**Characterization of the Hanford 300 Area
Burial Grounds**

**Final Report
Decontamination and
Decommissioning**

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INTRODUCTION

The Hanford Site was established in December 1942 after successful demonstration of a sustained nuclear reaction in Chicago, Illinois. Subsequently, the Manhattan District of the U.S. Army Corps of Engineers at Hanford, Washington, was charged with production of defense materials, primarily plutonium. By 1945, a nuclear fuels fabrication plant, reactors, chemical processing and separations plants, laboratories, and waste storage facilities were completed, and weapons material produced. The 300 Area of the Hanford Site was designated as the laboratory section of the project. Nuclear reactor design, testing, and demonstration; chemical separations, reprocessing, and design; and experimentation were conducted at the 300 Area laboratories until 1947 when the Atomic Energy Commission (AEC) was established. Since that time the 300 Area has served as a general research and development facility. The U.S. Department of Energy (DOE), the successor to the AEC, has assumed responsibility for nuclear waste management on the Hanford Site.

The 300 Area Burial Grounds were established in 1943 for the purpose of nonretrievable disposal of radioactive waste. Radioactive waste materials from numerous laboratory-scale chemical separations processes and related activities were collected and buried at 10 sites in and adjacent to the 300 Area. The burial sites were in active service during different periods of time until they were retired (by 1973). Due to the nature of the Manhattan Project and its relation to national security, little information on burial locations, radionuclide inventory and waste form was kept. In addition, development of technological expertise related to radioactive waste management was initially of low priority.

Decontamination and decommissioning methods are now being considered by DOE for the ultimate disposition of retired nuclear facilities. The objective of decontamination and decommissioning is to provide protection to the public and the environment from radioactive and other hazardous materials potentially originating from such sources. For retired burial grounds, the alternatives selected must take into account certain characteristics, such as: location

and inventory of the burial sites, as well as the types of structures used; physical attributes of the area; environmental factors and potential pathways; and mechanisms of radionuclide transport.

The original objective of the "Characterization of the Hanford 300 Area Burial Grounds" project was to develop the technology and methods for deriving the necessary information. During the course of the study, the scope was broadened to include description of specific alternatives. The results of this project provide information that can be used in determining appropriate disposition of burial grounds. The project was sponsored by the DOE Division of Environmental Control Technology and conducted by the Pacific Northwest Laboratory (PNL) from 1975 through 1978.

To meet the objectives, the work involved the following steps (Figure 1):

1. review of previous related investigations
2. identification of suitable disposition alternatives for nuclear waste burial grounds
3. review of regulatory issues
4. survey of the general area, burial sites, and operations
5. analysis of the geohydrologic system, potential transport pathways, and monitoring procedures
6. technology development and characterization.

For the technology development and characterization of individual aspects of the 300 Area Burial Grounds and surrounding environment, the work was divided among four tasks:

Task I - Geophysical Evaluation

Task II - Geochemical Analysis

Task III - Fluid Transport Characterization and Modeling

Task IV - Biological Transport

This report provides a compilation of all facets of the project. Topical reports have been written covering each of the four tasks. A detailed discussion of pertinent regulations has also been issued under separate cover.

FIGURE 1. Project Sequence

CONCLUSIONS

The "Characterization of the Hanford 300 Area Burial Grounds" project consisted of a review of decontamination and decommissioning alternatives; an overview of the burial sites and operations; a description of the surrounding environment; and an assessment of radionuclide migration. Methodologies for characterizing nuclear waste burial grounds were developed and/or applied to the 300 Area. The results of this project are summarized in the following conclusions.

LITERATURE SURVEY

Several related reports were reviewed. However, the information from these publications did not provide a definitive baseline for identifying appropriate disposition alternatives for the 300 Area Burial Grounds. Instead, alternatives were identified by assessing available information and the results of this project. Some of the documents reviewed are discussed in this report.

ALTERNATIVES

- Alternatives identified for the nuclear waste management of retired Hanford 300 Area Burial Grounds are: 1) exhumation and translocation, 2) entombment, 3) perpetual care, and 4) abandonment.
- The nuclear waste management activities required by selection of any of the four alternatives are: 1) safety assessment, 2) site assessment, 3) research and development, 4) site stabilization, 5) radiological monitoring, and 6) reporting.
- Burial site use categories identified for each nuclear waste management alternative are: 1) exhumation and translocation - unrestricted use (release of the site to the public), 2) entombment - conditional use (permits nuclear and/or nonnuclear use of the site), 3) perpetual care - restricted use (permits only nuclear activities at the site), and 4) abandonment - unrestricted use.

- The perpetual care alternative, under which the Hanford 300 Area Burial Grounds are currently being operated, was suggested as the most plausible alternative.
- Exhumation and translocation and entombment were suggested as having less viability for waste management as compared to perpetual care because significant additional hazard above that currently existing may result if these alternatives were selected.
- Selection of the abandonment alternative was evaluated as inappropriate unless the radiocontaminants within burial sites were found to occur at innocuous activity levels.
- Selection of combinations of nuclear waste management alternatives for the Hanford 300 Area Burial Grounds may prove beneficial for continuous site safety.

REGULATORY ISSUES

- Regulatory issues pertaining to decontamination and decommissioning of Hanford 300 Area Burial Grounds include: 1) the Atomic Energy Act, 2) the Energy Reorganization Act, 3) the National Environmental Policy Act, 4) the Clean Air Act, 5) the Federal Water Pollution Control Act, 6) the Toxic Substances Control Act, 7) the Resource Conservation and Recovery Act, and 8) the Safe Drinking Water Act.
- DOE's nuclear waste management activities and selection of alternatives for the Hanford 300 Area Burial Grounds may, however, be impacted by the following: 1) DOE may be subject to NRC review if proposed legislation is passed; 2) recently published EPA draft criteria may limit the selection of alternatives; and 3) any deviation from current nuclear waste management practices currently in effect relative to the 300 Area Burial Grounds may require a statement of environmental impact.
- DOE will be required to comply with recently initiated legislation through the Toxic Substances Control Act, the Resource Conservation and Recovery Act, etc., which may limit the selection of nuclear waste management alternatives available.

WASTE INVENTORY

- A paucity of information exists relative to: 1) the exact location of Hanford 300 Area Burial Grounds waste burial structures, 2) operations and post-operational practices utilized for waste burial, 3) environmental monitoring of specific waste burial sites, 4) and evaluation of pathways of radionuclide migration.
- The inventory of contaminants existing within the 300 Area Burial Grounds has not been sufficiently recorded, so assessment of sites may be inaccurate. In addition, the selection of decontamination and decommissioning alternatives based on inventory rationale would be inappropriate.
- Very little information exists relative to the waste form within which radionuclides were disposed. Thus, assessment of the potential migration of radionuclides or general site assessment may be inaccurate.

GEOHYDROLOGIC SYSTEM

- The geohydrologic system of 300 Area Burial Grounds is complex. Sufficient data and computational techniques exist to simulate the migration of ground water in the saturated zone below these burial grounds. However, only generalized data and initial computational requirements are available to simulate groundwater waste migration within the unsaturated hydrologic system. Assessment of the transport of radionuclides preferentially sorbed within the sediments cannot presently be accurately simulated. The migration of radionuclides of greatest transport potential equaling or closely approximating that of water can be simulated to a limited accuracy.
- No evidence was found of transport of specific radionuclides, including tritium, ruthenium, and uranium, attributable to leaching from waste burial structures into the underlying groundwater system.

- A rise in the elevation of the surrounding groundwater zone was evaluated relative to the potential for inundation of the burial trenches and similar disposal structures, which could result in radionuclide transport. Inundation was suggested to possibly occur by the following factors: 1) an increase in river stage may result in a rise in the groundwater table below the burial grounds; 2) injection of process water into the geohydrologic system in near proximity to the burial grounds, which could result in a localized rise in the groundwater table elevation; 3) irrigation in near proximity or upgradient from the burial grounds, which could result in localized or regional increased elevation of the groundwater table; and 4) construction of a water impoundment structure, i.e., a hydroelectric dam, which could severely change the elevation of the regional groundwater table.
- Riverbank storage phenomena do not appear to result in inundation of 300 Area waste burial structures.
- Injection of process water into trenches as is currently practiced was not found to adversely affect the integrity of waste containment.
- Limited irrigation practices as evaluated by groundwater simulation models do not appear to cause a rise in the groundwater table.
- Construction of the proposed Ben Franklin Dam and the resultant changes in groundwater table elevation will probably result in negligible impact to the burial grounds. However, in some instances the flow paths or water potentially transporting radionuclides from burial sites to the Columbia River would be shorter and the travel time subsequently decreased.

PATHWAYS AND MONITORING

- A brief assessment of potential releases of radionuclides from the Hanford 300 Area Burial Grounds was conducted relative to the air, direct and water pathways.

- The highest potential for adverse impacts was suggested as resulting from the air pathway. The mechanism identified potentially causing exposure was wind erosion of backfill material covering existing buried waste.
- Radiation monitoring results relative to this study for onsite and off-site sampling stations have shown no contribution of radiological exposure to the public from waste management activities.
- The maximum direct exposure from within the 300 Area Burial Grounds during the latest survey was computed at $0.0854 \text{ rem year}^{-1}$ which closely approximates background radiation levels.
- No evidence of airborne dispersion of radionuclides potentially derived from the burial grounds could be found by examination of monitoring records.
- No evidence of uptake by plants occurring outside the perimeters of the 300 Area Burial Grounds could be found by examination of monitoring records.
- No evidence of animal dispersal or uptake by animals inhabiting areas peripheral to the burial grounds could be found by examination of monitoring records.
- There have been no recorded significant radiological health effects sustained by the public from retired Hanford 300 Area Burial Grounds.

TECHNOLOGY DEVELOPMENT

Technologies have been developed under this project which permit:

1) geophysical buried waste location and mapping, 2) geochemical evaluation of uranium/sediment interactions in buried waste, 3) modeling and soil physics evaluation of water migration through waste burial sites, and 4) biological assessment of radionuclide transport vectors.

LITERATURE SURVEY

The purpose of the literature survey was to determine if past investigations could be used to develop recommendations and rationale for evaluating decontamination and decommissioning alternatives. The results were contradictory, however, and could not provide a definite consensus. The following text summarizes the literature reviewed.

U.S. GEOLOGICAL SURVEY (LaSala and Doty, 1976)

LaSala and Doty (1976) surveyed geohydrological disposal of radioactive waste materials in burial grounds at the Hanford Site. This survey was basically an assessment of the suitability of existing burial sites for long-term confinement of radiocontaminants. The assessment criteria were developed principally from a geohydrologic and geomorphological treatment. In their study, Burial Ground 5 and the 300 North and Wye Burial Grounds were found unsuitable for long-term waste containment because they had been reported to contain plutonium in significant quantities. Furthermore, Burial Grounds 9 and 5 were found unsuitable for waste containment because of internal drainage where meteoric precipitation may collect and inundate the buried waste materials. Consequently, radionuclides could be transported to the nearby Columbia River.

All of the 300 Area Burial Grounds, except 300 North and Wye, were also found to be inappropriate for radioactive waste burial. These sites are located on large terrace landforms near the 300 Area and as such may be subject to flooding. Flood waters could effectively transport radionuclides into the aquatic biosphere in a relatively short time. The inventory of radionuclides in these burial sites was also found to be inaccurate; therefore, the potential environmental safety of these sites was questioned.

The waste management waste burial alternative suggested by LaSala and Doty (1976) for Burial Grounds 5, 300 North, and 300 Wye was exhumation and translocation of the waste to a more environmentally acceptable site. They

also suggested monitoring radiocontaminants in the unsaturated groundwater system of waste burial sites, and continued research on radionuclide transport in unsaturated soil systems.

NATIONAL ACADEMY OF SCIENCES, 1978

The National Research Council, National Academy of Sciences conducted a review of radioactive waste management on the Hanford Site (NAS, 1978). This review assessed technical and scientific information relative to all Hanford radioactive waste materials. However, significant emphasis was given to radioactive waste burial. The report concluded that current waste management policies have not resulted in adverse environmental effects; i.e., buried materials currently do not pose an appreciable radiation hazard to occupational workers or the surrounding offsite population. For low-level waste, NAS suggested that waste disposal areas with deep water tables are preferable to those with shallow water tables. (Note that the approximate mean water table elevation below the 300 Area Burial Grounds is on the order of 6 m.) Of the waste management alternatives for low-level waste materials, the report suggested that exhumation of waste should be conducted only in such instances where exhumation would be manifestly safer than having the waste in place. Other alternatives were not adequately discussed.

This survey report also suggested that waste management of high-level and transuranic waste (which are also contained within the 300 Area burial sites) has been adequate in that there have been minimal adverse environmental effects to occupational workers and to the public. The probability of a credible accidental discharge of high-level waste affecting the population from normal waste management operations in the foreseeable future was also thought to be negligible. Specific treatment of high-level waste relative to 300 Area Burial Grounds was not given; however, the conclusions derived are applicable to high-level and transuranic waste categories that exist in the 300 Area Burial Grounds. Other factors evaluated were monitoring, environmental effects, and site treatments.

Monitoring

The panel of the National Academy of Sciences concluded that monitoring and environmental surveillance currently practiced on the Hanford Site are adequate to ensure detection of any abnormal release of radioactivity. The panel reviewed the potential for catastrophic environmental factors, i.e., flooding, which would affect the containment of radionuclides disposed within the Hanford Site. The factor of highest probability was flooding of the Columbia River and subsequent inundation of areas containing radiocontaminants. A flood of sufficient magnitude was hypothesized to occur within a period of several thousand years. This flood would possibly transport all contaminants from the 300 Area Burial Grounds into the aquatic environment; however, due to dilution, the radiation dose, calculated on a conservative basis, would be within prescribed limits.

Changes in climatic regime at the Hanford Site were also considered. The probability of climatic change that would adversely affect the waste containment was concluded to be minimal.

Environmental Effects

The report discussed environmental effects which could occur through agrarian processes, wind erosion, and exhumation of radiocontaminants by biological organisms. It was concluded that agrarian processes and other mechanisms of radionuclide release are of nominal consequence. Agrarian practices were not considered significant because farming is not conducted at controlled burial grounds on the Hanford Site. Wind erosion, i.e., deflation and scouring of surficial materials, was not considered to be viable mechanism for exhumation of buried radionuclides because the ground surface above burial sites is made up of nonerodible residual sedimentary particles.

The report also suggested burrowing animals and deep-rooted plants have only a nominal impact in exhuming radiocontaminated waste. This conclusion was based on available environmental monitoring information.

Site Treatments

Several waste site treatments were identified by NAS which were thought to partially prevent radionuclides from entering the biosphere from the waste containment structures. These alternatives include paving waste disposal structures with impermeable material and mounding with gravel to prevent wind erosion and to intercept rainfall. Also proposed was chemical treatment of surficial soils and gravel mounding which would inhibit establishment of deep-rooted plants. This activity was suggested for ditches and surface ponds. Another suggested operational practice was to excavate radionuclide-bearing material, package it, place it in interim storage and ultimately dispose of it in a permanent disposal repository. This alternative, however, was treated as untenable because of increased health hazards and monetary problems. The report summarized waste management alternatives by suggesting that disturbance of contaminated sediments be considered only when a clear and probable danger to the population is demonstrated. Finally, the report recommended increased research regarding development of radionuclide transport barriers, barriers to intrusion by biota, and soil-physics/soil-chemistry of radionuclide transport in earth materials subject to various conditions.

NATIONAL ACADEMY OF SCIENCES, 1976

This Committee report concerning radioactive waste management of low-level shallow land burial of waste materials (NAS, 1976) evaluated waste management activities relative to high-level, transuranic, and other waste disposal at Energy Research and Development Agency^(a) (ERDA) controlled sites. A specific treatment of waste burial at the Hanford Site was included, which required the development of rationale for permanent disposal of waste containment until such time as radionuclides reach an innocuous level of activity. The objective, as discussed, should also result in a guarantee that transport of contaminants be adequately monitored so that corrective actions may be undertaken if loss of containment occurs. The report also suggested that waste

(a) Predecessor to the Department of Energy

containment may be assured through the use of drain fields to prevent water from entering the waste materials. Records management of monitoring, cost-benefit analyses and safety assessments were suggested as requirements for site management.

The NAS Committee indicated that exhumation of waste materials not intended for retrieval was not viable unless the radiation hazard from the buried waste was greater than the hazards resulting from exhumation. An example cited was an exhumation test that was conducted at the Idaho National Engineering Laboratory. This test determined that waste containment within burial cartons, drums, and boxes was not accomplished because of degradation by corrosion and decomposition. Plutonium had migrated from these primary containment vessels into the sedimentary matrix within burial trenches. The Committee report also recommended against the exhumation waste management alternative for high-level and transuranic waste if the ultimate fate of the exhumed material is unknown, e.g., disposal at a permanent waste repository. Thus, the benefits of exhumation and interim storage are questionable, especially if a permanent storage technique is not specified. Consequently, the development of a permanent waste repository for high-level and transuranic waste in the near future was proposed.

Another conclusion was that insufficient data exist to enable the prediction of the effects of current and future burial at specific sites. Thus, monitoring of sites relative to radionuclide transport and parameters controlling transport was considered in that new technology as suggested by the report will manifestly increase the safety of land burial. Research in the area of radionuclide transport and monitoring was strongly recommended by the Committee.

BATTELLE-COLUMBUS LABORATORIES (Duguid, 1977)

A survey of short-term improvements on the land burial of low-level radioactive waste was conducted to assess and document waste management activities and recommendations (Duguid, 1977). This survey was suggested by ERDA site operators. This report suggested that all buried low-level waste is susceptible to erosion and radionuclide transport through mechanisms of leaching

and capillary conductivity. All ERDA contractors were reported to have continuing programs of surface maintenance to minimize erosion and drainage problems. However, transport by groundwater movement is also an important factor. Radionuclide movement in all burial sites was expected; however, the rate and magnitude of movement was reported to be dependent upon environmental factors, e.g., temperature, precipitation. The report recommended continued ground surface treatment to prevent rainfall infiltration in areas where consolidation of wastes has caused closed depressions within burial sites. The report concluded that past and present disposal activities may be inadequate, and that improvements in technology relative to waste management of low-level waste will provide an adequate waste management program. Development of low-level waste disposal criteria and standards was also suggested. The report additionally discussed an ERDA shallow land burial technology program that had been initiated to develop necessary technology to ensure adequate containment of buried low-level radioactive waste.

CONGRESSIONAL REPORTS, 1976

Congressional hearings and reports pertaining to the disposal of low-level radioactive waste (Congressional Report, 1976a,b) established the need to provide safe, effective storage for radiocontaminants until they no longer pose adverse health effects. This time may, in some instances, exceed 2.5×10^5 years. These hearings and reports also supported the need for improved monitoring technology since burial sites cannot be assured to totally contain all radiocontaminants. Present monitoring technology was assessed as primitive. The performance of waste burial sites relative to waste containment has not been uniformly good; therefore, a significant potential for future health hazards exists. These reports also exemplified the need to define steps to be taken at such time as a site is decommissioned. The prediction of the transport of radionuclides from waste burial sites cannot be made because of the lack of data concerning erosional and geohydrologic phenomena at burial sites.

Particularly, the perpetual care waste management alternative for low-level waste burial sites was not recommended because governmental or other institutional care must be continued for more than a few hundred years.

COMPTROLLER, 1976

The U.S. Comptroller's Office of the General Accounting Office issued a report intended as an assessment of land disposal of radioactive waste (Comptroller, 1976). The report provided a review of radioactive waste burial site selection. According to this report, based on geohydrologic information, many sites may not be effective as waste containment structures. The report related the conclusion of U.S. Geological Survey and Environmental Protection Agency officials that reasonable demonstration of toxic and long-lived radionuclide isolation has not been accomplished. Specifically at the Hanford Site, the rate of infiltration and the direction and flux of ground water are insufficiently known. This review report also identified a need to improve monitoring activities. In order to develop radioactive waste management controls, the report recommended that standards for determining unacceptable levels of radioactive migration from a site be established.

NUS CORPORATION (Mullarkey et al., 1976)

Nuclear fuel cycle radioactive waste disposal was evaluated and reported by the NUS Corporation (Mullarkey et al., 1976) in a study supported by the Atomic Industrial Forum, Inc. Site waste management activities were addressed regarding radionuclide transport. Western arid radioactive shallow land disposal sites were concluded to have no problems of rainwater-induced radionuclide migration. Alternatives to land burial were also considered in this report, including sea disposal. Sea disposal was regarded to be prohibitive unless no other alternative offering less harm to the environment could be identified.

FORD, BACON, AND DAVIS UTAH, 1977

Analysis of a shallow land burial reference facility was completed to augment development of a radioactive waste disposal classification system

(Ford, Bacon, and Davis Utah, 1977a,b). These studies were conducted for the Nuclear Regulatory Commission to support the evaluation of radionuclide transport from shallow land radioactive burial sites. These reports dealt with the transport of radioisotopes in the groundwater system from a generic site. The airborne pathway was found to be the most critical relative to population dose. This pathway was considered important if inadvertent intrusion to a retired site occurred. Intrusion was reported to affect suspension and resuspension of contaminated particulate matter which could result in inhalation by individuals.

In the case of intrusion, effects of parent radionuclides and daughter radionuclide decay chains for the inventory of high-level transuranic and other wastes were found to be negligible with the following exceptions: cesium-135, curium-244, thorium-232, uranium-235, curium-242, uranium-238, plutonium-241, and neptunium-237. Intrusion was thought to be inconsequential if the overburden depth between the ground surface and the buried waste was on the order of 1 m. The results also indicated that for a specific inventory of high-level transuranic and other waste the ground water was of secondary importance as a pathway whereby radionuclides would reach the biosphere. A sensitivity analysis of parameters controlling transport of radionuclides in the geohydrologic system, however, demonstrated the importance of leach rate, equilibrium sorption coefficient, groundwater velocity, and path length as the main controlling variables. From the inventory used in these reports, the radionuclides affecting population dose were technetium-99 and iodine-129. Other environmentally significant radioisotopes were identified, including: tritium, cesium-135, neptunium-237, and plutonium-239. Important decay chain daughters from the inventory were radium-228 and radon-222; however, the environmental effects of these radionuclides were suggested as negligible.

LAW ENGINEERING TESTING CO. (Grant and Corn, 1976)

An investigation concerning radionuclide transport in groundwater systems was conducted by Law Engineering Testing Co. to identify criteria for shallow land disposal (Grant and Corn, 1976). The report issued as a result of this

investigation suggested that minimizing contact between ground water and radio-contaminated waste was of primary importance. Hydrologic isolation by onsite impoundment of ground water that has contacted contaminated waste was suggested as a viable waste management activity.

