluated.

The probability of future land uses on-site or in adjacent areas which could interfere with the site meeting performance onjectives is another consideration in complying with this criterion. The recovery of subsurface mineral or water resources could result in land subsidence, increased erosion, and/or significant changes in the hydrogeologic system of the site. In addition, locating a site in an area of high present or potential land value increases the likelihood of intruders accessing the site after institutional control has ended.

10. To the extent consistent with other criteria, the site should be selected with consideration given to location of waste generation, access to all-weather highway and rail routes, and access to utilities.

A certain risk exists from the transport of radioactive waste from points of generation to final disposal. This risk is a function of the waste form, nuclide content, vehicle safety, transportation systems, and distance traveled. By considering major points of waste generation and transportation routes in site selection, this risk can be reduced. Locating a site with regard to waste generators and transportation systems also minimizes the cost of land disposal. Additional economic factors that can be controlled through site selection include access to utilities, materials for site construction, operation and closure, and public services.

11. <u>The site should be selected consistent with federal laws and regulations.</u>

The site selection process should include an analysis on how readily the proposed site could comply with laws and regulations affecting site operations. These laws do not specifically exclude areas from development as shallow land burial sites but do impose constraints that sites must meet. Areas where compliance with these constraints could be difficult should be identified during the site selection process. Federal laws that a disposal site must comply with include but are not limited to: Clean Air Act (PL 95-95), Federal Water Pollution Control Act (PL 95-217), Safe Drinking Water Act (PL 93-523), National Environmental Policy Act (PL 91-190).

12. <u>The site should not be located within areas that are protected from such use by federal laws and regulations.</u>

Federal laws which preclude, by intent, the selection of low-level waste disposal sites within the boundaries of areas protected under them include but are not limited to: Wilderness Act of 1964 (PL 88-577), Wild and Scenic Rivers Act (PL 90-542), Endangered Species Act of 1973 (PL 93-205), National Wildlife Refuge Act of 1966 (PL 89-669), Laws establishing National Parks, Historic Properties-Preservation (PL 89-665), Archeological and Historical Preservation Act of 1974 (PL 93-291).

CONCLUSION

The twelve site selection criteria presented are intended to provide the frame work for the siting at shallow land burial facilities. They are based on the systems concepts of waste management which recognizes the use of performance objectives. The criteria are the tools for determining how well a proposed site will meet the performance objectives for land disposal of low-level radioactive waste.

Work supported by U.S. Department of Energy under contract No. DE-AC07-76ID01570 with EG&G Idaho, Inc.

REFERENCES

1. Papadopulos, S. S. and I. J. Winograd, Storage of Low-Level Radioactive Wastes in the Ground: Hydrogeologic and Hydrochemical Factors, U.S. Environmental Protection Agency, EPA-520/3-74-004, 1974.

2. Office of Nuclear Waste Isolation, NWTS Criteria for the Geologic Disposal of Nuclear Wastes: Site-Qualification Criteria, U.S. Department of Energy, Washington, DC, January 1980.

3. International Atomic Energy Agency, Underground Disposal of Radioactive Waste: A Guide to Shallow Ground Disposal, International Atomic Energy Agency, Vienna, Austria, 1979.

4. Cherry, J. A., R. W. Gillham, G. E. Grisak, and D. L. Lush, "A Concept for Long-Term Isolation of Solid Radioactive Waste in Fine-Grained Deposits," in Management of Low-Level Radioactive Waste, Vol. 2, M. W. Carter, A. A. Moghissi, and B. Kahn, eds., Pergamon Press, Elmsford, New York, 1979.

5. Desaulniers, D. E., J. A. Cherry, P. Fritz, "Origin, Age, and Movement of Pore Water in Argillaceous Quaternary Deposits at Four Sites in Sothwestern Ontario," Journal of Hydrology, 50, pp. 231-257, 1981.

6. Apgar, M. A. and D. Langmuir, "Groundwater Pollution Potential of a Landfill Above the Water Table," Groundwater, Vol. 9, No. 6, 1971.

7. Tamura, T., L. D. Eyman, A. M. Eyman, A. M. Stueber, and D. S. Ward , Progress Report of Disposal Area Studies at Oak Ridge National Laboratory, ORNL-5514, 1980.

8. Wischmeier, W. H. and D. D. Smith, Predicting Rainfall Erosion Losses--A Guide To Conservation Planning, U.S. Department of Agriculture, Agricultural Handbook No. 537, 58 pp., 1978.

9. Curtis, N. M., Jr., A. G. Darrach, and W. J. Sauerwein, "Estimating Sheet-Rill Erosion and Sediment Yield on

Disturbed Western Forest and Woodlands," U.S. Soil Conservation Service Technical Notes, West Technical Service Center, Portland, 33 pp., 1977.

10. Brady, N. C., The Nature and Properties of Soils, MacMillan Publishing Co., Inc., New York, 639 pp., 1974.

11. Bailey, F. G., "Estimating Soil Loss From Wind Erosion and Designing Wind Erosion Control Systems in Idaho," U.S. Soil Conservation Service Technical Notes, 14 pp., 1980.

12. Freeze, R. A., and J. A. Cherry, Groundwater, Prentice-Hall, Inc., Englewood Cliffs New Jersey, 604 pp., 1979.

13. Bolt, B. A., W. L. Horn, G. A. MacDonald, and R. F. Scott, Geological Hazards, Springer-Verlag, New York, 328 pp., 1975.

14. Brown, D. J., "Migration Characteristics of Radionuclides Through Sediments Underlying the Hanford Reservation," in Disposal of Radioactive Wastes into the Ground, IAEA, Vienna, pp. 215-225, 1967.

15. Robertson, J. B., Digital Modeling of Radioactive and Chemical Waste Transport in the Snake River Plain aquifer at the National Reactor Testing Site, Idaho, U.S. Geological Survey Open-File Report IDO-22054, 41 pp., 1974.

16. Brookins, D. G., "Retention of Transuranic, Other Actinide Elements, and Bismuth at the Oklo Natural Reactor, Gabon," Chemical Geology, Vol. 23, pp. 307-323, 1978.

17. Brookins, D. G., "Thermodynamic Considerations Underlying the Migration of Radionuclides in Geomedia: Oklo and Other Examples," in Scientific Basis for Nuclear Waste Management, G. J. McCarthy, ed., Plenum Press, New York, pp. 355-366, 1978.