Groundwater intrusion whereby the saturated groundwater zone may contact the waste from below was also discussed. The separation distance of waste burial structures, e.g., trenches, was suggested to be such that trenches should be elevated above the piezometric groundwater surface sufficiently to reflect the uncertainties in fluctuation of the piezometric surface. Climatic conditions were reported to disturb trench cap material; thus, the thickness of the cap material should be sufficient to negate potential problems, or additional barriers should be used to protect the burial trench cover material. Vegetation was suggested for use over burial trenches for erosion control and enhancement of evapotranspiration. Evaporation enhancement by utilizing cap materials of high moisture retention capacity was also suggested.

Exposure of contaminants reaching the aquatic environment was reported as significant if radionuclides are discharged to the shoreline of a nearby surface water body. Exposure of surficially deposited radionuclides can be critical in this instance because a buildup of radionuclides can occur and direct water body exposure may result.

DAMES AND MOORE (Aiken et al., 1977)

Radionuclide migration from shallow land burial sites was evaluated, and a methodology was developed to enable the assessment of radionuclide migration and resulting radiocontaminant doses in a study conducted by Dames and Moore, Inc. (Aiken et al., 1977) for the Atomic Industrial Forum, Inc. A parametric evaluation of factors affecting radiation dose from buried radiocontaminated waste concluded that no single parameter primarily influences radiation dose. Parameters with a wide range of variability: volumetric trench water, unsaturated zone hydraulic conductivity, unsaturated zone retardation coefficients, dilution, path length, saturated zone hydraulic conductivity, and water/radionuclide contact time were sensitive to dose calculations. Those parameters

with low variability, e.g., porosity, were relatively insensitive. The contact time between water and waste was found to be proportional to the extent of migration; i.e., maximum water/radionuclide contact time resulted in maximum migration. Further research in the areas of leach testing, unsaturated zone contaminant transport, water balance, and gas flux was recommended.

DAMES AND MOORE, 1978

Radionuclide migration monitoring at the Oak Ridge National Laboratory and the Idaho National Engineering Laboratory was also evaluated by Dames and Moore (1978). This report suggested development of a monitoring criteria for groundwater sampling. The sampling frequency and distance between sampling points was suggested to be such that at least 10% of any radiocontaminated concentration be detectable as it passes a point peripheral to a waste burial site.

LOS ALAMOS SCIENTIFIC LABORATORY (Smith et al., 1976)

Waste management alternatives and site assessment related to shallow land burial of radioactive waste were developed for ERDA in a document prepared by investigators at Los Alamos Scientific Laboratory (Smith et al., 1976). The single most important factor affecting radionuclide waste containment, as identified by the report, is the degree to which ground water can contact the waste, thus causing subsequent waste migration. According to this environmental monitoring report, results have identified only nominal adverse environmental effects at Hanford. Smith also reported that Hanford has negligible environmental surveillance of burial grounds that can identify major radionuclide pathways.

The extent of tritium migration at the Hanford Site was qualitatively indicated in the report as "possible vapor diffusion in soil." The extent of radionuclide migration and the presence of radionuclide transport media were expressed as "none observed" and "none indicated," respectively. The report

also suggested that natural conditions are sufficient to prevent adverse environmental effects, and the only identifiable potential problem was a dramatic climatic change. Possible radionuclide migration caused by deep-rooted plants and their subsequent wind dispersal was identified, and future problems of uncontrolled plant growth were summarized. Erosional problems at DOE sites were reported as minimal where burial grounds are located on upland areas. Erosion control as reported is employed at all DOE sites for stabilization control.

Smith also discussed the lack of a national policy regarding decommissioning of radioactive waste burial sites and a need for national direction pursuant to decommissioning operations. Decommissioning of burial grounds was defined as those activities taken onsite to provide site suitability for restricted public use after completion of burial operations. Experience in decontamination of burial sites was found to be negligible, and identification of and planning for decommissioning was also reported as receiving only minimal assessment.

Alternatives to decommissioning were discussed, including perpetual care, i.e., those activities currently being undertaken by DOE contractors at waste disposal sites, and waste relocation. The perpetual care alternative pertains to surveillance and maintenance of retired burial site surfaces. Current practices of perpetual care were found to be inadequate to guarantee that radiocontaminants will not migrate from waste trench sites. Burial site engineering was suggested to provide modification of the physical aspects of waste containment in waste burial grounds. Engineering activities were, however, suggested as only providing short-term control. Engineering practices which attempt to seal trench bottoms and sites were discussed as detrimental practices. The most attractive decommissioning alternative was identified as waste removal, i.e., exhumation and disposal at another site. However, this alternative was thought to be counterproductive based on safety and monitoring criteria. Therefore, exhumation was evaluated as a viable alternative in only those instances when radiocontamination from a site poses present or future hazard to surrounding populations or when long-term care and maintenance costs approximate costs for exhumation.

DEPARTMENT OF ENERGY, 1978

Programs were developed for initiating decontamination and decommissioning activities at DOE sites (DOE, 1978). The report identified planning activities, ongoing and proposed decontamination and decommissioning activities, research and development activities, standards and criteria development, remedial activities and surveys to be conducted by various DOE divisions. Relative to the Hanford Sites, the report identified progress plan development for Hanford retired facilities. It generally discussed retired radiocontaminated facilities and lands, and suggested that after decontamination and decommissioning of a specific facility or site the intrinsic value of the facility/site can be preserved and that the land can be put to other use.

Unrestricted public use of a site was inferred as a basic requirement of decontamination and decommissioning where residual contamination levels at a site are environmentally acceptable. Potential hazards were reported as controllable where sites are located on DOE-controlled reservations. The majority of these sites whereby control can be maintained were reported within the boundaries of the Hanford Site. An important criteria was that risk to terrestrial and aquatic ecosystems should be maintained at negligible levels during decontamination and decommissioning activities.

DECONTAMINATION AND DECOMMISSIONING ALTERNATIVES

Several alternatives can be considered for the disposition of waste burial facilities. However, these alternatives must be evaluated for specific sites so that waste management operators can implement the most reasonable and effective mode of treatment to assure safety. The selection of alternatives is a function of the site, inventory, present operational mode, the radionuclide transport pathways, and research conducted to investigate or characterize the site.

Decontamination and decommissioning alternatives for nuclear reactors and nuclear fuel reprocessing plants have been previously developed (Smith et al., 1976; Schneider and Jenkins, 1977). The alternatives identified in these reports were specific to buildings and associated engineered structures, e.g., reactor cores, chemical processing buildings. These alternatives include: 1) dismantlement, 2) entombment, 3) protective storage, and 4) layaway. The alternatives cover a spectrum of activities from complete removal of the facility to leaving the facility as it exists with minimal decontamination and security activities.

In this project, a different set of alternatives was developed in order to provide an adequate spectrum of decontamination and decommissioning alternatives for burial sites, specifically the Hanford 300 Area Burial Grounds. These alternatives cover the range of plausible activities from removal and relocation of radiocontaminated material to leaving the site as it exists.

A general discussion of the requirements of each alternative is provided below. The requirements were, for the most part, developed from past experience of burial ground operators (Wheeler and Smith, 1979; Horton, 1979; Holcomb, 1979; Kendall et al., 1979; Harnes and McKinney, 1977). This discussion is meant to provide only a generic outline of possible approaches to decontamination and decommissioning.

ALTERNATIVES IDENTIFIED FOR THE 300 AREA BURIAL GROUNDS

The alternatives identified for decontamination and decommissioning of the 300 Area waste burial sites are: 1) exhumation and translocation, 2) entombment, 3) perpetual care, and 4) abandonment. These alternatives are described in their order of decreasing probable site safety and decreasing probable cost in decontamination and decommissioning. The first three alternatives may entail engineering activities which will prevent future exposure to occupational workers and to the public. The last alternative entails no activities other than those involved before and during termination of operations or care of burial grounds. The current alternative for the Hanford 300 Area Burial Grounds is perpetual care.

Each alternative requires some environmental assessment before it is implemented. The abandonment alternative requires this assessment and assumes acceptable occupational and public safety. The remaining alternatives require post-operational modification of the facility so as to achieve occupational and public safety within regulatory limits. For each alternative, site monitoring, records keeping, and periodic reevaluation of safety and procedures are essential. If, at any time through the duration of activities, monitoring and safety criteria or guidelines are not met and safe conditions are not achievable, another alternative should be employed. An environmental impact statement may be required if an alternative is selected that will require post-operational site modification. The selection of alternatives should consider regulations as stipulated by the Council of Environmental Quality relative to the National Environmental Policy Act (43 FR 55978-56007).

The decontamination and decommissioning alternatives are addressed in Table 1, with the required activities at the facility, the needed control practices, and the potential use categories of the facilities. The required activities of the facility respective of its alternative pertains to the ultimate disposition of the site. Control of the site involves providing acceptable occupational and public safety through construction of barriers, liners and stabilization of surficial materials in addition to providing monitoring and surveillance. The use category pertains to how the facility can be employed after completion of decontamination and decommissioning activities. Use categories are discussed later in the section.

TABLE 1. Decontamination and Decommissioning Alternatives

<u>Alternative</u>	<u>Activity Required</u>	<u>Control</u>	<u>Use Category</u>
a) Exhumation and Translocation	Remove primary waste and contaminated matrix materials to acceptable levels. Remove barriers and monuments. Reestablish site to near natural conditions.	Decontamination and removal of facility.	Unrestricted
b) Entombment	Stabilize facility in place	Provide engineered barriers and liners to encapsulate waste. Provide passive monitoring systems. Provide periodic surveillance.	Conditional
c) Perpetual Care	Stabilize facility in place.	Provide some engineered barriers. Provide active and passive monitoring systems. Provide periodic surveillance. Provide periodic maintenance.	Restricted
d) Abandonment	Abandon site.	None	Unrestricted

Exhumation and Translocation

The exhumation and translocation alternative generally involves the removal of buried radioactive waste materials by excavation and the transport of these materials to another waste handling facility. This practice precedes restoring the original facility for unrestricted use. The general activities involved in this alternative are depicted in Figure 2.

Safety

The primary requirement of exhumation and translocation is the preparation of a detailed safety review and assessment. This primarily entails

FIGURE 2. General Required Activities for Exhumation and Translocation

evaluating waste generation records, present and potential site characteristics, existing radionuclide inventory, disposal mode, present and potential waste containment, present and potential monitoring activities, present surveillance and security activities. Another part of the safety review is to evaluate how sufficient data should be acquired to define what additional decontamination and decommissioning is required. The preliminary decision for selection of this alternative may then be made. The next segment of the safety review includes development of scenarios for decontamination and decommissioning and the development of procedures that will assure minimal risk to occupational workers and the public until such time as the facility is restored and released for unrestricted use. Secondary reviews of safety requirements and updating of procedures will probably be required throughout the decontamination and decommissioning project.

Methodology

The second requirement of this alternative is to compile additional data sufficient to specify what additional research, development, engineering and other work is needed. Site assessment involves detailed evaluation of radionuclide pathways; drilling and sample collection and analysis which will delineate the waste migration; surveys to locate buried waste and waste structures; and evaluation of any other natural or facilities parameters which may affect the waste management work to be conducted at the site. Additional research and development needs are identified during this phase, and work is initiated to determine solutions to identified problems, e.g., development of high-level waste handling techniques for unsolidified waste in burial sediments. Demonstration of developed methodologies, apparatus, analytical techniques and procedures may be required. Site assessment results may then require evaluation prior to proceeding with the initially selected alternative or selection of another alternative if safety within prescribed limits is not realized.

Design

The third requirement of exhumation and translocation is to design facilities and apparatus which will be used during exhumation and removal and treatment of contaminated waste. This design phase utilizes results obtained during site assessment, research and development, and demonstration as outlined above. The design of actual facilities will depend on such factors as the size, inventory, exhumation rate, and safety assurance required.

Exhumation

The next phase of operations should be a test conducted to exhume actual buried waste. This test should be used as a prerequisite to actual excavation and exhumation. This operation should be required to evaluate the performance of facilities, equipment and personnel. At such time as systems performance is determined to be functionally adequate to ensure safety, actual full-scale operational waste retrieval may be initiated.

Site Restoration

After dismantlement of all site facilities, the site should be restored to near its natural conditions. Site restoration should include backfilling of trenches and other burial structures with natural fill (sedimentary or soils materials). The site topography may be maintained or modified to be morphologically consistent with that of the surrounding terrain. Subsequently, topsoil or other geologic material capable of sustaining a plant cover could be placed over the disturbed materials. A plant cover capable of stabilizing the topsoil and fill materials may then be planted on the site.

Use

The ultimate goal of this alternative can then be achieved when the site is released for unconditional use to the public. The safety of future use relative to nuclear materials and facilities is assumed adequate and any activity consistent with land utilization plans can be conducted.

Records

Records should be kept through the duration of activities which will provide data on safety assessment, environmental assessment, design, construction, methodologies, procedures, treatment, health physics, monitoring, inventory,

contingencies, and site release. These records should be assimilated at the time of site release into a document recording all aspects of decontamination and decommissioning operations.

Entombment

The in-situ encasement of buried radioactive waste materials at a waste disposal site constitutes the entombment alternative. This activity involves encapsulating the waste material and contaminated sediments within structural barriers and liners which have a sufficient longevity to assure waste containment integrity. The integrity of the barriers and liners should be assured until such time as the contaminants within these structures reach innocuous levels. For burial sites containing high-level and transuranic wastes with half-lives that may exceed 2.0×10^4 years, the longevity of the encasing barriers and/or liners would need to be assured in excess of 2×10^5 years. For sites having high concentrations of uranium-thorium and uranium-thorium daughter isotopes with half-lives that exceed 4×10^9 years, the integrity of encasing structures should be assured for 4.0×10^{10} years. The activities required to implement this alternative are summarized in Figure 3, which shows a sequential system that may ultimately produce a reliable waste containment site.

Safety and Methodology

Detailed safety review and assessment of this disposition mode are the primary requirements from which other activities will be developed and initiated. The primary and secondary requirements should be commensurate with the exhumation and translocation alternative.

Design and Entombing

The third requirement involves the design of facilities and apparatus required to entomb the waste. The design should be specific for each site depending on the inventory, present waste storage structures, and safety requirements for encasement of the waste. The design of waste encasement structures (barriers and liners) should be conducted concurrently with the design of the site facility. The site facility during decontamination and

FIGURE 3. General Required Activities for the Entombment Alternative

decommissioning is composed of those structures which enclose the site during the time barriers and liners are being emplaced. Subsequent to the design phase entombing barriers should be emplaced.

Site Restoration

After emplacement of entombing barriers, the burial site should be restored to near natural conditions. Restoration may include backfilling over entombment structures with natural fill. Radiation monuments and similar structures should be used to prevent inadvertent intrusion.

Use

A significant departure in the last step of decontamination and decommissioning activities from the exhumation and translocation alternative is the use category assigned to the site. The entombment alternative may require specification of conditional use. Under this use category the waste encasement structure may not be penetrated. However, the site itself may be used for either non-nuclear or nuclear activities which will facilitate a broader spectrum of use as opposed to the restricted use category where only nuclear-related activities can be employed.

Monitoring and Records

Site monitoring, records keeping, and periodic reevaluation of safety and procedures will be essential. Because of the conditional use category, site monitoring and related surveillance activities may be required until such time as the potential radiological dose is within acceptable limits. A report of decontamination and decommissioning activities should be issued when the site is released to conditional use. Additionally, periodic reports may be required throughout site monitoring and surveillance activities after the use category is established.

Perpetual Care

The perpetual care alternative is defined as a continuation of existing potential activities that are required to preclude unacceptable occupational and public risk. This alternative constitutes continuous maintenance,

surveillance, and monitoring over the time during which buried waste materials exceed established acceptable levels of safety. The monitoring and surveillance activities of this alternative should be increased compared to that of entombment. The status of each retired site under this alternative assumes acceptable and continued safety maintained over an extended time. Encasement of the waste materials and contaminated burial structures is not essential. However, in some instances, barriers and liners may be installed which will prevent appreciable waste migration and intrusion. The activities required for implementation of this decontamination and decommissioning alternative are illustrated in Figure 4.

Safety and Methodology

The primary activities necessary to complete this alternative are similar to those for entombment, i.e., a safety review and development of procedures, site assessment, research and development, and implementation. The purpose of the assessment is to determine the adequacy of the site in its present and/or future condition. If the site in its present configuration is deemed adequate to retain contaminants, site stabilization and restoration work may not be required. However, if the safety review and assessment identifies deficiencies in site containment retention capacity, additional work should be conducted to assure the integrity and longevity of the site. Barriers and/or liners may be required to prevent the transport of contaminants to the hydrosphere and biosphere. These engineered structures may be designed so as to impede radionuclide transport, invasion, biointrusion, etc., while not totally encasing the waste material or preventing intrusion. Thus, the activities are commensurate with the entombment alternative, but the magnitude of the efforts are reduced due to a lesser safety requirement. However, the results of this alternative if selected should be adequate to maintain desired safety.

A significant departure from the entombment alternative is that the site may have to be stabilized to provide some assurance of long-term protection against waste migration and intrusion. This involves treatment of the burial

site to augment the integrity of the burial structure. Thus, once the site is defined as acceptable, it is stabilized in order that present conditions be approximately maintained over the duration of burial. Site restoration activities can be conducted as described in the previous two alternatives.

Site Restoration

After site stabilization and restoration is completed, the site may be released for restricted use. The restricted use of this site is much the same as discussed under the entombment alternative. However, the restricted use may be more limiting. The waste materials that have been buried have been partially encased and the site stabilized. However, the buried waste structure is by design more penetrable, i.e., subject to intrusion and less efficient in containing radionuclides, thereby increasing their relative hazard.

Use

Restricted use should be permitted to include only related nuclear site activities. Related nuclear activities may, for example, include above-ground interim storage of waste contaminants or storage of nuclear production fuels. The efficiency of the site for land utilization is thus increased and, due to the related surveillance and monitoring activities at the site, an increase in required safeguards may be minimized.

Monitoring

As previously discussed under the entombment alternative, monitoring activities may be required throughout the decontamination and decommissioning activities, and after site restoration. The magnitude of monitoring efforts may, however, be increased due to the perceived increased availability of radioactive constituents which may more readily enter the hydrosphere or ultimately the biosphere. The pathways of radionuclides potentially leading to occupational workers and the public may require monitoring throughout post-operational activities. Furthermore, monitoring over an increased spatial distribution may be necessary to identify potential or actual transport of contaminants. The result of the perpetual care alternative compared to

entombment may be an increase in monitoring, surveillance and maintenance, a decrease in containment waste burial structure integrity and longevity, and an increase in perceived hazard.

Records

The need for adequate documentation concerning safety, site assessment, engineering design, site activities, and monitoring and surveillance is again emphasized. Furthermore, increased data recording is necessary to adequately define site performance, etc., to permit stochastic evaluation and rapid assessment such that remedial activities may be initiated if unacceptable contaminant transport or intrusion is detected. Documentation should also be issued after completion of site restoration. Monitoring reports should be issued at an increased frequency after the site has been released to its designated use. In addition, a report covering all phases of the development and completion of decontamination and decommissioning utilizing the perpetual care alternative should be issued upon ultimate release of the site.

Abandonment

Abandonment consists of dismantlement and withdrawal of existing facilities. This waste management alternative requires a thorough safety review and site assessment, and only minimal site activities. This alternative may be selected after review and designation of the site as environmentally acceptable. The environmental acceptability of this site will subsequently permit unconditional use of the site for either nuclear or non-nuclear activities. The requirements for release of a site under this alternative are presented in Figure 5.

Safety

The primary requirement of this alternative is a safety review of the site and the radioactive materials at the site. This safety review differs from those previously presented in that procedures for decontamination and decommissioning engineering efforts are not required. The review of safety is expected to provide the initial information needed to designate a site for its specific use category.

After a preliminary safety review, site assessment may follow which will further evaluate the site, its inventory, burial conditions, pathways of radionuclide migration, and rates of migration. Reevaluation of safety will be conducted as was discussed under the previous alternatives.

Use

When the site has been designated as acceptable within allowable radiological, occupational, and public safety standards, it may be released as it exists. Any activity which may exacerbate the site or the waste structures, and/or the existing inventory, will be permitted. Intrusion into the waste constituents will be permitted due to acceptable levels of materials at the site.

USE CATEGORIES

The use categories discussed in this report are based primarily on the level of radioactive contamination of the site and the safeguards imposed to diminish the probability of these contaminants reaching the biosphere. Selection of a use category may be dependent on such factors as site topography, climatology, hydrogeology, demography, and potential land use, in addition to the site inventory and present conditions affecting the mobility of waste constituents. The three general use categories are: 1) restricted use, 2) conditional use, and 3) unrestricted (or unconditional) use.

Restricted Use

Restricted use of a waste burial site permits only nuclear activities at that site. In addition, these activities need to be compatible with the site so that site safety is maintained. This category may be invoked when the established guidelines for radionuclide inventory exceed those permitted in unrestricted areas, for instance, where significant contamination levels of high-level waste, transuranics, long-lived fission products, and naturally occurring radioisotopes occur. It is intended that exposure from a waste burial site categorized as restricted within the airborne and water pathways will be within limits imposed by the site operator or regulatory agency for restricted areas.

Conditional Use

The conditional use of a waste burial site may permit nuclear and/or non-nuclear activities to be conducted at the site. This use category may be applicable where contaminants within a waste burial structure have been sufficiently contained by encasement in barriers and/or liners, and potential public exposure is minimized. The contamination levels in and adjacent to the burial site, and those contaminant levels potentially resulting from a release from the site over the life of the site, should not exceed those administrative controls and standards established for public exposure within unrestricted areas.

Unrestricted Use

The unrestricted use of a nuclear waste burial site permits release of the site to the public such that human exposure from radionuclides emanating or potentially emanating from all pathways will be within established dose limits. Breach of the burial structure through surface manipulation or intrusion into the waste by humans or biotic organisms should be permissible because the residual contaminant levels within the total volume of the structure should be below the imposed limits.

COMBINATIONS OF ALTERNATIVES

Combinations of radioactive waste burial site disposition alternatives may be applied to increase the efficiency and minimize actual or perceived hazards from those sites. Combinations of these alternatives may be used as illustrated in Figure 6. The alternatives and major post-operational activities are illustrated in Figure 6 in their perceived order of difficulty; i.e., exhumation and translocation will require a substantial development and engineering effort compared to abandonment which requires negligible site activities. The alternatives are also illustrated in descending order relative to the irreversibility in modification of the alternative or selection of another alternative if acceptable safety criteria are not achieved. For example, reverting from the entombment alternative to that of abandonment will be unrealistic due to such factors as radioisotope type and total inventory. The

FIGURE 6. Combinations of Disposition Alternatives

compatibility of ultimate use categories, therefore, may not be achievable when going from a difficult alternative to a simplified alternative. However, as illustrated, viable combinations of alternatives could be initiated by reversion of a simplified alternative to one of greater complexity and increased safety.

After post-operational decommissioning activities and related site activities are completed, a decision based on the performance of completed activities, monitoring, and potential facilities use should be made. If the site safety is satisfactory, the site may be released based on a predetermined use category. If the site safety is evaluated as not satisfactory another alternative or combination of alternatives would be in order. An example of this is also illustrated in Figure 6, where at the completion of post-operational decommissioning activities, a decision point is reached and reversion of the alternative can result in selection of either the exhumation and translocation, entombment, or the perpetual care alternatives.

REGULATORY ISSUES

Regulatory issues considered in this study were thought to be applicable to decontamination and decommissioning and related activities at many retired nuclear facilities including the 300 Area Burial Grounds. These regulatory issues are discussed to evaluate nuclear waste management alternatives and are not to be considered as applicable to litigation.

Eight major statutes were identified: 1) the Atomic Energy Act of 1954, 2) the Energy Reorganization Act of 1974, 3) the National Environmental Policy Act, 4) the Clean Air Act, 5) the Federal Water Pollution Control Act, 6) the Toxic Substances Control Act, 7) the Resource Conservation and Recovery Act, and 8) the Safe Drinking Water Act.

The Atomic Energy Act of 1954, as amended [42 U.S.C. 2011 et seq.] and the Energy Reorganization Act of 1974 [42 U.S.C. 5801 et seq.] give DOE authority in the management of its own activities. As provided in Section 110(a) of the Atomic Energy Act, DOE appears to have the responsibility to see that the activities of DOE and its contractors promote common defense and security, protect health, and minimize danger to life and property in pursuit of DOE's activities.

A possible exception to DOE's authority is stipulated in Section 202(4) of the Energy Reorganization Act of 1974. It covers licensing by the Nuclear Regulatory Commission (NRC) of retrievable surface storage facilities and facilities for the authorized expressed purpose of subsequent long-term storage of DOE-generated high-level waste not used for research and development purposes.

The 300 Area Burial Grounds are not "retrievable surface storage facilities," since the intent of these waste burial sites was disposal not storage. The 300 Area Burial Grounds are also not typically thought of as being "authorized for the express purpose of nuclear waste storage." Authorization in this instance would possibly refer to Congressional authorization and, as such, Section 202 of the Act would not apply to these sites. Therefore, NRC

would not have jurisdiction over these sites. None of the identified waste management alternatives would be consequently affected unless Congressional authorization was possibly forthcoming.

The 300 Area Burial Grounds are also not considered "subsequent"; i.e., facilities constructed or otherwise utilized after enactment of the above legislative act. Subsequent activities may, however, be interpreted to include the exhumation and translocation and entombment alternatives. The applicability of the Energy Reorganization Act to substantiate long-term storage for the perpetual care and abandonment alternatives, however, is not obvious. If Section 202 of the Act is interpreted to apply to waste generated after enactment, the Act then would not be applicable to any of the waste management alternatives identified.

Materials disposed to the 300 Area Burial Grounds may in some instances be defined as high-level waste (AEC, Manual Chapter 0511). Thus, applicability to Section 202 of the Act relative to this factor is implied. In that some 300 Area Burial Grounds contain high-level wastes, the NRC licensing authority may be applicable to the previously identified waste management alternatives.

The materials within the subject burial sites originated in part from production in addition to "research and development activities." Thus, Section 202 may not impact the waste management alternatives chosen for the 300 Area Burial Grounds depending on characterizing the sites as recipients of research and development wastes.

The implication exists that Section 202 may apply to at least three waste management practices, i.e., exhumation and translocation, entombment, and abandonment, relative to the 300 Area Burial Grounds, and, as such, NRC may have some preemptory authority. Section 202 does not appear to apply to any alternative unless it involves new generations of nuclear technology. Therefore, the existing perpetual care alternative, if continued, will probably not invoke application of NRC licensing statutes.

The Atomic Energy Act of 1954 as amended Section 161(b) may also jurisdictionally impact the 300 Area Burial Grounds in that the Environmental Protection Agency (EPA) has authority to regulate offsite radioactive emission. The EPA has issued draft criteria for radioactive waste (43 and Reg. 53,262) which may be applicable to existing DOE waste management facilities. The criteria reported are to be used for developing specific environmental standards for different radioactive waste sources [Id. 53,263]. These criteria may curtail the choice of decontamination and decommissioning alternatives for the 300 Area Burial Grounds.

Criterion 1 as developed by the EPA indicates that the criteria do apply to all the 300 Area burial site waste management alternatives, i.e., "the supporting fuel cycles (of military and research reactors) including spent fuel if discarded, fuel reprocessing wastes, and radionuclides removed from process streams or effluents." Criterion 2, which provides that "controls based on institutional functions should not be relied on for longer than 100 years," could rule out the "perpetual care" alternative for the sites. Criterion 4, which "limits the risks acceptable for waste management," could pose even more difficult problems. Criterion 4 could rule out the "exhumation and translocation" alternative if it required exposure to workers in excess of the expected population exposure were the wastes left alone. Yet all the other alternatives may imply the continuance of institutional controls indefinitely (violating Criterion 2) and might also imply an expected future risk at a total higher than permitted under Criterion 4. The environmental standards that the EPA will develop pursuant to the above criteria may further limit the waste management alternatives for the 300 Area Burial Grounds.

The National Environmental Policy Act (NEPA) [42 U.S.C. 4321 et seq.] requires Federal agencies to prepare an environmental impact statement (EIS) in connection with any Federal actions significantly affecting the quality of the human environment [Id. 4332]. Alternatives for waste management of 300 Area Burial Grounds may conceivably affect the human environment and, therefore, applicability to NEPA may be realized. Any action which deviates

from present practices (perpetual care), including exhumation and translocation, entombment and abandonment, may require an environmental impact statement. For entombment, perpetual care, or abandonment, the Hanford Waste Management Operations Final Environmental Impact Statement (ERDA, 1975) or a brief amendment may suffice. If the exhumation and translocation alternative is chosen, a new site will have to be selected for relocation of the waste. If this relocation site is not already operated under existing license, agreement, or other Federal control, an EIS would again be required. Such an EIS would assess the impacts associated both with the new site and with the process of translocation.

A more difficult question pertains to perpetual care, which is essentially a continuation of present practices. This alternative could constitute sufficient Federal action to initiate application of NEPA. Congress may want agencies to address environmental consequences not only in considering future projects, but also in reviewing present policies in programs. On this basis, a decision by DOE to forego other actions and continue the present policy of perpetual care at the 300 Area Burial Grounds may initiate application of NEPA.

The Clean Air Act [42 U.S.C. 7401 et seq.] including the 1977 amendments, provides a comprehensive framework for the regulation of airborne pollutants by Federal and state governments. Section 118(a) of the Clean Air Act provides that any Federal agency having jurisdiction over a facility is subject to all Federal, state, interstate, and local requirements with respect to the control and abatement of air pollution. Therefore, the 300 Area Burial Grounds would be subject to the Clean Air Act, as well as state and local requirements. If EPA determines the hazards of radioactive air emissions, it is to include these substances in the list published under Section 108(a)(1) or 112(b)(1)(A), which would subject radioactive emission to regulation either through ambient air quality standards under Section 108 or, more likely, emission standards under Section 112. Therefore, all of the identified waste management alternatives may be subject in part to the above regulations.

The Federal Water Pollution Control Act (FWPCA), as amended by the Clean Water Act of 1977 [33 U.S.C. 1251 et seq.] provides a comprehensive framework

for the control of water pollution by the Federal government and the states somewhat analogous to control of air pollution under the Clean Air Act. Federal agencies such as DOE are thus subject to the pollution limitations promulgated by EPA under the authority of the Act.

Section 502 of the Act defines pollutants to include "radioactive materials." However, the Federal Water Pollution Control Act does not include source, by-product, and special nuclear materials. Nonetheless, the 300 Area Burial Grounds may include substantial quantities of nonradioactive toxic waste, such as carcinogens. These burial sites may also contain radioactive materials other than source, special nuclear, or by-product material, such as radiotracer pharmaceuticals. These materials would constitute pollutants under the FWPCA, and thus be subject to regulation.

A key distinction in the FWPCA involves point sources versus nonpoint sources of pollution. Point sources are subject to the effluent limitations, technology standards, and permit procedures of the National Pollutant Discharge Elimination System. Nonpoint sources of pollution are regulated solely through State Water Quality Management Plans. The 300 Area burial sites in question are probably nonpoint pollution sources, if in fact they are pollution sources at all. State Water Quality Management Plans specifically refer to "disposal of pollutants on land or in subsurface excavations." Since the burial sites involve disposal of potential pollutants in subsurface excavations, the FWPCA will potentially subject them only to the Washington Water Quality Management Plan applicable to the Hanford Site, adopted pursuant to 40 CFR Part 130.

The Toxic Substances Control Act (TOSCA) [15 U.S.C. 2601 et seq.] provides a framework for the regulation of toxic substances. [From Microbes to Men: The New Toxic Substances Control Act and Bacterial Mutagenicity/Carcinogenicity Tests, 6 Env't'l L. Rev. 10248 (1976).] TOSCA gives EPA the authority to regulate the disposal of substances if disposal would present an unreasonable risk of injury to health or the environment [15 U.S.C. 2605]. While the Act specifically excludes source material, special nuclear material, and by-product material, as defined in the Atomic Energy Act of 1954, from coverage [15 U.S.C. 2602], EPA could possibly determine that the disposal of other

materials buried in the 300 Area sites presents significant health or environmental hazard. The extent of EPA's authority to regulate 300 Area Burial Ground activities relative to TOSCA depends on two issues. First, TOSCA is unclear as to EPA's authority to regulate the activities of Federal agencies such as DOE. The Act frequently refers to commercial manufacturers and processors, but never expressly includes or excludes the Federal government. Secondly, if TOSCA does apply to DOE, it probably only applies prospectively: TOSCA would thus affect only the exhumation and translocation alternative or possibly the alternatives involving new practices at the present site.

The Resource Conservation and Recovery Act of 1976 [42 U.S.C. 6901 et seq.] regulates the treatment, storage, transportation and disposal of hazardous wastes having adverse effects on health and the environment. While the Act expressly applies to Federal facilities [42 U.S.C. 6961], it expressly excludes from coverage source, special nuclear, and by-product material as defined by the Atomic Energy Act of 1954 [42 U.S.C. 6903(27)]. However, to the extent application of the Act is not inconsistent with the Atomic Energy Act of 1954, it could still apply to management of the wastes at the 300 Area Burial Grounds should they contain materials defined as hazardous by the EPA [42 U.S.C. 6905]. Such application would subject DOE to the record keeping, labeling, permitting and other requirements of the Act in connection with maintenance of the present sites or with exhumation and translocation alternatives.

The Safe Drinking Water Act [42 U.S.C. 300g et seq.] provides a comprehensive framework for drinking water standards to be set by EPA. Section 1401(6) of the Act defines the contaminants for which EPA is to set standards to include "any physical, chemical, biological, or radiological substances or matter in water." The standards promulgated by EPA at 40 CFR Part 141 include maximum contaminant levels for various radionuclides. Presumably, the 300 Area Burial Grounds could contribute to the presence of radionuclides in public drinking water supplies. However, since the Act applies to the owners of public drinking water systems, and not directly to facilities

operators other than those who emplace pollutants by well injection, the Act would appear not to apply directly to DOE's activities in connection with the 300 Area Burial Grounds.

Based on the above assessment of regulatory issues, all of the identified waste management alternatives may in some way be affected by or fall under the jurisdiction of Federal and/or state statutes. The exhumation and translocation alternative will probably be subject to the most regulatory limitation. The entombment and abandonment alternatives will probably require less regulatory review. The perpetual care alternative currently in effect will probably be subject to the least legislative limitations.

GENERAL SITE DESCRIPTION

Before an assessment of specific burial grounds can be made, the characteristics of the surrounding area must be understood. This section describes the general features of the Hanford Site. Much of the general information discussed in this section was derived from this project. Specific data, however, were derived from the Hanford Waste Management Operations Final Environmental Impact Statement (ERDA, 1975).

The Hanford Site consists of a large (920 km²) government reservation located in southeastern Washington State between 119° 17' and 119° 50' west longitude and 46° 19' and 46° 51' north latitude. Figure 7 illustrates the major geologic features of the Hanford Site and adjacent areas. A distinguishing feature of the Hanford Site is the Columbia River, which flows from the west where it enters the Site and subsequently north-easterly and southerly until it exits the Site at the southern boundary.

TOPOGRAPHY

The Hanford Site is bounded on the southwest, west, and northwest by large anticlinal and monoclinal ridges which are common in this area of the state. The elevation ranges from the lowest southeastern terminus at approximately 105 m above mean sea level (MSL) to approximately 1095 m above MSL at the summit of Rattlesnake Mountain which forms the southwestern border. The interior portion of the Site is dominated topographically by the Pasco Basin, a large asymmetric synclinal depression. The center of depression of the Pasco Basin is in the east-central portion of the Site.

Where the Columbia River flows through the northern and eastern sections, the land is dominated by river terraces. Further toward the center of the Site the topographic expression changes to form an extensive alluvial plain. This alluvial plain consists of aggradational features including large areas in the southern section composed typically of aeolian dunes. These dunes are in most areas partially stabilized by native vegetation; however, numerous occurrences of active dunes can be found. Degradational features of the

FIGURE 7. Basalt Surface in the Pasco Basin;
Major Structures Identified

Source: ERDA (1975)

interior alluvial plain include incised hills and gullies formed by intermittent fluvial streams. Other degradational features include deflation sites caused by atmospheric wind activity and river bank erosion.

The Rattlesnake Hills, the southwestern boundary, consist of asymmetric anticlinal ridges. Alluvial features emanating from this and related geomorphological features make up the southwestern and western portions of the Site. The typical resulting topography trends from these areas in a radial pattern to lower elevations and ultimately to the Columbia River. The Yakima River forms a morphological boundary on the southern boundary where it has incised through the Rattlesnake Hills and flows to the northeast and then to the southeast where it forms its confluence with the Columbia River to the south of the Site.

The White Bluffs, which are remnants of glaciofluvial materials deposited in the Pasco Basin, are located in the northern and northeastern portions of the Site. These bluffs are typically exposed directly adjacent to the Columbia River where, in several places through the reach of the Columbia River as it flows through the Site, large slump blocks and slides, mass wastage and alluvial fans aggrade the river.

SOILS AND STRATIGRAPHY

The land surface on and above the Hanford Site is, for the most part, overlain by aeolian and glaciofluvial-derived soil profiles. These soils consist typically of mixed granitic, quartz, and basaltic sands formed on colluvium, alluvium, and loess deposits on foot slopes and terraces. These soils are classified as torriorinents and torripsammments, which are shallow, coarse-textured materials originating in arid environs. The engineering and agricultural uses of these soils are generally limited.

The Pasco Gravels underlie most of the central, north-central, and southern portions of the Site. This stratigraphic unit is exposed at the gravel surface in several places but is mostly covered by soil profiles. The Pasco Gravels are usually graded with boulders and cobbles grading to sands and silts from lower to upper elevations within the unit, respectively. Through the

reach of the Columbia River from the northwestern boundary of the Hanford Site to the southern boundary, lateral grading is evidenced by the occurrences of progressively finer materials to the downstream sections.

The origin of these materials is from glacial floods occurring from between possibly 50,000 years to 10,000 years ago, i.e., mid-Pleistocene to early Holocene geologic epochs. The source area for most of these sediments is from northeastern Washington and northern Idaho. The parent materials are granitic and metasedimentary.

The Ringold Formation sequentially is superimposed over the Columbia Plateau flood basalts over much of the Hanford Site. Occurrences of this unit within the central portion are not noted probably due to erosion of this material by the ancestral Columbia River channel. Large sections of this formation, which composes the White Bluffs, are exposed north of the present Columbia River within the Site. The stratigraphic section of this formation consists of a lower fine-textured clay to silty member, a middle member indurated to partially indurated conglomerate member, and an uppermost member consisting of fine sand to silt. For the most part, these formation members are laterally continuous to semicontinuous as evidenced by strikes of beds along the White Bluffs which may extend many kilometers.

The Ringold sediments primarily originated from fluvial deposition of materials from the ancestral Columbia River. The three distinct members of this formation are indicative of sediment depositional regimes of the ancestral river which was controlled by structural uplift and subsequent downcutting of the adjacent topography to the south and southeast of the region. The age of these materials is probably between 1 million to 2 million years before present (the Pliocene geological epoch). The source material as evidenced by evaluation of mineralogic composition of rock types is mainly derived from northern and northeastern Washington, with lesser amounts of materials derived from central Washington also present.

Directly underlying the Ringold Formation is an extensive sequence of the Columbia Plateau flood basalts. These flows consist of continuous to semicontinuous flows interbedded within weathered materials and plagioclase beds which

in some instances suggest lacustrine or fluvial deposition and later terrestrial deposition. Basalt flow sequences are exposed at various locations along the Rattlesnake Hills and in the north-central portion of the Site at Saddle Mountain and Gable Butte. The age of these volcanic deposits is possibly from 50 million to 8 million years before present (Eocene to Pliocene epochs).

FLUVIAL RELATIONSHIPS

The Columbia River and, to a lesser extent the Yakima River, are the only continuous rivers traversing specific segments of the Hanford Site. The reach of the Columbia River extends over 76 km through Hanford. Typical thalweg depths between 3 to 13 m occur within this river reach. The channel width depending on location and stage varies between approximately 120 to 200 m. The maximum river discharge may exceed $1.7 \times 10^7 \text{ } \ell \text{ sec}^{-1}$, whereas minimum discharge of slightly greater than $1.0 \times 10^6 \text{ } \ell \text{ sec}^{-1}$ has occurred. Maximum velocities, which depend on stage location and related factors, have been measured which slightly exceed 12 km/hr. The dynamics of the river are somewhat controlled by Priest Rapids and McNary Dams located upstream and downstream from the Hanford Site, respectively. Bedload material in the reach extending through the site is typically sand and silt with lesser amounts of clay. The bed material through much of the cross section of the river in this area is armored with imbricated cobbles and boulders. The bed load probably consists of only a small percentage of the total load, whereas the suspended load is thought to be the major transport mode.

The Yakima River extends approximately 25 km from near the southwestern border of the Hanford Site where it turns southeastward from the base of Rattlesnake Mountain until it passes the southwesternmost extension of the Hanford Site. Typical main channel depths extend from approximately 1 m to 20 m with an approximate mean depth of 2 m. Depending on location, stage, etc., the channel width varies from approximately 40 to 90 m. Flows ranging from in excess of $5.7 \times 10^5 \text{ } \ell \text{ sec}^{-1}$ to as low as $3.9 \times 10^4 \text{ } \ell \text{ sec}^{-1}$ are typical of this river segment near the Site.

A large intermittent drainage area exists adjacent to the footslopes of Rattlesnake Mountain which trends northwest-southeast over much of the southwestern area of the Site. This area is referred to as the Cold Creek Drainage. A small amount of runoff and associated alluvial material accumulate in this drainage and are transported downslope. Most of this material of fine texture is transported eastward by aeolian processes.

In the north-central location of the Site is located a small naturally occurring lake contiguous with the saturated groundwater system. Drainage of this water body is through the saturated groundwater system to the Columbia River in a northwesterly direction. Recharge is predominantly from the west-northwest with origins from the Rattlesnake Hills and adjacent areas.

Surficial erosion over most of the Hanford alluvial plain is perpetuated by meteoric rainfall, although resulting sheet, rill, and gully erosion is of little importance to surface erosion. Due to low average rainfall and high infiltration capacity of the surficial sediments and soils, most of the incident rainfall percolates downward thereby reducing effects of runoff. Only where slopes are of an order greater than 10° from the horizontal is water erosion consequential.

GROUNDWATER HYDROLOGY

The groundwater hydrology of the Hanford Site, consisting of the partially saturated zone, the unconfined aquifer and the confined aquifer, is controlled by the geology, meteorology, and fluvial hydrology existing at or near the Pasco Basin. These complex systems are interrelated throughout the groundwater domain in this area.

The partially saturated zone is that section of the region containing water at pressures less than atmospheric. This zone is bounded above at the ground surface and at the water table below. Meteoric water in the form of rainfall infiltrates into this zone. The transport of this water depends on the ground materials, the thermodynamic potentials affecting the fluid, and the meteorology in addition to the properties and quantity of the fluid itself. Meteoric water is transported in this zone simultaneously in gas and liquid

phases. Over the majority of the areal extent of the Hanford Site, the partially saturated zone occurs vertically through surface soils and surficial aeolian deposits, Pasco Gravel deposits, and ultimately into the underlying Ringold Formation. The 300 Area Burial Grounds are within this zone.

The unconfined aquifer is that section of geologic strata containing water bounded on its upper extremity by the water table and below by relatively impermeable geologic formations. This continuous aquifer system is typically bounded by relatively impermeable basalt ridges occurring to the southeast and west within the confines of the Site. Recharge of this aquifer occurs at the footslopes of these ridges from where incident precipitation has collected. Another recharge source affecting the southern section of the Site is the Yakima River. Recharge to the unconfined aquifer may also occur from leakage of the underlying confined aquifer vertically upward through existing fracture systems or relatively low permeability basalt and interbed materials.

Another form of recharge which affects the unconfined aquifer is irrigation which has recently been developed upgradient from the Site to the west. The main discharge boundary for the Site, however, is the Columbia River which acts as the lowermost hydraulic potential surface for the surface of the unconfined aquifer. The lateral extension of this aquifer is approximately 40 km from the northwestern section of the site along Yakima Ridge to the eastern site boundary of the Columbia River. The maximum saturated thickness is on the order of 75 m in the northwestern section of the Site. The aquifer is typically contained in the unindurated and partially indurated Ringold Formation and to a lesser degree in the Pasco Gravels and associated surficial deposit. Ground water within this aquifer typically moves downgradient from the northwest to southeast in the southern section of the Site. The gradient in the northern section, however, is to the north and northeast directions.

In the confined aquifer system, low or impervious confining layers overlies pervious layers. These layers confine ground water at relatively high piezometric pressures which are between aquacludes or aquitards. Infiltration

into the confined aquifer system occurs at an elevation above most of the central portion of the Site. Thus, due to confinement the hydraulic head relationships existing at lower elevations result in increased piezometric surface elevations, i.e., the elevation to which water will rise in wells penetrating confined aquifers above that of the existing water table. The piezometric surface of the upper confined system ranges from approximately 300 m MSL adjacent to Rattlesnake Mountain to approximately 125 m MSL in the southeastern section of the Site. These elevations correspond with water-table elevations of approximately 160 to 115 m MSL near the same locations, respectively. The elevation of the water table in some locations does, however, exceed that of the piezometric surface in the north-central section of the area. Water transmitting zones within the confined aquifer are typically silt confined by clay within the lower Ringold Formation and interbeds of sedimentary material, plagonites, and brecciated zones within the underlying basalt flow sequences below the Ringold Formation.

METEOROLOGY

The Hanford Site has a mild arid climate with hot dry summer and cool moist winter seasons. Meteorological systems affecting the Site originate from the Pacific Ocean to the west. The Cascade Mountains, also to the west, influence the meteorology whereby a rainshadow is produced by the mountains which results in mean precipitation values of less than about 30 cm. The Cascade Mountains also influence the wind direction and magnitude.

The annual temperature as measured in the north-central section ranges from a maximum of approximately 34°C to a minimum of -6°C. The maximum monthly average temperature, as well as the daily maximum, occurs in July; conversely, the minimum temperatures occur in January (Figure 8). The data in Figure 8 represent a 30-year compilation and assessment of data for normal temperature records and a 59-year record for temperature extremes. The thermal regime above the given surface between approximately 1 and 200 m is expressed similarly by low temperatures and temperature differences during the winter months and the inverse during the summer months. The thermal gradient above the

FIGURE 8. Annual Variation of Normal and Extreme Daily Maximum and Minimum Temperatures

Source: ERDA (1975)

ground surface is at a maximum between 0300 and 0700 hr with the magnitude of change in gradient being less in the winter months. The maximum difference in temperature above the ground surface to approximately 200 m occurs in spring and summer months between 1000 and 1600 hr. Figure 9 illustrates mean temperature versus time for four months using three levels.

Subsurface temperatures have also been recorded at depths of approximately 1.2, 38, and 91 cm at the same location. The range in subsurface soil/sediment temperatures is between approximately 65 and -19°C, 34 and -6°C and 29 and 0°C for the 1.2, 38 and 91 cm depths, respectively. The highest mean monthly temperature at the 1.2 cm level is in July at about 32°C. For the lower depths, the highest values occur during August at about 81 and 79°C for the 38 and 91 cm depths. The lowest mean monthly averages occur in January for all

FIGURE 9. Diurnal Course of Temperature for Three Levels, January, April, July, and October
Source: Stone et al. (1972)

depths. Figure 10 illustrates subsurface temperatures for all three depths and subsurface temperatures at all three depths versus air temperature at the 1-m level above the ground surface.

The incident precipitation in the form of rainfall, snow, sleet, etc. near the north-central portion of the Site averages approximately 15 cm/year. The maximum monthly and daily precipitation in the form of rainfall occurs in February and June, respectively, whereas the minimum values for monthly rainfall occur in March through August and October on the average. Precipitation in the form of snow, rain, and sleet occurs with monthly and daily maximum during February and December, respectively. The majority of the total precipitation falls during the months of November, December, and January. The least amount falls during the months of July, August and September. Rainfall occurring in one day can exceed 11 cm and on an hourly basis it can exceed 0.9 cm, as recorded. A maximum hiatus, however, between rain events can exceed 80 days. Figure 11 shows mean monthly precipitation for a 58-year period.

Wind on the Hanford Site basically occurs by two mechanisms: 1) differential pressure concurring with frontal activity and 2) gravity wind affected by the atmosphere, thermal regime, and topography. The maximum wind velocity occurring in the north-central section of the Site, where a complete meteorological station has existed for over 30 years, was approximately 110 km hr^{-1} . Maximum velocity wind of in excess of 60 km hr^{-1} occurs during all months of the year with the highest frequency of high wind velocities (greater than 50 km hr^{-1}) occurring from November through February. The velocity distribution from the ground surface vertically upward tends to be somewhat constant above 2 m during high wind velocity events. The maximum and minimum monthly averages range from approximately 17 to 2 km hr^{-1} for the months of April and November, respectively.

The maximum wind velocity was recorded in the month of June. The hourly diurnal wind velocity ranges between approximately 8 and 21 km hr^{-1} at an elevation of approximately 15 m. The highest hourly average occurs in the

FIGURE 10. Average Monthly Subsoil and Air Temperatures
Source: Stone et al. (1972)

FIGURE 11. Average Monthly Precipitation Amounts Based on the Period 1912 - 1970

Source: Stone et al. (1972)

month of June, whereas the lowest velocities typically occur in November. From January until June-July the highest mean hourly velocities increase from approximately 1200 to 2100 hr from approximately 9 to 21 km hr^{-1} , respectively. Then from June-July until December the highest mean hourly average decreases from approximately 21 to 10 km hr^{-1} , respectively. The dominant wind velocity occurs at less than approximately 5 km hr^{-1} during November, December, and January, while during the remainder of the annual cycle it occurs between approximately 5 and 11 km hr^{-1} . Yearly averages of mean hourly wind velocities are greatest at approximately 2000 hr and lowest at 0500 and 0600 hr. Table 2 identifies monthly and annual mean wind velocity recorded in the north-central section of the Hanford Site.

Wind direction on site is influenced by the abovementioned frontal and orographic effects and local topographic channeling. Thus, the wind direction at several locations on the Site will differ because of these general effects with respect to the location of the monitoring station. In the north-central area the direction of wind persistence is from the north-northwest and occurs in excess of 90% of the time through an annual cycle. November, December, January, and February winds are predominantly northwesterly while the remainder of the months exhibit a north-northwesterly directional persistence. In the southeastern section of the Site the wind direction is from the north-northwest. However, southeasterly and southwesterly persistence contributes significantly to the directional frequency. High-velocity winds predominantly occur from the southwest octant. Figure 12 illustrates wind roses for two locations on site. The points of the roses show which direction the wind is coming from.

Relative humidity measured in the north-central section of the Hanford Site typically ranges between approximately 89% and 22% from January to July, respectively. Monthly mean values for 15 years range from approximately 27% to 31%. The temperature (dry bulb temperature) monthly averages at 1300 hr are inversely proportional to the relative humidity throughout an annual cycle. This is illustrated in Figure 13 which shows the average hourly dry bulb, wet bulb, temperature, relative humidity, and dew point temperature relative to time and temperature-humidity percentage.

Clear and partially cloudy days average approximately 200. The maximum hourly mean sky cover occurs during December and the minimum in July with values ranging from approximately 8% to 3%, respectively. Mean hourly sky cover tends to decrease from January to July and then increases on a mean monthly basis until December. Table 3 illustrates mean hourly and monthly sky cover in conjunction with sky cover measurements of solar radiation made at the same location. The highest and lowest solar radiation values averaged on a monthly basis occur in July and December at approximately 700 and 60 langley, respectively. The lowest monthly mean values correspond with low sun declination, and the highest values conversely correspond with the high sun declination.

TABLE 2. Monthly and Annual Mean Wind Velocity,
Hanford Site, North-Central Section

Source: Stone et al. (1972)

Hour Beginning (PST)	Months												Year
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
00	6.2	6.9	8.2	8.7	9.0	9.9	9.8	9.1	7.9	6.6	6.1	6.1	7.9
01	6.1	6.7	8.0	8.4	8.5	9.1	9.0	8.3	7.3	6.3	6.1	6.0	7.5
02	6.0	6.7	7.9	8.0	7.9	8.4	8.1	7.5	7.0	6.0	5.8	6.0	7.1
03	5.9	6.6	7.5	7.5	7.6	7.7	7.5	6.9	6.8	6.0	5.7	5.8	6.8
04	5.8	6.6	7.3	7.1	7.3	7.5	7.1	6.5	6.3	5.8	5.8	5.8	6.6
05	5.7	6.5	7.2	6.9	6.6	6.8	6.5	6.0	6.1	5.8	5.5	5.5	6.2
06	5.6	6.3	6.9	6.5	6.9	7.7	7.1	5.6	5.5	5.5	5.3	5.5	6.2
07	5.5	6.0	6.6	7.6	7.2	7.5	6.9	6.1	5.9	5.2	5.2	5.4	6.3
08	5.5	6.2	7.5	8.4	6.8	6.9	5.6	5.6	6.3	5.4	5.2	5.4	6.2
09	5.6	6.6	8.0	8.2	6.6	6.5	5.2	5.2	6.1	6.2	5.9	5.3	6.3
10	5.9	6.8	8.4	8.4	6.8	7.0	5.6	5.3	6.2	6.4	6.3	5.7	6.6
11	6.5	7.3	8.8	8.6	7.2	7.4	6.1	5.6	6.6	6.3	6.5	6.1	6.9
12	6.9	7.7	9.2	9.1	7.6	7.6	6.5	6.0	7.0	6.8	6.6	6.3	7.3
13	6.8	7.8	9.7	9.6	8.1	8.1	7.2	6.6	7.0	7.2	6.7	6.4	7.6
14	6.7	7.9	10.1	10.2	8.7	8.7	7.7	7.2	7.6	7.4	6.4	6.3	7.9
15	6.2	8.0	10.2	10.5	9.4	9.4	8.3	7.8	8.1	7.5	6.3	6.0	8.1
16	6.2	7.6	10.4	11.1	9.9	10.5	9.1	8.5	8.5	7.3	6.1	6.0	8.4
17	6.4	7.4	9.6	11.3	10.7	12.0	10.3	9.5	8.8	7.4	6.5	6.2	8.8
18	6.7	7.7	9.4	10.9	11.2	12.9	11.4	10.3	9.1	8.0	6.4	6.2	9.2
19	6.8	7.6	9.5	10.9	11.3	13.0	12.1	11.2	9.8	7.9	6.4	6.1	9.4
20	6.6	7.6	9.4	11.0	11.4	13.0	12.8	11.8	9.7	7.6	6.4	6.0	9.5
21	6.4	7.3	9.1	10.5	11.5	12.8	13.2	12.0	9.3	7.4	6.2	6.0	9.3
22	6.1	7.3	8.4	9.9	10.6	12.1	12.3	11.0	8.7	7.1	6.2	6.0	8.8
23	6.1	7.2	8.3	9.1	9.8	10.9	10.7	9.9	8.1	6.8	6.2	6.1	8.3
Avg	6.2	7.1	8.6	9.1	8.7	9.3	8.6	7.9	7.5	6.7	6.1	5.9	7.6

FIGURE 12. Surface Wind Roses Based on 5-Year Averages (1952 - 1956).
Speeds given in miles per hour.
Source: ERDA (1975)

FIGURE 13. Annual Hourly Averages of Dry Bulb and Wet Bulb Temperature, Relative Humidity and Dew Point Temperature (1957 - 1970)
Source: Stone et al. (1972)

In a mean hourly basis, as would be expected, the highest solar radiation occurs at approximately 1200 hr. Figure 14 represents mean, highest, and lowest solar radiation levels in units of langleys on a monthly basis.

Atmospheric pressure changes perpetuated by frontal activity passing over the Site ranged from approximate mean hourly averages of 200 to 100 mb, corrected to sea level. Higher pressure typically occurs in the winter months and decreases until midsummer during June-July and then increases again until December-January. The atmospheric pressure extremes between high and low pressure also occur during the months of December and January. High pressure activity typically occurs based on mean hourly observations between 0700 and 1100 hr, whereas low pressure activity occurs between 1500 and 1900 hr measured on the same basis.

DEMOGRAPHY AND LAND USE

The population distribution in the vicinity of the Hanford Site based on projected census information to 1977 demonstrates the proximity and magnitude of population in uncontrolled areas adjacent to the Site. In 1977 the

TABLE 3. Mean Hourly and Monthly Sky Cover.
Tabular values based on the period
1957 to 1970

Source: Stone et al. (1972)

Hour Beginning (PST)	Months												Year
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
00	7.1	6.0	5.2	5.1	4.6	4.4	2.4	2.5	3.4	4.5	6.6	7.4	4.9
01	7.1	6.1	5.4	5.2	4.6	4.1	2.2	2.5	3.4	4.5	6.7	7.5	4.9
02	7.1	6.1	5.4	5.3	4.5	4.0	2.1	2.4	3.5	4.7	6.6	7.5	4.9
03	7.3	6.2	5.4	5.2	4.8	4.5	2.4	2.4	3.5	4.8	6.4	7.4	5.0
04	7.4	6.3	5.5	5.5	5.2	4.7	2.5	2.8	3.5	4.8	6.5	7.5	5.2
05	7.4	6.7	5.7	6.0	5.6	5.0	2.7	3.3	4.3	5.0	6.6	7.8	5.5
06	7.5	7.2	6.3	6.2	5.6	4.9	2.6	3.4	4.5	5.5	6.8	7.8	5.7
07	8.1	7.5	6.6	6.3	5.6	4.8	2.7	3.3	4.4	5.9	7.5	8.3	5.9
08	8.3	7.6	6.8	6.3	5.4	4.7	2.5	3.2	4.3	5.8	7.7	8.4	5.9
09	8.2	7.6	6.7	6.3	5.5	4.8	2.4	3.0	4.2	5.8	7.6	8.3	5.9
10	8.2	7.5	6.6	6.4	5.6	5.0	2.5	3.2	4.3	5.8	7.4	8.5	5.9
11	8.1	7.3	6.8	6.5	5.8	5.3	2.6	3.2	4.3	5.8	7.4	8.4	5.9
12	8.1	7.4	6.9	6.7	6.0	5.2	2.8	3.3	4.3	6.0	7.6	8.3	6.0
13	8.1	7.4	7.0	7.0	6.2	5.3	2.9	3.4	4.4	6.2	7.7	8.2	6.1
14	8.0	7.4	7.0	7.0	6.1	5.3	3.0	3.5	4.4	6.3	7.6	8.1	6.1
15	8.0	7.4	6.9	6.9	6.3	5.4	3.1	3.6	4.4	6.4	7.5	8.1	6.2
16	8.1	7.4	6.9	7.0	6.4	5.6	3.2	3.7	4.4	6.4	7.3	8.0	6.2
17	7.9	7.2	6.9	6.8	6.2	5.4	3.2	3.6	4.4	6.2	7.1	7.8	6.0
18	7.5	6.7	6.7	6.7	6.1	5.4	3.1	3.4	4.4	5.9	6.9	7.6	5.9
19	7.4	6.3	6.3	6.4	6.1	5.3	3.2	3.2	4.2	5.6	6.6	7.6	5.7
20	7.3	6.2	5.9	6.0	5.8	5.2	3.0	3.1	3.9	5.4	6.5	7.5	5.5
21	7.1	6.2	5.7	5.6	5.2	4.8	2.8	2.8	3.8	4.9	6.6	7.4	5.2
22	7.2	6.3	5.4	5.4	4.7	4.3	2.4	2.7	3.6	4.8	6.5	7.3	5.0
23	7.0	6.2	5.3	5.2	4.5	4.0	2.3	2.6	3.4	4.6	6.7	7.2	4.9
Avg	7.6	6.9	6.2	6.1	5.5	4.9	2.7	3.1	4.0	5.5	7.0	7.8	5.6

FIGURE 14. Average, Greatest, and Least Daily Solar Radiation Totals (1953 - 1970)
Source: Stone et al. (1972)

approximate number of persons living within an 80-km radius of the 300 Area was 160,000. The major population centers are located in urban areas including the cities of Kennewick, Pasco, Richland, Prosser, Grandview, Sunnyside, Toppenish and Walla Walla within Washington State and Hermiston and Umatilla within the State of Oregon. The distribution of the larger cities among the aforementioned is typically close to the Hanford Site and, more specifically, close to the 300 Area. Population centers tend to occur along the Yakima River to the west of the Site and along the Columbia River to the south. The remaining areas tend to be rural with a relatively low population density. Figure 15 indicates the estimated population distribution with respect to radial distance away from the Hanford 300 Area.

FIGURE 15. Estimated Geographic Distribution of the 1973 Population
Source: ERDA (1975)

Within the boundaries of Hanford Site, two major uses of the land occur. The primary use is industrial, which includes nuclear facilities such as fuels processing and fabrication, reactor development, reactor electrical power generation, reactor waste processing and reactor waste disposal. The secondary use is recreational in that the northern section of the area, north and northeast of the Columbia River, is used as wildlife refuge by the Bureau of Sports Fisheries and Wildlife. Another use of the Site includes preservation of a specific sector to the west and southwest which has been dedicated to an ecological reserve used for scientific research purposes. Outside the boundaries radially, the use of land is primarily for dryland and irrigated agricultural purposes. Adjacent to the Site on the north and east, irrigated agriculture as part of the Columbia Basin Irrigation Project prevails. The southern octants are dominated by dryland agriculture and to a lesser degree irrigated agriculture and light industrial use. The western octants contain dryland and lesser amounts of irrigated agricultural areas.

ECOLOGY

The Hanford Site is climatologically classified as a shrub-steppe desert. Other classifications have likewise categorized the area as a cool desert, a mid-latitude desert, or a winter wet cool steppe. Both terrestrial and aquatic systems prevail.

The terrestrial system consists of shrub-steppe plant communities. The main communities, based on areal extent, are the sagebrush/cheatgrass association and the sagebrush-bitterbrush/cheatgrass association. The sagebrush/cheatgrass vegetation type occupies the western portion of the site. Recovery of this vegetation type after physical disturbance of the soil surface or by fire is presumably very slow and invasion of these disturbed sites by deep-rooted plants, e.g., tumbleweed and cheatgrass results. The sagebrush-bitterbrush/cheatgrass vegetation type occupies the eastern portion. Recovery of this vegetation type by the above identified mechanisms is also slow. After disturbance within these vegetation types, tumbleweed and cheatgrass also are the primary plant species to invade. In addition, these disturbed sites are prone to erosion by wind. In areas where the soils have been disturbed by

agricultural tillage greater than 30 years ago, cheatgrass is the predominant species. Tumbleweed occurs in these areas where soil texture is dominated by heterogeneous coarse mineral fractions.

Areas mainly composed of cheatgrass typically produce in the range of 75 to 130 g m^{-2} year of surficial herbaceous biomass. Of the surficial material, approximately 8% by weight of the plant litter is decomposed each year; in other words, the biological half-life is on the order of 6 years. The decomposed material and associated nutrients and other elements typically re-enter the nutrient cycle within the plant association.

Animals indigenous to desert ecosystems are found over most of the Site. In addition, animal species associated with fluvial systems are also found in and near the Columbia River. Deer, rabbit, raccoon, coyote, porcupine, beaver, muskrat, mice, and gophers constitute most of the mammalian population. Avian species typically include partridge, pheasant, goose, duck hawk, eagle, falcon, meadow lark, magpie and crow. Of these many are somewhat transitory and do not reside within the Hanford boundary for extended time periods. Numerous species of insects inhabit the Site with the order Coleoptera (beetles) the most abundant. The majority of insect populations occupy near-surface or below-ground habitats. Also, numerous reptile species, including lizards and snakes, occupy nearly the same habitat.

The fluvial system within and about the littoral zone of the Columbia River constitutes a habitat for a variety of aquatic organisms. Phytoplankton make up from approximately 2 to 0.1 g m^{-3} dry weight biomass relative to summer and winter seasons, respectively. Periphyton constitutes the only other major algal type populations. Benthic organisms are relatively numerous with total biomass of the order of 15 g m^{-2} wet weight. Numerous species of sport fish and coarse fish also inhabit the Columbia River near the Site. Anadromous salmon and steelhead, whitefish, sturgeon, and bass serve as a food source from this reach of river.

The transfer of native and riparian organisms in the form of human food ingestion on or from the Hanford Site is minimal. A few individual species controlled by wildlife and fisheries agencies are ingested. Shrub-steppe ecosystems provide little food typically used for human consumption. However, if the ecosystem is modified by irrigation and other riparian practices, these areas may become productive as a nutrient source and contaminants may be incorporated and transferred through primary and secondary food webs to human populations.

BURIAL SITE DESCRIPTIONS, OPERATIONS, AND INVENTORIES

The 300 Area Burial Grounds are located in the southeast sector of the Hanford Site directly north of the City of Richland, Washington. Figure 16 illustrates the location of Burial Grounds 1 through 8 in relation to the 300 Area boundaries and structures, and Figure 17 shows the location of the 300 North and 300 Wye Burial Grounds. Physiographic boundaries of the burial sites include: 1) the Yakima River to the south and west, 2) the Columbia River to the east and north, and 3) the Rattlesnake Hills to the west.

The legal description of the burial grounds is as follows:

<u>Burial Ground Alpha or Numeric Descriptor</u>	<u>Legal Description of Approximate Burial Sites</u>
300 - 1 (618 - 1)(a)	NE 1/4, NW 1/4, NW 1/4, Section 11, T 10 N, R 28 E.
300 - 2-3 (618 - 2,3)	SE 1/4, SW 1/4, SW 1/4, Section 12, T 10 N, R 28 E.
300 - 4 (618 - 4)	NE 1/4, NW 1/4, SW 1/4, Section 12, T 10 N, R 28 E.
300 - 5 (618 - 5)	SW 1/4, NE 1/4, SW 1/4, Section 12, T 10 N, R 28 E.
300 - 7 (618 - 7)	NW 1/4, SE 1/4, SW 1/4, Section 3, T 10 N, R 28 E.
300 - 8 (618 - 8)	NW 1/4, NW 1/4, NW 1/4, Section 11, T 10 N, R 28 E.
300 - West (618 - 9)	SE 1/4, SE 1/4, SW 1/4, Section 3, T 10 N, R 28 E.
300 - North (618 - 10)	SE 1/4, SE 1/4, SW 1/4, Section 21, T 10 N, R 27 E.
3 - Crib	SE 1/4, SE 1/4, SW 1/4, Section 21, T 10 N, R 27 E.
300 - Wye (618 - 11)	NW 1/4, NW 1/4, NW 1/4, Section 5, T 11 N, R 27 E.

(a) Numbers in parentheses are currently used to designate the 300 Area Burial Grounds. The numbers 300 - 1 through 5, 7, 8, and West, North, and Wye were used until 1979.

FIGURE 16. Locations of Burial Grounds 1 through 8

FIGURE 17. Location of the 300 North and Wye Burial Grounds

BURIAL GROUND LOCATIONS

Burial Ground 1 is located in the northeast sector of the 300 Area directly within the 300 Area perimeter exclusion fence. It is adjacent to the 333 Building to the west and approximately 15 m from the 306 Building to the south. To the east at an approximate distance of 60 m are located two large sanitary waste leaching trenches and at approximately 190 m in the same octant is the Columbia River. The burial site consists of (as recorded) three trenches approximately 5 m wide by 45 m in length by 5 m in depth. The orientation of the trenches is east-west in the longest dimension. The burial trenches were covered by approximately 1.2 m of overburden material. The burial site areal extent is approximately $1.5 \times 10^4 \text{ m}^2$. The site is bounded by radiation monuments.

Burial Grounds 2 and 3 are located next to the 300 Area on the northeastern boundary adjacent to the area perimeter exclusion fence. These separate burial grounds are located within the same exclusion area, and therefore are treated as one site. The burial site contains five trenches of unknown dimensions, four trenches within Burial Ground 2 and one trench within Burial Ground 3. The orientation of these trenches is north to south with respect to the long dimension of the trenches. These burial trenches were covered with an unknown depth of overburden when they were discontinued from service. The areal extent of both burial grounds is approximately $4.1 \times 10^4 \text{ m}^2$. The site is bounded by radiation monuments and a perimeter fence. During the construction of this fence, contaminated waste was encountered outside of radiation monuments. Subsequently, the burial site perimeter fence was moved in a lateral dimension approximately 5 m to the north so as to enclose the site and discourage inadvertent intrusion. This site is bounded on the south at a distance of approximately 20 m by the 333 Building and Burial Ground 1.

Burial Ground 4 is located approximately 300 m north of the 300 Area perimeter fence. To the southeast of the site at a distance of approximately 100 m is Burial Ground 5 and east of this site is the Columbia River at approximately 90 m distance. Burial Ground 4 consists of one trench oriented

with its longest dimension in a northeastern-southwestern direction, of unknown size and depth and depth of overburden. The areal extent of the site covers approximately $3.8 \times 10^3 \text{ m}^2$. The site is bounded by radiation monuments and a perimeter fence.

Burial Ground 5 is located north-northwest of the 300 Area at an approximate distance of 210 m. This site consists of a facility used for burial of solid waste and aboveground pyrolytic decomposition. Burial Ground 4 is north-northwest of Burial Ground 5. Large aqueous effluent process ponds are located directly south ^{of BG #5} and to the ^{west} east of the Columbia River. Burial Ground 5 consists of one trench oriented northeast-southwest by its longest dimensions. The areal extent of this site is approximately $1.6 \times 10^4 \text{ m}^2$ consisting of one trench of unknown dimensions which was covered by approximately 0.3 m of overburden. The site is bounded by radiation monuments and a perimeter fence.

There is no burial ground in the 300 Area designated as Number 6. The 300 Area West Burial Ground, ^{and} ~~also named~~ Burial Ground 7, ^{are} ~~is~~ located approximately 330 m ^{and 200 m} directly west of the 300 Area perimeter. ¹⁵⁹⁻⁵⁷ ~~This site~~ is approximately 150 m ^{west} southwest of Burial Ground 8. The Columbia River is approximately 600 m directly to the east of ~~this burial site~~. The site consists of one trench of dimensions approximately 6 x 40 x 2.5 m with respect to width, length, and depth. The trench was covered with approximately 1.2 m of overburden material. The areal extent of this site is on the order of 900 m^2 and is bounded by radiation monuments and a perimeter exclusion fence. *Wrong*

Burial Ground 8 is located directly adjacent and to the north of the 300 Area next to the area perimeter fence. The relative location is on the order of 30 m north of the 313 Building, 50 m from Burial Grounds 2 and 3 and 275 m from the Columbia River to the east. Directly to the east approximately 120 m are the sanitary waste leaching trenches. To the northeast at a distance of approximately 60 m are aqueous process ponds which are recipients of liquid wastes from 300 Area laboratory operations. The burial site consists of an unknown number of burial trenches of unknown dimension and overburden depth. The trench orientation and that of the site with respect to the long

dimension is nominally north-south. The areal extent is approximately $1.8 \times 10^4 \text{ m}^2$. The site is bounded by radiation monuments. A parking lot was constructed over most of the site, and subsequently the radiation monuments were emplaced at grade within the parking lot area. In the northern quadrant of the site in an attempt to construct an electrical transmission structure, contamination was encountered below grade. The boundary of the site was extended northward where radiation monuments now delineate the areal extent of the site. No perimeter fence bounds this site.

The 300 North Burial Ground is located away from the 300 Area to the north-northwest at a distance of approximately 6.4 km. To the northwest of this site is the Fast Flux Test Facility, a testing and demonstration facility for the DOE Breeder Reactor Program. To the north and northwest of the site is the Washington Public Power Supply System commercial electrical power production reactor complex at an approximate distance of 5 km. The Columbia River is to the east at a distance of about 3.5 km. The site consists of 12 burial trenches, the dimensions of the largest trench being on the order of $100 \times 25 \times 8 \text{ m}$ with respect to length, width, and depth. Small trenches and pits also exist with dimensions approximating $15 \times 5 \times 8 \text{ m}$.

In addition to trench structures at this site, vertical bottomless disposal caissons of approximately $0.75 \times 4.5 \text{ m}$ in diameter and length, respectively, were buried below grade. The areas in the center of the site and in the southwest section of the site were used for these burial structures. Eighty-nine of these individual burial structures exist within the 300 North Burial Ground. Most of the burial trenches are oriented northeast-southwest with respect to their longest dimension; the center vertical caisson array is oriented northwest-southeast; and the southeastern caisson array is nominally oriented east-northeast west-southwest also with respect to the longest dimension of the array. Burial structures were covered to a depth of 0.8 m with overburden. The site areal extent is approximately $8.1 \times 10^4 \text{ m}^2$. The site is bounded by radiation monuments and a perimeter exclusion fence.

The 316-4 Crib, used for aqueous waste disposal, is located adjacent to the 300 North Burial Ground. This site consists of a bottomless stainless steel tank approximately 6 m in diameter buried below grade to a depth of approximately 7.5 m. Stainless steel ventilation risers and waste influent risers extend from this tank upward to grade where they are exposed. Depth below grade to the top of the bank is on the order of 1.2 m. A discharge line extends from below grade northward to within approximately 3 m of the 300 North Burial Ground. The areal extent of this site is approximated at 121 m^2 . Radiation monuments are located around the influent and ventilation risers. No perimeter exclusion fence encloses this site.

The 300 Wye Burial Ground is also located at approximately 13 km in a northwesterly direction away from the 300 Area. Directly to the east of this site is the Washington Public Power Supply system power reactor complex which presently includes two reactors under construction and associated peripheral facilities. As part of this complex to the southeast of the 300 Wye Burial Ground is a research agricultural complex and reactor intake structures and reactor waste heat dissipation structures. Directly south of the site near the site boundary is a meteorological station. The Columbia River is located approximately 5.5 km to the east. The Wye Burial Ground consists of three burial trenches approximately 270 m in length, 15 m wide and 5.5 m deep. The trenches are oriented east-northeast with respect to their long dimension. To the north of these trenches within the Wye site is located an array of 50 disposal caissons such as those discussed under the 300 North Burial Ground. In addition, four large caisson structures, 2.5 m in diameter by 3 m in height, with offset riser structures are located to the west adjacent to the aforementioned caissons. These disposal caissons were installed below grade to an approximate depth of about 4.5 m. The areal extent of the site covers approximately $3.4 \times 10^4 \text{ m}^2$ and is bounded by radiation monuments and a perimeter exclusion fence.

OPERATIONS

Radioactive waste has been produced from the laboratory and engineering development area (300 Area) beginning soon after initiation of operations of the Hanford Site in 1943. From 1944 to present, radioactive waste has been produced in the 300 Area from a number of facilities including nuclear fuels fabrication operations, radioactive chemical separations development and pilot operations, nuclear reactor development and testing operations, and general biological chemical and physical laboratory operations. Radioactive waste or waste material suspected of containing radiocontaminants were disposed to 300 Area Burial Grounds (Burial Grounds 1-5, 7, 8, North and Wye) from 1944 to 1968 when a decision was made to dispose all radioactive waste generated from the 300 Area ^{Laboratory} to within the chemical separations areas (200 Areas).

The decision for redirecting the disposal location from 300 to 200 Area Burial Grounds was primarily based on geohydrological factors (Backman et al., 1963). For example, the 200 Areas were thought to be advantageous for waste burial in that the depth to the water table was sufficient to exclude the possibility of leaching; precipitation in the 200 Areas had not been shown to leach contaminants to the water table; and the ion exchange properties of the buried sediments were approximately high enough so that radiocontaminants would be adsorbed before entering the biosphere. The converse was thought to be true for the 300 Areas relative to burial inventory and waste type at each burial ground. Therefore, 300 Area Burial Ground operations were terminated and the burial sites were retired. Surface maintenance and backfilling of overburden over buried waste trenches was completed at or after the time of retirement of each site. Radiological monitoring of some of these sites was conducted on an infrequent basis from the date of retirement until routine monitoring of the Hanford Site was established.

Categories of Activity

The radiocontaminated waste material disposed to the 300 Area Burial Grounds was categorized and disposed by different techniques based on the activity of the waste material (McCormack, undated). The techniques used to dispose waste were based on radiological exposure potentially encountered from

the waste. Waste materials at the time of generation from laboratory or engineering investigations or decontamination of contaminated facilities were classified as low, intermediate, or high activity.

Radiation levels for low-activity waste generally varied from approximately 0.005 to 0.05 R hr⁻¹ at a distance of 0.3 m from the waste. Low-activity material, consisting of a variety of by-product material and contaminated scrap and decontamination material, was collected at each waste generating facility. Low-activity waste handling was performed based on the size and composition of the disposed material. Small contaminated material was collected in cellulose cartons approximately 0.5 m³ in volume. These cartons were posted with radiation symbols. When liquid materials, such as decontamination solvents, were incorporated into the waste material, liners of polyethylene were often utilized within the disposal cartons. A steel shield approximately 2.5 cm in thickness was often used to surround the cartoned waste to reduce potential dose. The steel shield was removed prior to disposal. Low-activity waste cartons were stored in large waste receptacles such as detachable dump truck carriers while awaiting transport to a respective disposal site. Large-volume contaminated material, e.g., building rubble and solid laboratory equipment too large to process to be efficiently disposed in cellulose cartons, was put in large waste receptacles to await transport to an operating burial or burning site. Some materials such as contaminated small radiometallurgical scrap were placed directly in transport receptacles without containerization and were disposed in the same manner as large-sized low-activity waste.

Low-activity liquid and some solid or partially solidified radiocontaminated waste materials were collected in laboratory or engineering development facilities in 208-l steel drums. For example, drummed solvent that was used in nuclear reprocessing chemical process development and contaminated with uranium was disposed in relatively large volumes within waste burial trenches. These steel drums, after receiving sufficient volumes of waste materials to fill them or ~~at such time as the radiological dose was prohibitive~~, were sealed and stored awaiting transport to burial sites. *the 300-l drums in the trench.*

Only low activity waste

An additional mode of disposal used for low-activity liquid waste, such as radiocontaminated process water or extraction solvents, was to directly discharge waste to tank trucks. Tank trucks were placed at a facility producing liquid effluent until the capacity of the truck was reached, and at that time effluent discharge was terminated or another tank truck was used until its capacity was reached. Tank trucks were then driven to liquid effluent disposal sites, such as the 316-4 Crib.

Intermediate and high activity waste

Radiation levels much higher than 0.05 R hr^{-1} were, however, occasionally experienced. Therefore, a distinction between proportionately low, intermediate and high levels of activity was not made, and occasionally intermediate- and high-activity materials were disposed by operations equivalent to those utilized for low-activity waste.

The criterion for intermediate waste was activity levels effectively reduced to tolerable exposure by radiation workers by 0.1 m of lead. Large volumes of intermediate-activity waste were disposed to the 300 North and 300 Wye Burial Grounds. Some intermediate-activity waste was disposed commensurate with that discussed under low-activity waste. Intermediate-activity liquid waste disposed to the 300 North and 300 Wye Burial Grounds, however, was uniquely discharged. Typically, waste generated from radiometallurgical facilities was remotely disposed in expendable 6-l aluminum drums with length, diameter, and wall thickness dimensions of 0.18, 0.25, and $6.3 \times 10^{-4} \text{ m}$, respectively. These drums were placed inside a polyethylene bag prior to receiving waste in order to assist in preventing contamination of the outside of the drum. Radioactive liquids such as solvents were placed in polyethylene bags or small stainless steel containers and then placed in the 6-l drums. Solid or partially solidified materials were directly placed in the drums. As the drums became nearly full or the radiation exposure became limiting, the drums were often filled with a gelatinous material of unknown composition. This gel was thought to effectively trap particulate matter in the drum and reduce the potential for drum failure and subsequent contamination of facilities.

After filling, sealing, and removing the exterior polyethylene covering, each 6-l drum was remotely placed in a transport cask. This cask is illustrated in Figure 18. The cask was constructed primarily of lead and steel to

FIGURE 18. 6-l Cask for Transport of Liquid Waste to the 300 North and 300 Wye Burial Facilities

provide shielding and handling. A locking mechanism was used to secure two 6- ℓ drums into place inside the center of the cask for transport on a truck to either the 300 North or 300 Wye Burial Grounds.

Radiation levels of 0.005 to 0.2 R hr⁻¹ at 0.3 m distance away from the loaded transport cask were typical. However, higher activity was occasionally found.

Where radioactive waste was not effectively reduced to relatively appropriate exposure limits by 0.1 m of lead, it was considered high activity. High-activity waste was then shielded with greater thickness of lead. High-level waste was in some instances disposed in unknown concentrations to waste trenches encased in concrete of unknown dimension. For the most part, however, handling of high-level waste was conducted using a technique similar to that used for intermediate waste. High activity liquid, solid, and partially solidified wastes were typically remotely placed in 1- ℓ drums and mechanically sealed. The drums were then remotely placed in a transport cask specifically designed to accommodate 121 1- ℓ drums. This cask is illustrated in Figure 19. The cask was constructed of a lead core of shielding with a minimum thickness of 0.25 m and an outer layer of steel. Interior to the shielding was a rotating chamber where 1- ℓ drums were placed. The drums were loaded from the top of the cask and at the time of burial discharged through the bottom of the cask. The cask was transported on a truck to either the 300 North or 300 Wye Burial Grounds.

No information exists concerning the external exposure of these waste materials; however, radiation levels at 0.3 m distance away from the cask exceeding 0.2 R hr⁻¹ are thought to be reasonable.

Burial Techniques

Radioactive waste generated within the 300 Area was disposed to the ground by several waste discharge or burial techniques. The disposal of radioactive waste from the 300 Area became more sophisticated, and increasing burial efficiency and safety were realized throughout burial operations from 1944 until all 300 Area Burial Grounds were retired in 1973.

FIGURE 19. Transport Cask for 121 1-ℓ Drums

Trench burial, the primary burial technique employed, affects the largest volume of radioactive waste in the 300 Area Burial Grounds. The typical burial trench structure was constructed by excavating soil and sediment materials

with a dragline and bulldozer to form a trench. This trench was excavated to a depth probably not exceeding 7 m below grade. The width of each trench nominally exceeded the depth by a factor of about 2 because of the angle of repose of the geological material at the 300 Area Burial Ground sites. The length of each trench is on the order of tens of meters to lengths probably not exceeding 300 m.

The material excavated from each trench was typically placed adjacent to the excavation in a parallel configuration to the trench in the form of a pile by the dragline. The spoils pile covered basically the same surficial area as that area excavated for the trench. Thus, where several trenches were located in one burial ground, the spacing of subsequent burial trenches was controlled by the amount of material excavated from the original trench. The typical configuration of burial trenches is illustrated in Figure 20. Several other burial trench designs were used; however, these alternative trench designs varied from the design discussed above only by an increased width to depth ratio.

After excavation, waste was transported to the trench by dumptruck which reached the burial trench by a road constructed within the excavation or by a road constructed on top of previously buried material. Figure 21 illustrates a dimensional projection of waste discharge into a burial trench. Waste materials in various forms were dumped in a random fashion from the truck into the trench floor until the trench volume at the discharge site was reached or at such time as operational standards dictated backfilling. Backfilling of previously excavated geologic materials was accomplished by blading the material in the spoils pile adjacent to the discharge point down and onto the waste. This backfilling operation was continued until the waste was covered with a layer of spoils material. Discharge of waste from trucks and successive backfilling then continued over the length of the trench until the volume of the excavation was filled with waste materials and interlayered backfill material.

The next operational step employed was surficial treatment of the filled trench. This was accomplished by blading the trench with a bulldozer which often compacted the waste to a limited degree. Blading of the surface of the

FIGURE 20. Typical Configuration of Burial Trenches

FIGURE 21. Waste Discharge into Burial Trench

filled trench also included providing top backfilling of the trench with a layer of uncontaminated geologic material. This top backfill was provided to reduce direct exposure from the buried waste and to prevent intrusion and airborne dissemination of the waste materials and the geologic material that was contaminated during burial.

In some instances after the top backfill material was bladed and leveled over the filled trench, a trench cap was then laid over the top backfill material. The trench cap typically consisted of a relatively thin veneer of coarse aggregate derived from gravel quarries which exist in the vicinity of the 300 Area. This trench cap material was provided to further reduce exposure and airborne dissemination. It is not presently apparent that a trench cap of coarse aggregate covers all burial trenches at each site.

Intermediate- and high-activity wastes were directly disposed to burial trenches in some cases. However, after 1954 most intermediate- and high-activity wastes were buried in engineered structures in either the 300 North or 300 Wye Burial Grounds. Figures 22 and 23 illustrate the configuration of these buried structures. Figure 22 shows one buried caisson consisting of five 208-L drums which were welded together and their tops and bottoms removed. These structures were installed in an excavation approximately 5 m in depth below the original ground surface. This excavation was, in most cases, equivalent to that used for trench disposal, except the caissons were set in the bottom of the trenches along the longest dimension and backfilled with spoils material to grade before waste disposal operations commenced. Thus, open caissons were exposed at the ground surface.

A specially designed truck containing intermediate- and high-activity waste in transport casks disposed drummed waste into the caisson. Figure 24 illustrates a truck waste discharge operation. The truck, consisting of a shielded operator housing and a trailer with parts installed through its bed over which a cask was set, was then positioned over a caisson and the operator remotely activated discharge of drummed waste from the cask directly into the caisson. Repeated discharge of drummed waste was continued until such time as one of the following criteria was met: 1) dose at ground level reached a pre-determined operational level; 2) the caisson was full; or 3) particulate or

FIGURE 22. Intermediate- and High-Activity Disposal Structure Using 208-L Drums in Vertical Configuration

FIGURE 23. Intermediate- and High-Activity Disposal Structure Using Large Vertical Caisson

FIGURE 24. Truck Waste Discharge Operation

liquid contaminants were found outside the top of the caisson (a result of falling drums breaking and rupturing the contents). When one of the above criteria was met the caisson was capped with a concrete plug. The subsequent operations of blading and backfilling were conducted commensurate with those discussed under trench operations.

Another caisson disposal approach was initiated in about 1964 in the 300 Wye Burial Grounds (Figure 23). This disposal caisson design was used because direct radiation exposure from the vertical welded drum caissons often exceeded operating limits. This design basically consisted of a bottomless corrugated steel culvert 3 m in diameter by 3 m high installed below grade to a depth of approximately 7 m. The caisson was set on concrete footings around its lower perimeter and the top of the caisson was fitted with a concrete slab through which a steel riser pipe was installed. The riser pipe was designed such that an offset of 30° from the vertical was provided which resulted in the ground discharge opening being about 3.5 m offset from the center of the buried caisson. This offset allowed the discharged drummed waste to fall into the buried caisson at a depth of between 4.5 and 7 m so that the overlying spoils backfill material attenuated most of the direct radiation from the discharged drum. Disposal of waste into these structures by specially designed trucks was performed in much the same manner as that discussed under disposal into vertical caissons. Surficial treatment of the land surface and backfilling was conducted in the same manner as vertical emission disposal.

Radiation monuments were installed peripheral to the burial trenches immediately after burial or at a later date depending on the operational directive in effect at the time of burial. These radiation monuments were provided to delineate the areal extent of belowgrade contamination at each burial, although in isolated cases these monuments did not mark the limit of contamination.

The typical radiation monument consisted of a concrete pillar approximately 1.5 m in height and 0.3 m in diameter. The tops of the monuments were fitted with stamped brass radiation hazard markers which included topographical coordinates. These monuments were installed partially below grade to a depth of 1 m. In some instances, e.g., the 300 Wye Burial Ground, the monuments

were connected by cables which were tagged with radiation symbols. This monument and cable structure enclosed the burial site to some degree to provide warning and discourage inadvertent intrusion into the buried waste.

Perimeter fences were constructed around some burial sites, Burial Grounds 1 and 2, for example, during early operations in the 300 Area. Perimeter fences around all 300 Area burial sites were not installed until about 1975 when restrictions on public access to the Hanford Site were somewhat relaxed. The purpose of the perimeter fences fitted with radiation symbols was to preclude or minimize the chance for inadvertent exposure or intrusion. Perimeter fences also prevent large browsing animals from inhabiting burial sites.

BURIAL SITE INVENTORY

Because record keeping was not required, detailed information is not available on radionuclide inventory in the 300 Area Burial Grounds. The information that is available was obtained from such sources as interoffice memoranda, letters, and process engineering reports. *and indicated as a lab waste.*

The disposed waste form generally consisted of laboratory refuse, including laboratory decontamination fibrous and celluloid material, glassware, metallic material, and other failed equipment and contaminated structural scrap. The waste was for the most part of solid phase; however, substantial amounts of aqueous and partially solidified liquid waste was generated from the 300 Area and disposed in 300 Area Burial Ground trenches. As previously discussed, solid contaminated waste was put in cellulose cartons or wooden boxes, while large solid material, such as contaminated building rubble, was disposed directly to trenches. Aqueous waste material was treated by additions of gelatinous material and put in closed metallic cartons. The metallic cartons were sealed and disposed in buried vertical caissons within the 300 North and Wye Burial Grounds. In general, the waste materials disposed to all 300 Area Burial Grounds can be considered as a mixture of high-level, transuranic, and other waste. Historical records are available which suggest

this mixture; however, the paucity of data on waste type, quantity and activity is noted. Large amounts of untreated contaminated aqueous process wastes were also injected into crib structures.

Radiocontaminated waste disposed to Burial Ground 1 consisted primarily of dry uranium, plutonium and fission products of unknown concentrations and quantities. Because no historical records were kept, evaluation of elemental and isotopic concentrations, waste form, packaging, etc., cannot be made.

Burial Ground 2 was used for disposal of uranium-contaminated equipment and materials, plutonium, and fission products. The uranium waste was typically solid metallic uranium oxides in the form of metal cuttings from reactor fuel fabrication facilities in the 300 Area. Historical records for this site are also inadequate for prediction of contaminant form and quantity.

Burial Ground 3 was primarily used for disposal of uranium waste in the form of contaminated building material derived from the 313 Building. Burial Ground 4 was also principally used for disposal of uranium-contaminated miscellaneous materials. Again, the contaminant form and quantity are unknown.

Burial Ground 5, in general, contains uranium-contaminated material including 17% aluminosilicate solid material and metallic crucibles with activity levels less than 200 mrad/hr. Pyrolitic and other combustible material was disposed to this site and periodically burned. This material was often contaminated with uranium. Surface contamination within the burial site at the time of retirement was less than 1 mrad/hr.

^{300 West}
1 Burial Ground ~~5~~ contains contamination in the form of drummed (208-l containers) solvent with moderate amounts of uranium. This material was segregated and disposed in this burial site because of the pyrolitic and explosive hazard of the solvent. Materials buried at this site were derived primarily from the 321 Building between 1955 and 1956. The quantity of radiocontaminants and the radioactivity are unknown.

Burial Ground 8 was used mainly for disposal of dry solid waste derived from reactor fuels manufacturing. The principal contaminant was uranium in the form of metallic cuttings from the fabrication of fuel pins. The quantity of uranium waste and other contaminants is unknown. The 300 West burial site

was used only for the disposal of uranium-contaminated uranyl nitrate hexahydrate (UNH) and methyl isobutyl ketone (hexone). This contaminated solvent was put in 208-l drums. The quantity of liquid buried is approximately 1.9×10^4 l; however, the uranium concentration is unknown.

The 300 North Burial Ground received solid, partially solidified, and liquid waste from the 300 Area. Trench areas were used for containerized and loose, noncontainerized dry solid waste, whereas vertical caissons were primarily used for nonsolid waste. Typically, low- to moderate-activity beta-gamma waste was put in trenches and moderate- to high-activity beta-gamma waste was disposed in caissons. This burial site was chiefly used for fission product disposal; however, significant amounts of plutonium were also disposed here. In addition to radiocontaminants, quantities of nonradioactive beryllium wastes were disposed. The quantity and activity of wastes at this site is not well known; however, historical records have suggested that on the order of 2000 Ci of beta-gamma wastes and 1 kg of plutonium were disposed at this site.

The 300 Wye Burial Ground received much the same waste and of the same waste form as that of the 300 North Site. Low- to moderate-activity dry solid wastes were disposed to trenches and moderate- to high-activity partially solidified and liquid materials were disposed in caissons. The radiocontaminant inventory consisted of a preponderance of fission products and transuranics. Historical records suggest that on the order of thousands of curies of beta-gamma waste and on the order of kilograms of plutonium were buried at this site.

In order to accurately inventory the type and quantity of radionuclides and other contaminants within the 300 Area Burial Grounds, a substantial sample collection and analysis effort would be required. Because it is known that an extreme variety of contaminated wastes in various waste forms were disposed to these burial sites, a sample collection effort of stochastic validity would require exhumation of a substantial quantity of waste. The exhumation of this waste may result in significant hazard to occupational workers. Additionally, the cost of exhumation of contaminated samples is thought to be prohibitive. Thus, it was decided that, for the 300 Area Burial Grounds, an

assessment and quantitative evaluation of the migration of radiocontaminants from burial structures would provide information far more useful than site inventory. Techniques and results of this evaluation are detailed in the following sections.

GEOHYDROLOGY OF HANFORD 300 AREA BURIAL SITES

Understanding the geohydrologic system is crucial to assessing radionuclide migration and subsequently choosing disposition alternatives. The geohydrologic system underlying the 300 Area Burial Grounds consists of the geologic material from the ground surface downward through unconsolidated media and into underlying consolidated formations.

The water table below the 300 Area waste burial sites is found in the unconsolidated Pasco Gravels. The Ringold Formation underlies these materials below the waste burial sites and the water table breaches this formation in the proximity of the Columbia River. Figure 25 illustrates the location at the 300 Area Burial Grounds within the south section of the Hanford Site. Included in this illustration are wells from which stratigraphic information was interpreted by evaluation of surface trench technology, drilling data and geophysical logs. Cross sections are also shown. Major topographic and physical features are shown for purposes of orientation. Figures 26 through 31 are cross-sectional projections of the stratigraphic configurations occurring below the 300 Area Burial Grounds.

A number of test wells were drilled in the Hanford 300 Area Burial Grounds to evaluate the possibility of migration of waste from trenches and caissons. Data derived from these test wells also were used in evaluating lithology of the burial sites. Drilling techniques and results are discussed in the Technology Development and Characterization Section of this report.

300 NORTH BURIAL GROUND

Figure 26 is a nearly east-west section from directly southeast of the 300 North Burial Ground to near the Columbia River (A-A') covering a lateral distance on the order of 3 km. A thin veneer of aeolian silty sand typically isotropic and homogeneous in texture extends downward from the ground surface to an approximate mean depth of 2 m. The mean grain size of this material ranges from fine to medium sand depending on sample location. The thickness

FIGURE 25. General Location of Burial Grounds (Burial Grounds 1-5, 8 and West are located near the F-F', G-G' Sections of the map)

FIGURE 26. Stratigraphic Section Near the 300 North Burial Ground, East-West (see Figure 25 for location of section)

of the surficial material decreases from A to A' somewhat proportional to the distance from the burial site to the river. The thickness of this material is, however, locally a function of ridge height of partially stabilized dunes. These dunes are expressed as longitudinal topographic features typically oriented in this area in a nearly east-west direction.

The topographic relief of these features ranges from less than 1 m to a maximum of approximately 5 m from trough to crest. The burial disposal structures, trenches, caissons, and a liquid waste crib, located at or near the 300 North Burial Ground are incised into the aeolian sands and gravels. The depth of excavation for these structures usually does not exceed 7 m; thus, the disposal structure excavations extend through the surficial material and to a limited depth into the upper portion of the underlying material. Therefore, the geologic material backfilled in and around these structures is probably a heterogeneous mixture of aeolian silty sand and sandy gravel. Below this material from depth of a range of about 3 m to 30 m are the Pasco Gravels.

The Pasco Gravels consist of interbedded, nonindurated, anisotropic, heterogeneous sands and gravels of Pleistocene glaciofluvial and lacustrine origin. Grain size of this material ranges from fine to coarse sand. Coarse-grained material of gravel size occurring typically in a coarse sand are found in beds, stringers and lenses throughout this stratigraphic unit. The range of particle size is varied with respect to depth and location. Large imbricated boulders and gravels indicative of fluvial deposition are directly overlain by fine-grained material of probable lacustrine deposition. Graded bedding is apparent in a few locations where lenses of coarse material anisotropically grade to finer materials in a vertically upward direction. This trend is indicative of quiescent fluvial deposition, a resurgence of fluvial degradation, and subsequent deposition and relative quiescence occurring in a cyclic manner. Lithologic discontinuity of bedding features between wells of limited lateral distance on the order of tens of meters demonstrates the variability of deposition in this area.

The water table occurs below the 300 North Burial Ground at a depth of approximately 20 m from the ground surface. The vertical distance between the maximum depths of waste disposal structures (trench bottoms) at 7 m to the water table is then approximately 13 m. The water-table elevation in this area is nominally 114 m MSL extending in an east by southeast direction to the Columbia River at a gradient of approximately $2.2 \times 10^{-3} \text{ m m}^{-1}$. The water table from the 300 North Burial Ground eastward to the Columbia River extends wholly within the Pasco Gravels. A marker bed of white sand extends in a somewhat continuous mode below the 300 North Burial Ground occurring at a depth of approximately 30 m. However, this bed is not continuous laterally over an extended areal distance insomuch as well logs taken on the order of 21 m away from this site show no evidence of this bed. The contact between the interbedded Pasco Gravels and the Ringold Formation occurs at this site at approximately 36 m below the ground surface, 100 m MSL. The Pasco Gravels are distinguished from the Ringold Formation materials by the predominance of basaltic materials in the sand and larger grain sized fractions of the Pasco Gravels.

The Pasco Gravels are also typically less chemically altered than the Ringold Formation sediments. The saturated groundwater domain within the unconfined aquifer below and downgradient from the 300 North burial site thus exists within the Pasco Gravels and the Ringold Formation. The flux of water and contaminants is from nearly west to east downgradient to the Columbia River. The saturated groundwater system is monitored from wells with designations S6-E4 in the site proximity and wells S6-E14, S3-E12 and S11-E12 downgradient from the site (Figure 27). Figure 27 is another cross-sectional projection of the lithology below the 300 North Burial Ground interpreted from log data from well sections that extend nearly north to south. Figure 28 is a similar projection of lithology with a northwest-southeast extension.

300 WYE BURIAL GROUND

The 300 Wye Burial Ground geohydrologic system is somewhat similar to that found at the 300 North site because the depositional processes occurring are similar. From Figure 27, which illustrates the location of waste burial

FIGURE 27. Stratigraphic Section Near the 300 North Burial Ground, North-South (see Figure 25 for location of section)

FIGURE 28. Stratigraphic Section Near the 300 North Burial Ground, Northeast-Southeast (see Figure 25 for location of section)

sites and associated natural and engineered facilities, lithologic sections D-D' (Figure 29) and E-E' (Figure 30) are identified in the proximity of the 300 Wye Burial Ground. Figure 29 is an illustration of the near-ground surface stratigraphy below the 300 Wye waste disposal site and that area extending southeastward approximately 5 km to the Columbia River and northwest approximately the same lateral distance. Aeolian silts and sands mantle the ground surface in this area to depths of from less than 1 m to several meters. This material occurs in the form of longitudinal dunes with a nearly west to east trend indicative of wind direction in this area. These dunes are typically partially stabilized by a sparse growth of vegetation. At the boundaries of the 300 Wye Burial Ground the thickness of this material is approximately 1.5 m. Burial structures were emplaced within excavations made through the aeolian sands and gravel material and into underlying lithologic materials. The material used as backfill around these site burial structures then is presumably a heterogeneous admixture of aeolian silts and sands and underlying glaciofluvial sedimentary material.

Aeolian silty sands in this area are underlain by the Pasco Gravels. The mean grain size of this material through Section E-E' grades as follows: medium to coarse sand to cobbles in the northwest octant, then coarse sand and gravels to coarse sand and cobbles to the southeast. Thus, the material decreases in texture from relatively fine-grained materials to the west to very coarse-grained materials to the east. This change in texture indicates a more active aggradational/depositional mode of the Columbia River which probably migrated laterally in an eastwardly direction during deposition of this material. This same relationship is expressed in Figure 28 with an increase in texture trending in a southeasterly direction.

Graded bedding is also apparent in numerous lithologic units within the Pasco Gravels. At the base of this unit a discontinuity between the Pasco Gravels and the Ringold Formation is somewhat apparent. The cause of this discontinuity is probably a hiatus in deposition and subsequent weathering between the latter stages of deposition of the Ringold Formation and initiation of deposition of the lower Pasco Gravel beds. However, due to the textural

FIGURE 29. Stratigraphic Section Near the 300 Wye Burial Ground, North-South (see Figure 25 for location of section)

FIGURE 30. Stratigraphic Section Near the 300 Wye Burial Ground, East-West (see Figure 25 for location of section)

similarity between the lower Pasco Gravel sediments and the Ringold Formation, a distinct contact between these stratigraphic formations is not readily apparent. The surface of the saturated groundwater zone at the water table closely approximated the contact between these formations.

The water table at the 300 Wye Burial Ground occurs at a depth below ground surface of approximately 20 m 115 m MSL corresponding to an approximate mean depth below burial structure excavation of 14.5 m. The water elevation gradient from west-northwest to east-southeast over a lateral distance of approximately 5.5 km is approximately $1.6 \times 10^{-3} \text{ m m}^{-1}$. The subsequent flux of water and radiocontaminants occurs in a nearly west to east direction ultimately to the Columbia River. The unconfined aquifer consisting of the Pasco Gravels and Ringold Formation downgradient from the 300 Wye Burial Ground is monitored by wells of alpha-numerical designations WPPSS WNP-2, 11-0, 11-1, 12-1, 13-1AB, 9-E2, 4-E6, 14-E6, 10-E12, and 15-E13 (Figure 31). Figure 29 illustrates a cross-sectional stratigraphic projection running north-south D-D' from the 300 Wye Burial site to east of the Fast Flux Test Facility, a DOE breeder reactor testing facility.

BURIAL GROUNDS LOCATED WITHIN THE 300 AREA

The southeasternmost section of the Hanford Site, including the 300 Area, is also illustrated in Figure 27. A number of radioactive waste burial disposal sites including Burial Grounds 1-5, 7, 8, and West are located in or in close proximity to this area. Figure 31 shows these waste burial structures relative to other waste disposal structures and the Columbia River. The subsurface geohydrologic system below and adjacent to the 300 Area is composed of the same materials as the 300 North and 300 Wye Burial Grounds. Figure 31 illustrates cross-sectional projections F-F' and G-G' of the stratigraphy and geohydrologic system in this area. A surficial deposit of silty sand of aeolian origin in nearly all locations covers the surface and extends vertically downward to a mean depth of approximately 2.5 m. These aeolian materials occur as discussed previously in longitudinal dunes which trend nominally in a west to east direction. The textural composition of this material also approximates

FIGURE 31. Stratigraphic Section Near the 300 Area Burial Grounds 1-5, North-South and East-West, North-South, East-West (see Figure 25 for location of sections)

that previously discussed for the 300 North and 300 Wye burial sites. The Pasco Gravels also underlie this aeolian silt and sand as discussed. The Pasco Gravels, however, in the area of and adjacent to the 300 Area exhibit a significantly coarser texture.

The grain size ranges from coarse sand to cobbles to boulders, and the texture is extremely variable in its vertical section because of somewhat semi-continuous and discontinuous beds and lenses indicative of fluvial deposition. Deposition of this material by the ancestral Columbia River during Pleistocene glacial floods, i.e., two major catastrophic fluvial events, (R. E. Brown of PNL; Lindberg and Bond, 1979) is evidenced by graded beading and imbrication of coarse-textured material. The lower section of the Pasco Gravels grades from sandy gravels to sands and the upper section is predominantly sand and gravel and boulders. An erosional surface above gravel and boulder beds of the upper Pasco Gravels and the overlying silts and sands shows a discontinuous depositional erosional regime occurring in recent geological time. Burial structures, such as trenches in the burial grounds adjacent to and within the 300 Area, are incised through the aeolian silt and sand and into the upper part of the Pasco Gravels to an approximate depth of 4.5 m. Thus, the trench bottoms extend typically into the coarse textured gravels and boulders of the upper Pasco Gravels.

Below the upper Pasco Gravel layer is the lower graded Pasco Gravel unit in which the water table occurs. The water-table depth within this lower unit is nominally 15 m from the ground surface, i.e., approximately 10 m below burial trench bottoms for those trenches west of the 300 Area. For those trenches to the north and northeast of the 300 Area, the mean water-table depth is approximately 12 m with a corresponding depth between trench bottoms and water table at approximately 7 m. The water table occurs within the Ringold Formation west of the 300 Area and within the Pasco Gravels near the Columbia River. From Figure 31, Section G-G', an incised river channel filled with Pasco Gravels occurs near the Columbia River extending in a north-south direction along the channel course. The groundwater gradient in this area is typically west to east; however, the gradient and corresponding flux is dominated by

riverbank storage influenced by the stage of the Columbia River located adjacent to the east of the 300 Area. The groundwater system in this area is monitored by the 23 wells shown in Figure 25.

GROUNDWATER CONDITIONS

The geohydrologic system below the Hanford 300 Area Burial Grounds is affected by a number of natural or induced groundwater conditions. These conditions include riverbank storage, process water injection, irrigation, dam construction, and flooding.

Bank Storage Effects

The water-table elevation below burial ground sites along the Columbia River is somewhat affected by the quantity of water stored in the saturated groundwater zone above base river stage, i.e., bank storage. The water-table elevation at these sites is then a function of the river stage and the geologic media and the water-transport-controlling mechanisms occurring upgradient and downgradient from each burial site. Riverbank storage will affect the safety of burial trenches if saturated ground water inundates burial trenches during flooding. Also, trenches could be inundated from below by an increased water-table elevation caused by increased flux of water upgradient of the burial site coupled with river stage fluctuation. Effects of riverbank storage in the vicinity of the 300 Area have been reported (Raymond and Brown, 1973; Lindberg and Bond, 1979); significant changes in groundwater elevation were identified. These changes were judged to be attributable to bank storage downgradient from Burial Grounds 300 North, 300 Wye, 1 through 8, and 300 West in a lateral distance away from the Columbia River at a distance of nearly 3 km. The change of water-table elevation with respect to river stage decreases with increased distance away from the river.

The maximum discharge of the Columbia River before construction of water impoundment structures was approximately $1.9 \times 10^7 \text{ l sec}^{-1}$ and correspondingly the lowest discharge was $1.1 \times 10^5 \text{ l sec}^{-1}$ using a river discharge of 1.4×10^7 and $1.4 \times 10^6 \text{ l sec}^{-1}$ (ERDA, 1975). Since construction of impoundment structures, i.e., McNary Dam down river from the Hanford Site, the mean

discharge is nominally 4.5×10^6 to 1.0×10^6 $\ell \text{ sec}^{-1}$ for high and low stages, respectively. Using data collected from 300 Area monitoring wells for a river discharge of 1.4×10^6 $\ell \text{ sec}^{-1}$ the groundwater gradient approximates $2.4 \times 10^{-3} \text{ m m}^{-1}$ and the effect of bank storage extends to the west from the Columbia River on the order of 3000 m.

In this project, results showed that for the high discharge case, i.e., a discharge of 1.4×10^7 $\ell \text{ sec}^{-1}$, the gradient approximates $4.0 \times 10^{-4} \text{ m m}^{-1}$ and bank storage extends to a distance approximately that of the low discharge case. For example, where a hypothetical burial structure is located 1000 m from the river at an altitude MSL of 115 m and with a trench depth of 5 m below ground, i.e., 110 m, the water table will occur at depths of approximately 103 and 107 m for the low and high discharge conditions, respectively. This shows that under recorded worst case conditions the inundation of burial trenches from below by the saturated groundwater system affected by river discharge has not been realized assuming given burial structure depths. Sustained flooding of the Columbia River to a depth of in excess of 2.5 m over that recorded for the maximum average flood stage would then be required to possibly inundate burial trenches.

Process Water Injection Effects

Another factor affecting the water-table elevation is discharge of waste fluids into the ground in the proximity of burial structures. In 1976, two process water trenches were constructed north in the 300 Area (Figure 32). These trenches consist of north-south trending open trenches of approximate dimensions of 500, 16 and 7 m in length, width and depth. These trenches are recipients of approximately 2.5×10^8 ℓ of wastewater per month. As the water from these trenches permeates the underlying strata into the saturated groundwater zone, groundwater mounds or groundwater surface lobes are formed. The morphology of the groundwater surface below these wastewater trenches is then a function of the regional groundwater system and perturbations to the system by localized discharged to the unconfined aquifer.

FIGURE 32. Waste Fluid Discharge Trench Recently Constructed Upgradient from 300 Area Burial Grounds

The groundwater surface laterally away from these liquid disposal trenches is increased in elevation below adjacent waste burial grounds up to a distance exceeding 600 m (Figure 33). Directly below the wastewater discharge trenches, the groundwater table has risen on an annual cycle to a maximum elevation in July to a height greater than 2 m over that which would occur under ambient conditions. This increase in water-table elevation, however, is not singularly a function of trench wastewater discharge; it is again a coupled effect of naturally induced groundwater flux, riverbank storage effects and trench discharge flux and duration. Burial Ground 3 is located directly downgradient from this site. The water-table elevation can be expected to increase to a height on the order of 1 m above the level occurring before initiation of water discharge to the process water trenches.

Inundation of waste burial trench bottoms which may result in significant radiocontaminant transport in the saturated groundwater system by discharge of process water at present is not probable. An increase in discharge of process water or coupled effects of bank storage, increased river stage, etc., and an increase in trench discharge may potentially increase the water elevation near existing retired 300 Area Burial Ground trenches.

Irrigation Effects

A similar factor which may potentially cause inundation of waste burial trenches resulting from a rise in the water table is irrigation. Two separate studies have been conducted to evaluate the effects of irrigation on the geohydrologic system relative to waste management practices (Cearlock et al., 1966; Reisenauer and Cole, 1975). The first report discussed numerical modeling results obtained for a proposed irrigation project located in Sections 9, 10, 16, and 15 T10N R27E to the southeast and northeast of the 300 Wye and 300 North Areas, at distances of approximately 3 km, respectively. Irrigating approximately 200 ha at a rate of $5.6 \times 10^1 \text{ m year}^{-1}$ for 5 months/year for 16 years was found to affect the groundwater elevation by a maximum difference in height of approximately 1.2 m.

FIGURE 33. Transient Water-Table Contours
(0.25-ft Contours)

Differences in water-table elevations simulated by the applied model extended on the order of 5 km. The maximum water-table elevation difference in excess over that presently existing at the 300 Wye Burial Ground was approximately 1.5×10^{-1} m, and no increased elevation was found below the 300 North Burial Ground (Figure 34). The effects of limited irrigation at a distance nominally away from a radioactive waste burial ground will probably result in an insignificant rise in the maximum water-table elevation and, therefore, effects of irrigation are thought to be negligible.

Irrigation of a large area within the Hanford Site, i.e., the east slope of the Rattlesnake Hills (Figure 35) to the west and northwest of 300 Area Burial Grounds was also evaluated relative to waste management practices (Reisenauer and Cole, 1975). For the evaluation, steady-state, numerical groundwater simulation models were used. Discharges to the saturated groundwater system by irrigation of approximately 1.4×10^4 ha at rates of 3.0×10^{-1} and 1.5×10^{-1} m year⁻¹ were found to result in increased water-table elevations in the irrigated area within a gradually decreasing change in elevation eastward toward the Columbia River where the effects were found to be negligible. Figure 36 illustrates the results of numerical simulations showing a decrease in water-table elevation eastward toward the Columbia River.

River Water Impoundment Effects

The geohydrologic system in the area of the 300 Area Burial Grounds may also be potentially adversely affected by surface-water management practices. A proposed hydroelectric dam, the Ben Franklin Dam, (Corps of Engineers, 1969) would profoundly affect the water-table elevation, the flux, the direction, and the magnitude of flux of water and potential radiocontaminants dispersed within the unconfined aquifer of the Hanford Site. The location of this proposed impoundment structure is within Sections 23 and 24 T 11 N R28E, which is east-southeast of the 300 North and 300 Wye Burial Grounds and north of the burial grounds in the immediate vicinity of the 300 Area. Construction of this structure would increase the mean river stage on the order of 15 m with a resultant increase in water-table elevation near the Columbia River at the site of nearly the same level.

FIGURE 34. Contour of Groundwater Elevation Difference -
0.5 ft Between Contour Intervals

At high discharge conditions an increase in the water table over that of 15 m near the dam site would be somewhat proportional at high discharge and the duration of high discharge conditions. Using mean stage conditions, the water elevation at the 300 Wye Burial Ground and the 300 North Burial Ground would be increased approximately 8 and 6 m, respectively, as a result of dam construction. The water-table rise at the waste burial sites in the proximity of the 300 Area would not be significantly increased. Figure 37 illustrates the increased water-table elevation and the increased water-table rise over ambient conditions. Inundation of waste burial trenches by the resultant increase in water table was not found to be a potential problem as a result of

FIGURE 35. Calculated Increased Water-Table Elevation After Irrigation of Rattlesnake Slope (see Figure 38 for ambient water-table map)

FIGURE 36. Cross Section of Actual and Predicted Water-Table Elevation After Irrigation of Rattlesnake Slope

dam construction; however, for those materials that may potentially reach the saturated groundwater system from waste disposal sites, the groundwater flow paths to the Columbia River will be shorter and the travel time of these constituents will be increased.

River Flooding Effects

Surface-water inundation caused by flooding initiated by landslide impoundment of the Columbia River was also evaluated (Corps of Engineers, 1969). Flooding was postulated to result by rapid failure of the White Bluffs directly adjacent to the river on the east bank with a slump mass of up to $4.5 \times 10^7 \text{ m}^3$ which would block the existing river channel, thereby directing the river channel to the west. Instability of the White Bluffs and landslide probability was, however, thought to be of a tenable nature.

FIGURE 37. Calculated Water-Table Elevation after Construction of the Proposed Ben Franklin Dam (see Figure 38 for ambient water-table map)

RADIONUCLIDE TRANSPORT PATHWAYS

The release of radioactivity from a waste burial facility to the biosphere may provide exposure to site employees, the general public, or both. After the time of release a radiocontaminant may be transported within the hydrogeologic system to either the atmospheric or the aquatic systems. After reaching any or combinations of the above systems, the radionuclide may enter the water, air, or direct radiation pathways. Upon entering a specific pathway, the radiocontaminant may remain in its original concentration, be dispersed and effectively diluted, or be concentrated. Considering present waste management practices and radiological monitoring data at Hanford, the potential for substantial radionuclide release from the 300 Area Burial Grounds is minimal.

After entering the biosphere, a radiocontaminant may expose occupational workers or the public by either internal or external dose mechanisms. Within the direct radiation pathway, only external radiation exposure can be experienced by direct radiation from the facility. For the airborne pathway, external exposure by air, submersion, and exposure from airborne-deposited materials may result, while internal exposure may result from inhalation and transportation and ingestion of materials deposited on foodstuffs. Transport of radiocontaminants within the water pathway also may result in external and internal exposure. External exposure may follow water immersion and exposure from waterbodies. Internal exposure from water may occur through ingestion of radiocontaminated water or radiocontaminated aquatic foodstuffs, or through ingestion of foodstuffs which have been directly contaminated by irrigation water.

The amount of radioactive dose received depends on numerous factors, including physicochemical transport mechanisms and biologic uptake, in addition to the quantity and type of radionuclides. The primary modes of exposure from a burial ground relative to this study are thought to be direct radiation, inhalation, and water ingestion. The other modes of exposure were not considered.

DIRECT PATHWAY

Direct radiation exposure can be brought on by physical proximity of workers and/or the public to buried waste materials. The magnitude of dose to individuals by direct radiation is dependent on the location of exposure, radionuclide inventory, and the duration of exposure. Direct radiation may be facilitated by intrusion during exhumation, or by residing on or in close proximity to buried waste where physical mechanisms have reduced the backfill cover over the waste. At present, direct exposure is considered negligible. Direct exposure data are presented in the Radiation Monitoring Section of this report. Prediction of future direct exposure via the direct pathway cannot be presently quantified because of the lack of information concerning buried radionuclide location, inventory, etc.

AIR PATHWAY

Exposure to radiation through the air pathway occurs primarily by inhalation of radionuclides, submersion within radiocontaminated air, or exposure to material deposited from air containing radiocontaminants. Radiobiological exposure via the air pathway in the area of the 300 Area burial sites is summarized in the Radiation Monitoring Section of this report. No present adverse impacts of exposure resulting from radionuclides entering the air pathway from the study area have been found. Future exposure from radionuclides derived from the Hanford 300 Area Burial Grounds cannot be quantified because of the paucity of data concerning waste inventory, waste form location, etc. *However, the available information was not sufficient to determine whether*

An important mechanism whereby buried radionuclides can become available to the air pathway is wind erosion. Wind erosion is thought to be the most important mechanism affecting the air pathway at the Hanford 300 Area Burial Grounds. Radiocontaminants can also enter the direct pathway through wind erosion.

The rate and magnitude of wind-induced erosion is a function of many complex factors, including climatological and meteorological variables of wind velocity, wind duration, persistence, precipitation, temperature and humidity, in addition to soil-sediment factors including saturation, texture, structure, cohesion, adhesion and cementation. Wind erosion may induce the transport of particulate matter by one of three mechanisms: 1) airborne transport, when the wind velocity is sufficient to produce drag on small particles to entrain the particles in the atmosphere where the settling velocity of the particles is exceeded by turbulent forces; 2) saltation, when wind drag is sufficient to entrain larger-sized particles into the atmosphere for short periods of time; and 3) creep, when particles move across the atmosphere soil-sediment interface by wind-induced drag.

Erosion of particulate materials overlying waste burial structures is a function of the particle size at the burial site from the time of waste trench backfilling and beyond. The particle is thought to be easily erodible if the texture is equivalent to fine and medium sand. The erodibility of particles decreases if the texture is either increased or decreased from fine and medium sand; i.e., coarse sand and coarse silt are not as prone to erosion. Very coarse sand and medium to fine silt are subsequently even more difficult to erode, and may only be erodible at very high wind velocities. Particulate erosion on the Hanford Site ranges between colloidal and pebble size materials (from 1.0×10^{-6} and 16.0 mm). The maximum particle size which is typically erodible under most conditions is, however, reported as 0.89 mm (Woodruff and Siddoway, 1965; U.S. Agricultural Research Service, 1968).

Wind-induced erosion is generally reduced by decreasing the drag on potentially erodible particles, either by decreasing the wind velocity or by increasing the adhesion and cohesion between particles or stabilizing agents. Decreasing the wind velocity is typically facilitated by buildings or natural shelters. The second method involves treating the surface with an artificial material which in part cements the particles, thus forming nonerodible or less-erodible aggregates.

An experiment evaluating the relative effectiveness of wind erosion controls was conducted on the Hanford Site (Hilst, 1955). The purpose of this experiment was to: 1) measure wind erosion under field conditions and develop experimental techniques to measure wind erosion; and 2) evaluate the retention of small particles on artificial and natural ground surfaces. Four ground treatments used were natural vegetative cover, furrowed surface, natural vegetative surface protected by an engineered barrier, and a rock-covered surface.

In terms of rate of erosion of particulate matter from each of the four treatments, the ranking of treatments for a high-velocity wind condition (wind velocity from 30 to 50 km hr⁻⁵) from highest to lowest showed: 1) furrowed surface, 2) natural vegetative surface, 3) rock covered surface, and 4) natural vegetative surface protected by an engineered barrier. For the case of moderate wind speeds (wind velocity from 8 km hr⁻¹) the ranking was the same as that of the high-velocity case. From this ranking, no conclusive interpretation of stability or the lack of stability for each treatment for all wind conditions can be made. However, several tentative interpretations can be made, including: 1) the rock treatment is the best for wind erosion at low to moderate wind speed; 2) the natural vegetative surface is the worst treatment for low to moderate wind speeds; 3) the furrowed surface and natural vegetative surface protected by an engineered barrier are intermediate in preventing wind erosion, considering all treatments at low to moderate wind speeds; and 4) as wind speed increases the furrowed surface becomes the most erodible, and the rock surface becomes more erodible than the natural vegetative surface with engineered barrier treatment by approximately a factor of five. From these data, then, a combination of rock surface and engineered barriers may provide partial stabilization of the ground surface at the Hanford 300 Area Burial Grounds. Treating the ground surface and construction of engineered barriers, etc., may be postulated as erosion treatment but requires detailed investigation because this combination may cause increased erosion under some conditions; e.g., barriers may actually induce wind erosion at high wind velocities.

The rate of wind erosion from Hanford 300 Area Burial Grounds was calculated to evaluate the time required to denude the top backfill material and potentially exhume waste materials (Woodruff and Siddoway, 1965; U.S. Agricultural Research Service, 1968). Using empirically derived and calculated values from the above references, and measured values from burial sites, the quantity and rate of denudation of sedimentary material overlying burial structures was examined in this study. Under worst case conditions, assuming that all sediment particles were erodible and that the particles were homogeneous and isotropic, the wind erosion was calculated to be $3.8 \text{ g cm}^{-2} \text{ year}^{-1}$, which is effectively 2.3 cm year^{-1} with respect to rate of denudation. Thus, if the buried waste material was covered by 1 m of material, the buried waste would be exposed in 43 years.

Wind erosion may have resulted in increased exposure rate in the 300 North Burial Ground, as evidenced by field gamma counting (this is discussed in the Radiation Monitoring Section of this report). However, sufficient data to quantitatively evaluate increased exposure rate are not available. The treatment to reduce the exposure used by the burial site operators is to cover the area of greater-than-background exposure with coarse aggregate.

The rate of wind erosion subsequent to burial ground surface treatment with rock aggregate was also calculated in this project. The basic parameters and empirical relationships used were applied to a mean case where 4% of the ground surface was covered by rock, while the underlying material was isotropic and homogeneous. Four percent rock cover is a mean value determined within the Hanford 300 Area Burial Grounds. The calculation was performed assuming that nonerodible fraction was deposited on the remaining noneroded ground surface on a yearly basis. Thus, by an interactive method, the wind-induced erosion and denudation were calculated. From this evaluation, it is evident that an increase in concentration of nonerodible material as burial top backfill cover over time reduces the wind-induced erosion and the rate of denudation (Table 4). The tabular values in Table 4 also demonstrate the effect of armoring of the ground surface by nonerodible sediment fractions.

TABLE 4. Calculated Erosion and Denudation Rate of Hanford
300 Area Burial Grounds Sediment(a,b)

Time (years)	Erosion (g cm ⁻² yr ⁻¹)	Denudation Rate (cm yr ⁻¹)	Cumulative Rate (cm)
1	2.2	1.3	1.3
2	1.8	1.1	2.4
3	1.3	0.8	3.2
4	1.2	0.7	3.8
5	0.8	0.5	4.3
6	0.8	0.5	4.8
7	0.7	0.4	5.3
8	0.5	0.3	5.6
9	0.5	0.3	5.9
10	0.3	0.2	6.1
11	0.3	0.2	6.3
12	0.2	0.1	6.5
13	0.2	0.1	6.6
14	0.2	0.1	6.6
15	-	0.1	-
16	-	0.1	-
17	-	0.1	-
18	-	0.1	-
19	-	0.1	-
20	-	0.1	-

(a) 4% of surface particles are nonerodible.

(b) Anisotropic heterogenous sediments.

- Surface is armored.

Within approximately 10 years, a sufficient cover of nonerodible particles will be established to assume no appreciable erosion. The calculated data also demonstrate that the removal of erodible sediment fractions does not appreciably occur below approximately 6 cm. The advantage of utilizing a surficial ground treatment to reduce erosion is suggested. However, in reference to the observations concerning erosion from rock surfaces on the Hanford Site, high-velocity winds may actually increase the rate of erosion from rock-treated surfaces (Hilst, 1955). Clearly, no definitive statement can be made at this time regarding an effective burial site surface which reduces wind-induced erosion.

In summary, the wind erosion mechanism may cause denudation of the top backfill material covering buried waste structures which may result in radiological exposure via the air pathway. Several treatments which may reduce wind erosion may be implemented to stabilize the top backfill material covering waste burial structures. However, extended research efforts concerning stabilization treatments may be required.

WATER PATHWAY

The most plausible radiological exposure scenario would be ingestion of drinking water derived from a groundwater well contaminated by a burial ground source. Presently, however, no drinking water wells are located within a source area influenced by the 300 Area Burial Grounds. Radiological dose in the area of the 300 Area Burial Grounds via the water pathway is summarized in the Radiation Monitoring Section of this report.

The migration or potential for migration of radionuclides from buried waste in the 300 Area Burial Grounds within the geohydrologic system is summarized in the Technology Development and Characterization Section of this report (Fluid Transport and Modeling). In most of the model simulations, under ambient meteorological and geohydrologic conditions, only negligible amounts of water potentially containing radionuclides originating from buried waste could enter the saturated groundwater system. Actual migration of radionuclides from buried waste in the 300 Area Burial Grounds is also summarized in the Technology Development and Characterization Section (Drilling). No conclusive evidence of migration of materials derived from buried waste into the groundwater pathway was found.

ENVIRONMENTAL MONITORING AT THE HANFORD SITE

Environmental monitoring conducted at the Hanford Site and the surrounding area provides a general quantitative assessment of existing and potential radionuclide transport. The environmental monitoring program conducted by PNL relies on a standardized array of monitoring locations and radioanalytical techniques operated over relatively long time periods (on the order of years) to parametrically investigate radionuclide transport pathways and ultimately human exposure within the biosphere (Houston and Blumer, 1978; Myers, 1978).

DIRECT RADIATION EXPOSURE MONITORING

External radiation to the population on and peripheral to the Hanford Site is a function of the natural radiation expressed as the external background dose and that radiation exposure caused by nuclear waste management operations. The natural background radiation at Hanford has been at perimeter locations on the order of approximately $0.068 \text{ rem yr}^{-1}$. To this measurement, 0.006 and $0.025 \text{ rem yr}^{-1}$ are added to account for neutron cosmic radiation and internal body radiation, respectively. The mean natural background dose from all sources is approximately 0.1 rem yr^{-1} (Houston and Blumer, 1978).

External radiation is monitored at 26 sampling stations on the Hanford Site and 28 stations peripheral to the Site with a sampling frequency of 1 month. Offsite and onsite (300 Area) external radiation doses are indistinguishable, indicative of negligible impact of Hanford waste management operations to the public.

Exposure rates are monitored on an infrequent basis to evaluate external radiation dose at selected burial grounds. Table 5 depicts results of a 1973 gamma survey conducted by the Atlantic Richfield Hanford Company on all 300 Area Burial Grounds with the exception of Burial Ground 1. The range in gamma exposure for all burial grounds monitored is between 0.085 and $0.064 \text{ rem yr}^{-1}$ with the highest level occurring in the southwest corner of

TABLE 5a. Gamma Survey Results,
Burial Grounds 2 and 3

<u>Point</u>	<u>Reading</u>	<u>rem yr⁻¹</u>
1	28-29	0.0749
2	28-29	0.0749
3	28-29	0.0749
4	27-28	0.0723
5	28-29	0.0749
6	32-33	0.0854
7	30-31	0.0802
8	28-29	0.0749
9	28-29	0.0749

Maximum exposure (gamma) = 0.0854 rem yr⁻¹
 Minimum exposure (gamma) = 0.0723 rem yr⁻¹
 Mean exposure (gamma) = 0.0763 rem yr⁻¹
 Standard deviation = 0.0039

TABLE 5b. Burial Ground 4

<u>Point</u>	<u>Reading</u>	<u>rem yr⁻¹</u>
1	25-26	0.067
2	25-26	0.067
3	25-26	0.067
4	25-26	0.067
5	25-26	0.067
6	25-26	0.067
7	25-26	0.067
8	25-26	0.067

Maximum exposure (gamma) = 0.067 rem yr⁻¹
 Minimum exposure (gamma) = 0.067 rem yr⁻¹
 Mean exposure (gamma) = 0.067 rem yr⁻¹
 Standard deviation = 0.00

TABLE 5c. Burial Ground 5

<u>Point</u>	<u>Reading</u>	<u>rem yr⁻¹</u>
1	25-26	0.0670
2	25	0.0657
3	26	0.0683
4	26	0.0683
5	26	0.0683
6	26-27	0.0696

Maximum exposure (gamma) = 0.0696 rem yr⁻¹
 Minimum exposure (gamma) = 0.0657 rem yr⁻¹
 Mean exposure (gamma) = 0.0679 rem yr⁻¹
 Standard deviation = 0.0013

TABLE 5d. Burial Ground 8

<u>Point</u>	<u>Reading</u>	<u>rem yr⁻¹</u>
1	25-27	0.0683
2	25-27	0.0683
3	25	0.0657
4	29-30	0.0775
5	27-28	0.0723
6	25-26	0.0673
7	24-25	0.0644
8	25	0.0657
9	25-26	0.0670
10	25-27	0.0683

Maximum exposure (gamma) = 0.0775 rem yr⁻¹
 Minimum exposure (gamma) = 0.0644 rem yr⁻¹
 Mean exposure (gamma) = 0.0685 rem yr⁻¹
 Standard deviation = 0.0038

TABLE 5e. 300 West Burial Ground

<u>Point</u>	<u>Reading</u>	<u>rem yr⁻¹</u>
1	26	0.0683
2	27-28	0.0723
3	26	0.0683
4	27	0.0710
5	25	0.0657
6	25-26	0.0670

Maximum exposure (gamma) = 0.0723 rem yr⁻¹
 Minimum exposure (gamma) = 0.0657 rem yr⁻¹
 Mean exposure (gamma) = 0.0688 rem yr⁻¹
 Standard deviation = 0.0025

TABLE 5f. 300 North Burial Ground

<u>Point</u>	<u>Reading</u>	<u>rem yr⁻¹</u>
1	25-26	0.067
2	24-25	0.0644
3	24-25	0.0644
4	25-26	0.0670
5	25-26	0.0670
6	25-26	0.0670
7	25-26	0.0670
8	25-26	0.0675
9	25-26	0.0670
10	25-26	0.0670
11	26-27	0.0696

Maximum exposure (gamma) = 0.0696 rem yr⁻¹
 Minimum exposure (gamma) = 0.0644 rem yr⁻¹
 Mean exposure (gamma) = 0.0668 rem yr⁻¹
 Standard deviation = 0.0014

TABLE 5g. Wye Burial Ground

<u>Point</u>	<u>Reading</u>	<u>rem yr⁻¹</u>
1	27-28	0.0723
2	26-27	0.0696
3	27	0.0710
4	26-27	0.0696
5	26-27	0.0696
6	25-26	0.0673
7	25-26	0.0673
8	26-27	0.0696
9	25-26	0.0673

Maximum exposure (gamma) = 0.0723 rem yr⁻¹

Minimum exposure (gamma) = 0.0673 rem yr⁻¹

Mean exposure (gamma) = 0.0693 rem yr⁻¹

Standard deviation = 0.0017

Burial Grounds 2 and 3. The highest mean value for gamma exposure at 0.076 rem yr⁻¹ is also found within Burial Grounds 2 and 3. Table 5 shows sampling location within each burial ground monitored, the gamma monitoring instrument reading range, the gamma exposure at each sampling location in units of rem yr⁻¹, and the maximum-minimum-mean and standard deviation about the mean of exposure.

The mean annual dose (0.068 rem) for the Hanford Site is exceeded relative to the mean gamma exposure for each burial site only in Burial Grounds 2 and 3. The value approximates 0.008 rem yr⁻¹. The highest value recorded in the same burial ground exceeds the external background by 0.013 rem yr⁻¹. The increased dose from this survey recorded in Burial Grounds 2 and 3, however, may not be attributable to radionuclide electromagnetic emission from buried waste because the dose is found to increase with increased proximity to the 333 Building where nuclear fuels are manufactured. The gamma exposure next to this building some 20 m south of Burial Grounds 2 and 3 was monitored during the above survey at 0.200 rem yr⁻¹ which exceeds external background by about 0.123 rem yr⁻¹. External exposure surveys are conducted on an annual basis within the 300 Area Burial Grounds; however, data commensurate with that taken

in 1973 are not recorded. At such times as external radiation exposure is found, remedial action is taken to alleviate exposure, and records do not reflect adverse exposure.

Monitoring of external radiation at the 300 Area Burial Grounds also includes surveys of radionuclide content in plants on each burial ground and evaluation of burial site facilities, including perimeter fences, radiation monuments, and the surficial configuration of burial trenches and other disposal structures.

Plants having higher than background levels of radionuclides have been noted on several burial grounds. Surface depressions presumably resulting from differential compaction of buried waste were also noted during monitoring surveys. When above background levels of exposure are encountered several remedial activities are routinely conducted to alleviate that occurrence depending on the type and location of the exposure. For example, plants that have exhumed buried waste through their root and vascular systems are typically harvested and placed in polyethylene bags and submitted for further radiochemical analysis. Exposure levels above background, identified by ground surface gamma monitoring instrumentation, that result from erosional and/or compaction phenomena are reduced to background by backfilling with natural coarse mixed aggregate over contaminated areas. Subsequently, radiation is attenuated to appropriate levels.

Monitoring is also conducted along the shoreline of the Columbia River. Past analytical evaluation of river sediment downriver from waste discharge facilities (plutonium production reactors, 100 Area) has identified contamination on river banks. To date, dosimetry surveys conducted over an approximate 5-km reach parallel to the 300 Area have not detected dose rates above natural background.

SOIL MONITORING

Monitoring of soil within and external to the Hanford Site is conducted to assess potential dissemination of radiocontaminants and resultant adverse radioactive dose to the public. On an annual basis, surface soil samples are extracted and analyzed by radiochemical techniques under the direction of

PNL. Twelve onsite locations and nine offsite sampling locations are used. Results from these annual surveys have indicated indistinguishable differences between onsite (300 Area) and offsite soil analytical data for radionuclides analyzed, i.e., cobalt-60, strontium-90, zirconium-95, niobium-95, cesium-134, cerium-144, americium-241, and plutonium-238 (Houston and Blumer, 1978). All other radionuclides are above background values by a factor approximating that of fallout from atmospheric detonations of thermonuclear devices. The maximum concentration of plutonium-239,240 and cesium-137 was 17 and 29 pCi g⁻¹ dry weight, respectively. Therefore, routine surface soil monitoring does not reveal airborne dispersion of radioactive waste from Hanford waste management activities.

FLORA MONITORING

Perennial and annual vegetation may incorporate radionuclides in the soil system into their vascular systems and tissues, or radionuclides may be directly deposited onto the aboveground portion of the plant. Routine monitoring, for the most part, shows negligible differences of radionuclide concentrations between onsite and offsite monitoring locations. Of the locations monitored, three onsite and four offsite locations are located near the 300 Area Burial Grounds. Radiochemical analysis of vegetative plant tissue was conducted by PNL for the same radionuclides analyzed for surface soils. Analytical results indicated that radionuclide concentration levels were attributable to worldwide fallout. The concentration of radionuclides in a few cases occurring above background levels away from existing facilities is probably attributable to Hanford operations. The routine monitoring results, however, clearly demonstrate that these concentrations are within acceptable concentration limits for both onsite and offsite locations. No contributions of radionuclides in plant tissue attributable to waste management operations at the 300 Area Burial Grounds was noted.

FAUNA MONITORING

Routine radiological monitoring of animals inhabiting or migrating through the Hanford Site is conducted to assess radionuclide availability and investigate

the transfer of radionuclides through food webs which may impact the public. Numerous species of animals inhabit areas where radioactive waste has been disposed. Deer collected on the Hanford Site were found to contain expected concentrations of naturally occurring potassium-40 (Houston and Blumer, 1978). Strontium-90 concentrations in deer tissue were regarded as attributable to fallout from atmospheric detonation of thermonuclear devices. The access to deer within the 300 Area Burial Grounds is severely limited because perimeter enclosure fences surround all burial sites with the exception of Burial Ground 8, which is for the most part capped with asphalt. Thus, present burials are thought to be adequate to exclude deer from the 300 Area Burial Grounds.

Burrowing rodents and mice inhabit waste disposal sites including the 300 Area Burial Grounds. These animals, as well as deer and other animal species, are routinely collected and analyzed for radionuclides. Transport of radiocontamination within and from waste disposal areas on the Hanford Site has been demonstrated.

SURFACE-WATER MONITORING

Columbia River water, being the base of hydrological system receiving ground water and surface runoff as well as liquid effluents from the Hanford Site, is routinely collected and analyzed (Houston and Blumer, 1978; Fix et al., 1975). Samples of river water and riverbank spring water are routinely collected up and downriver in addition to collection sites within the Hanford Site. These samples are analyzed by radiochemical and wet chemistry techniques. Ground water that has emanated from below radioactive waste disposal sites including the 300 Area Burial Grounds enters the watercourse of the Columbia River at several locations. Analysis of radiocontaminants in river and riverbank spring water provides general assessment of planned releases into the river.

Of the analytical results compiled from water directly sampled from the Columbia River, only low levels of iodine-129 at a maximum concentration of 1.0 pCi ml^{-1} and low levels of cobalt-60 at a maximum concentration of 5.0 pCi ml^{-1} were attributable to past releases of radionuclides from the

Hanford Site (100-N Area). The concentrations of all other radionuclides sampled at all locations directly from the Columbia River are nominally those commensurate with fallout derived from atmospheric thermonuclear detonations.

Riverbank springs discharge water to the Columbia River. This water originates from ambient ground water entering the geohydrologic system from the west of the 300 Area and liquid waste effluent discharges from 300 Area operations. These riverbank springs typically occur near the shoreline or below the surface of the water depending on river stage. Four such springs, which periodically discharge water derived from below the 300 Area, were monitored in 1975. These springs were sampled in the following locations: 1) riverbank springs No. 1 approximately 250 m east of 300 Area Burial Ground 4, 2) riverbank springs 300 Area No. 1 and 2 approximately 100 m east of the 337 Building, and 3) North Richland riverbank springs approximately 1.9 km southeast of riverbank springs sampling stations 300-1 and 2. Results from monitoring these springs during 1975 are tabulated in Table 6.

TABLE 6. Riverbank Springs Monitoring Results

River Bank Spring Location	Analysis	Concentration, pCi/ml		
		Maximum	Minimum	Mean
1	Tritium	4.0	0.50	1.3*
	Alpha	0.03	0.02	0.02
	Beta	0.08	0.08	0.08
300-1	Uranium	3.2	3.2×10^{-2}	9.0×10^{-1}
300-2	Uranium	7.2×10^{-1}	2.2×10^{-2}	3.6×10^{-2}
North Richland	Uranium	1.4×10^{-1}	1.0×10^{-1}	1.0×10^{-1}

(Modified after Fix et al., 1975.)

The results of riverbank spring water from sampling station No. 1 located east of Burial Ground 4 shows higher values of alpha, beta, and tritium when compared with well monitoring data (Lindberg and Bond, 1979). The concentration of tritium collected at this riverbank spring was nominally a factor of

five greater than any groundwater monitoring reports have indicated. This sampling location is located downgradient from 300 Area Burial Grounds 4 and 5.

The concentration of uranium at the other sampling locations was attributable to waste disposal operations within the 300 Area and consistent with concentrations determined by routine groundwater monitoring of wells in and adjacent to the 300 Area. All concentrations of radionuclides detected from riverbank springs monitoring did not exceed regulatory standards for drinking water.

GROUNDWATER CONTAMINATION

During the early stages of Hanford operation, nuclear fuels fabrication, reactor operation, radiochemical processing, and waste disposal resulted in releases of radioactive materials to the groundwater system at the Hanford Site. The disposal of liquid waste to the groundwater system over the past few years has, however, been dramatically reduced as a result of termination of nuclear fuels reprocessing and improved liquid effluent waste treatment efficiencies. Typically, liquid waste discharges have occurred in chemical separations areas (200 Areas), reactor area (100 Area), and at laboratory and engineering development areas (300 Area). Lesser volumes of liquid waste have also been discharged to the groundwater system at other locations within the Hanford Site, for example, the 316-4 Crib located adjacent to the 300 North Burial Ground.

Liquid wastes disposed to the ground typically percolate laterally and downward through unconsolidated glaciofluvial and lacustrine sands, silts, and gravel of the partially saturated groundwater system overlying the groundwater table, and are then transported to the unconfined groundwater aquifer. As the wastes move through the sedimentary materials, adsorption and ion exchange with minerals in the sediments cause some of the radioisotopes to be retained in the sediment above the water table. The longer lived and more hazardous elements such as ^{90}Sr , ^{137}Cs , and ^{239}Pu have favorable exchange and sorption characteristics and are, in general, effectively removed. Other radioactive elements and nonradioactive materials, such as ^{106}Ru , ^{99}Tc , ^3H (tritium) and

NO_3 , do not have good ion exchange characteristics and move through the ground at varying rates to eventually enter the ground water. When the contaminants enter the water table, they move in a downgradient direction with the ground water. As the radionuclides move in the ground water, their concentration is reduced by radioactive decay, ion exchange, diffusion and hydrodynamic dispersion.

Disposal of more than 5.0×10^{11} g of process water containing low-level waste and about 3.0×10^{11} g of intermediate-level waste over the past 30 years has profoundly increased the mean elevation of the water table (Figure 38). Groundwater mounds (areas of increased water elevation as a result of groundwater injection) have been created near chemical processing reactor and laboratory and engineering development areas as a result of disposal of process water (Phillips and Raymond, 1975).

Groundwater monitoring of radionuclide and chemically contaminated water is routinely conducted by sampling and physicochemical analysis. Of the more than 700 wells (Figure 39) drilled to ground water on the Hanford Site, approximately 330 wells are presently used for routine groundwater monitoring and about 1300 well-water samples are taken annually to provide 3700 analytical results for use in evaluating the status of contamination in the ground water. Sampling frequency varies from monthly to semi-annually, depending on well location and the analyzed constituent.

Samples are routinely analyzed for the radionuclides, ^{106}Ru , ^3H , ^{90}Sr , ^{137}Cs , and ^{60}Co . Total alpha- and beta-emission contents are also determined, as are NO_3 concentrations. Gamma scans are run on selected samples. Ground water from several wells is analyzed for a few chemical water parameters (sodium, sulfate, calcium, and pH) to monitor broader changes in water quality. Analyses for copper, fluoride and chromate ion are made on selected groundwater samples in the 300 Area since the fuel fabrication wastewater disposed at this site contains these contaminants. Temperature is logged on an intermittent basis to trace the movement of the thermally warm process cooling water in the ground water. Standard radiometric and chemical methods are used to analyze the routine groundwater samples.

FIGURE 38. Hanford Site Water-Table Map

The radionuclides, ^{106}Ru and ^3H , as well as NO_3 ion, are readily transported in the ground water with little decrease in concentration as a result of adsorption or ion exchange. They also can be detected in low amounts in the ground water relative to their respective concentration guides or drinking water standards. Therefore, these substances are used as primary tracers to monitor the movement of contaminated ground water away from disposal sites. Other radioactive and nonradioactive materials that occur in the ground are analyzed on an intermittent basis. A gross beta analysis is used to detect ^{106}Ru and specific isotope analyses are run at selected sites to confirm that ^{106}Ru comprises the major radioactive contaminant (other than ^3H) in the ground water away from the disposal sites.

Figure 40 shows the map of ^3H (tritium) concentration in the ground water with isopleths indicating three zones of 30 to 300 pCi/ml, 300 to 3000 pCi/ml⁻¹ and >3000 pCi/ml⁻¹. The ^3H pattern is similar to that observed for NO_3 concentration. Tritium in the 30 to 300 pCi ml⁻¹ isopleth occurs in the ground water below both the 300 Wye and 300 North Burial Grounds. This radionuclide is derived from disposal of contaminants upgradient as evidenced by a lateral migration originating from the chemical processing areas. Moreover, tritium contamination monitoring records from wells in these two burial grounds have shown no tritium contamination before the 30 to 300 pCi/ml⁻¹ isopleths reached in their respective locations. Thus, detectable tritium contamination is not being transported from burial grounds to the groundwater system in these areas. The routine analytical detection limit for ^3H is 1.0 pCi/ml. Tritium concentrations in excess of the concentration guide (3000 pCi/ml⁻¹) only occur beneath and adjacent to a few disposal sites in the 200 Areas. As with NO_3 , it is probable that ^3H occurs in the ground water in less-than-detectable amounts beyond the boundaries indicated in the figure.

Figure 41 shows the distribution of gross beta concentration (calculated as ^{106}Ru) in the ground water. The observed plume is similar to that of ^3H , but of reduced size and extent. The gross beta contamination plume has extended over a larger area in years past, but the radioactive decay rate is greater than the rate at which higher level contamination moves from the source

FIGURE 40. Tritium Concentration in the Ground Water

FIGURE 41. Gross Beta (Calculated as 10^6 Ru) Concentration in the Ground Water

areas. Isopleths outline gross beta concentrations of 0.1 to 1 pCi/ml⁻¹, 1 to 10 pCi/ml⁻¹ and >10 pCi/ml⁻¹. No occurrence of ¹⁰⁶Ru is found in the ground water near the 300 Area Burial Grounds.

Contamination of the saturated groundwater system by low activity uranium within and about the 300 Area has occurred since initiation of chemical processing operations in the 300 Area in 1944. This intentional release of uranium occurred in process ponds along the Columbia River and in waste discharge lines leading to these ponds. Figure 42 illustrates the concentration of uranium in the 300 Area and surrounding areas. The major concentrations of uranium are located near aqueous waste discharge sites and the areal concentration shows uranium isopleth concentrations up to approximately 10 pCi/ml⁻¹ extending to the Columbia River.

Burial grounds in and about the 300 Area operating from 1944 to 1973 were probably all recipients of uranium contaminants. However, detectable uranium from these burial facilities has not been transported into the geohydrologic system as evidenced by radiochemical analysis of ground water from groundwater monitoring wells in and in the vicinity of the 300 Area. Moreover, contamination isopleths in Figure 42 show no concentration of uranium attributable to waste burial in the ground water below these burial sites.

The concentration of alpha emitting radionuclides, analyzed as gross alpha, nearly follows that of uranium concentration in ground water in the 300 Area and the surrounding areas (Figure 43) during the same temporal interval. Thus, as with uranium concentration, groundwater monitoring records show no evidence of increased alpha radiocontamination in ground water attributable to waste management practices.

Beta contamination, analyzed as gross beta, in this same area within the saturated groundwater system is appreciably different in that the concentration of beta emitting radionuclides in the area of aqueous discharge ponds is nominally less than that in the surrounding area. This is probably due to dilution by large volumes of discharge water into the ponds. The general contamination pattern, however, follows those previously mentioned with an increase from west to east toward the Columbia River.

FIGURE 42. Concentration of Uranium in Ground Water in the Vicinity of the 300 Area

FIGURE 43. Concentration of Alpha-Emitting Radionuclides in the Vicinity of the 300 Area

Figure 44 illustrates the beta contamination isopleths in proximity of the 300 Area as of January 1977. From evaluation of this figure and groundwater monitoring reports calculated since 1944, no detectable contamination of beta emitting radioisotope originating from 300 Area Burial Grounds could be found.

Contaminants within the groundwater system in the 300 Area are transmitted in the saturated ground water at rates proportional to the chemical interaction of contaminants with the geologic material. Because the type and quantity of radionuclides in 300 Area Burial Grounds are not accurately known, and some radioactive constituents, e.g., tritium, ruthenium, etc., can be transported at a rate nearly equal to that of water, the flux of water is an appropriate analog to evaluating radiocontaminant transport under worst case conditions.

Evaluation of groundwater migration below the 300 Area by steady-state computer simulation techniques (Lindberg and Bond, 1979) shows relatively rapid flux of water below waste burial trenches in the proximity of the 300 Area to the Columbia River. The range in horizontal flux of ground water in this area is nominally 5 to 15 m day⁻¹ from west to east. This corresponds to travel times of about 90 days for ground water reaching the Columbia River from the area of Burial Grounds 300 West and 7. For the 300 Area Burial Grounds 1, 2, 3, 4, 5, 7, and 8, the travel times are much less as they are located nearer the Columbia River. The mean travel time for contaminated materials potentially derived from these sites to reach the river is on the order of 60 days. Figure 45 illustrates equipotential lines and streamlines which show the direction of flow of water in the saturated groundwater system below the 300 Area. The flow paths of any contaminants which could be derived from waste burial sites in this area would be east-southeast eventually discharging to the Columbia River.

ATMOSPHERIC MONITORING

The transport of airborne radiocontaminants on and in the region surrounding the Hanford Site is routinely evaluated by radiological monitoring. Particulate and vapor phase materials transported within the atmosphere are collected at 22 onsite and 24 offsite locations within and exterior to the

FIGURE 44. Concentration of Beta-Emitting Radionuclides in the Ground Water in the Vicinity of the 300 Area

FIGURE 45. Equipotential Lines Parallel to River and Stream-
lines Normal to River Showing the Ground Water
Flow Field in the Vicinity of the 300 Area

boundary of the Hanford Site, respectively (Houston and Blumer, 1978). Comparison of offsite and onsite analyses of gross alpha, gross beta, and iodine-131 activity shows indistinguishable statistical differences, and that concentrations are attributable to atmospheric detonations of thermonuclear devices. The mean gross beta concentrations for both offsite and onsite locations were approximately 1.8×10^{-1} pCi ml⁻¹ and the gross alpha concentrations for offsite and onsite were approximately 1.0×10^{-3} pCi ml⁻¹ (Houston and Blumer, 1978). Iodine concentrations in excess of detection limit were not found. The highest concentrations of gross alpha and gross beta detected in samples collected at sampling stations nearest to the 300 Area Burial Grounds were 4×10^{-3} and 4.1×10^{-1} pCi ml⁻¹, respectively.

Tritium concentration in the atmosphere was found not to exceed 1×10^{-1} pCi ml⁻¹. Airborne tritium concentrations at all locations are attributable to fallout. No tritium concentrations collected by routine monitoring in stations peripheral to the 300 Area Burial Grounds were found above that sustained by worldwide fallout.

TECHNOLOGY DEVELOPMENT AND CHARACTERIZATION

A major part of this project involved characterizing the 300 Area Burial Grounds and at the same time developing better methods for describing and evaluating burial sites. The four areas covered were: geophysics; geochemistry; fluid transport and modeling; and biological transport. In order to analyze soil interaction with specific isotopes, specialized drilling techniques were used to collect soil core samples from burial sites.

GEOPHYSICS

The safety of a nuclear waste burial facility is directly coupled with the buried material and its configuration within the geohydrologic system. Thus, the location, composition, quantity and configuration of waste materials are important considerations when evaluating waste management alternatives. Due to the uncertainty of location, composition, quantity and configuration of buried waste materials within the Hanford 300 Area Burial Grounds, a geophysical system was needed which could evaluate in situ waste materials and burial site geohydrology. The following is a summary of evaluation, development, and application of geophysical survey instruments and systems considered as useful to locate, map and define buried waste.

Geophysical Concepts

Several geophysical concepts were considered potentially useful for waste location and characterization. Of these concepts, several were rejected due to their costs and the lack of proven utility for shallow land burial survey application. The rejected concepts included: acoustic impedance measurements, radio-frequency interferometry, and electromagnetic surface wave measurement. Additional geophysical systems thought to be applicable to shallow land burial surveys were subsequently considered and evaluated on a preliminary basis by application of the system to the Hanford Site (Phillips et al. 1977). These systems included: metal detector, magnetometer, acoustic reflection, acoustic holography, ground penetrating radar, and thermal infrared imaging. Of these systems, the ground penetrating radar, magnetometer, and metal detector

systems were found to be useful for present applications. Individually, these three systems were not found to be sufficient for locating, mapping and detecting waste. Consequently, an integrated system utilizing the metal detector for reconnaissance surveys and subsequently using the magnetometer and ground penetrating radar for detailed surveys was found to be adequate. An acoustic holography survey heretofore not reported was also used to evaluate holographic techniques for location of buried waste.

Metal Detectors

Metal detectors were considered because large quantities of metallic waste materials were deposited in the 300 Area Burial Grounds. Two commercial metal detectors were tested (Figure 46). The primary detector was designed for industrial applications and is normally used to locate buried objects such as pipes or cables. The secondary instrument is typically for general purpose detection.

Both instruments operated on the induction balance, or transmit-receive, principle. In other words, one or two transmitter loop coils and one receiver loop coil are geometrically arranged in such a way that a null or zero-induction condition is obtained in the absence of nearby metallic objects. When the coils are properly adjusted, the receiver is insensitive to the electromagnetic field of the transmitter. However, a signal will be detected if the electromagnetic field at the receiver coil is altered by the superposition of a secondary electromagnetic field resulting from induced currents in a nearby metallic object or conductive mass. Deviations from the balance condition are detected as electrical signals in the receiver and are electronically converted to a meter deflection as well as to an audible tone.

Initially, tests on the metal detectors were conducted at a geophysics burial test site west of the 300 Area and at the 300 North Burial Ground. Tests were performed using a variety of metal targets with a wide range of shapes and sizes in addition to survey tests of unknown targets in existing burial trenches.

FIGURE 46. Metal Detector Testing

In general, the controlled tests showed that the metal detectors are insensitive, even at short range, to elongated metallic objects of small cross section. The sensitivity and the effective penetration depth depend on the shape, size, and orientation of the buried object. The test results indicated that the maximum depth at which a given object (not too elongated) can be detected by the metal detectors is typically two to four times its diameter, width, or other representative dimension. Metal detectors were found to be effective in locating buried oil drums and pipes and other large metal objects or masses in trenches.

Magnetometers

Magnetic field measurements by magnetometers can be used to locate buried ferromagnetic objects. Magnetometer geophysical methods are based on the principle that an induced magnetization is produced in any magnetic material buried within the earth's magnetic field. The induced field is superimposed on the earth's magnetic field and, if sufficiently large, can be detected as an aberration in the ambient field.

The induced magnetic field of buried objects which exist in 300 Area Burial Grounds depends on the size, shape, depth of burial, orientation and magnetic susceptibility of the object, as it exists with respect to the direction and intensity of the earth's magnetic field. In order to quantify and qualify the induced magnetic field resulting from buried metallic objects within burial grounds, magnetometer surveys were conducted. Computer models were used for data reduction and evaluation.

Two magnetometers were used to make test measurements (Figure 47), a proton precession magnetometer and a cesium vapor magnetometer. The principle of operation of the proton precession instrument is that the nuclei of hydrogen atoms contained in a hydrocarbon fluid will align their spin axes in the direction of an applied magnetic field. If that aligning field, produced by a coil around the sample fluid, is removed, the protons will precess about the direction of the ambient or earth's magnetic field. The frequency of the precession is measured electronically and is precisely proportional to the intensity of the ambient magnetic field. The precession frequency is internally converted to magnetic intensity in units of gammas.

FIGURE 47. Magnetometers: a) Proton Precession,
b) Cesium Vapor

The cesium vapor magnetometer measures the precession frequency of the magnetic moment of the unpaired electron in the cesium atom. Magnetic field measurements are based on the fact that the electron precession frequency is directly proportional to the intensity of the ambient magnetic field. Transitions between one of the ground state levels and a level in the first excited state are selectively induced by irradiating the cesium vapor with circularly polarized light. The electron population in the selected ground state level is quickly depleted by this optical pumping. The result is a decrease in the fraction of the incident light absorbed by the cesium vapor. The transmission of light through the sample cell is monitored by a photocell. Transitions tending to restore the electron population balance between the sublevels of the ground state are induced by applying a weak, swept-frequency magnetic field to the sample in a direction normal to the earth's magnetic field. When the frequency of the applied magnetic field is equal to the electron precession frequency, absorption of the irradiating light is sharply increased. A feedback loop between the photocell and a coil producing the applied magnetic field results in a resonance at the electron precession frequency, which is measured by a counting circuit and converted to magnetic intensity. Magnetometer surveys were conducted in several areas previously surveyed by metal detectors.

Precise measurements of the earth's magnetic field in the burial grounds were found to complement and extend the results of metal detector surveys by identifying ferromagnetic objects or masses. In addition, magnetometers appear to be more sensitive detectors of deeply buried, discrete, steel objects than the tested metal detectors.

Ground Penetrating Radar

Ground penetrating radar was another geophysical system evaluated and found promising for locating and characterizing waste materials. This system is primarily based on the propagation of short wavelength electromagnetic energy into the ground, the absorption of this electromagnetic energy, and backscatter of electromagnetic energy. As a radar pulse is propagated into the ground, the attenuation of a propagating plane electromagnetic wave in a dielectric medium such as the earth is given by the expression:

$$E = E_0 e^{-\alpha x}$$

where

E_0 = the initial electromagnetic field intensity,

α = the absorption coefficient,

x = the propagation distance.

It is convenient to express the absorption in terms of decibels per meter. The absorption loss, A , is given by:

$$Z = 20 \alpha / 2.3 = 8.7 \alpha \text{ db/m}$$

Then:

$$E = \text{the } E_0 e^{-0.115 A x}$$

The absorption coefficient is strongly frequency dependent and is a function of the electrical conductivity, the magnetic susceptibility or permeability, and the relative dielectric constant of the medium. For a medium of negligible magnetic permeability this relationship is given by:

$$\alpha = 0.0148 f \sqrt{K} \sqrt{1 + \tan^2 \delta} - 1^{1/2} \text{ m}^{-1}$$

where

$\tan \delta$ (the loss tangent) = $18\beta/Kf$

K = the relative dielectric constant

β = the conductivity of the medium (millimhos/m)

f = frequency (MHz)

The water content of the ground is the most important factor affecting electromagnetic absorption loss. An increase in moisture content of the sediment or other ground material greatly increases both the electrical conductivity and the dielectric constant of the ground. The magnitude of the effect of ground moisture depends on the composition and porosity of the ground material. The dielectric constant at normally used ground penetrating radar frequencies is generally in the range 3 to 30. The dielectric constant for most dry sediments or rocks is in the range 3 to 10. The dielectric constant of pure water is 81.

Measured values of absorption loss as a function of frequency and soil moisture are shown in Figure 48. These are laboratory measurements made within sandy sediments from the Hanford area. The expected absorption loss for a saturated volume of this material would be about 8 db/m at 100 MHz. Additional loss factors which affect the performance or effectiveness of a given ground penetrating radar system include reflective losses at the air-ground interface, geometrical spreading of the transmitted radar beam, the effective backscattering cross section of the reflective target, and the spreading of the reflected signal. A positive factor is a refractive gain due to the focusing effect of the dielectric medium.

FIGURE 48. Measured Values of Radar Signal Absorption Loss Versus Transmitted Frequency for Several Values of Moisture Content. The soil sample was from the Hanford area.

Radar signals are reflected or backscattered by objects or interfaces which have a dielectric constant different from that of the surrounding medium. The amplitude of a reflected or backscattered signal from a discrete object is determined not only by the difference in the dielectric constants of the object and surrounding medium, but also by the size, shape and orientation of the object.

Initial tests of ground penetrating radar were made with a prototype radar system in the 300 North Burial Ground. The transmitted signal used was 1000 MHz with an effective repetition frequency of 50 pulses per second. Figure 49 is a radar reflection profile acquired along a 15 m traverse in the burial ground. The bright spot near the center of the image is a known metallic object. This result was obtained with the radar system operated in a monostatic mode, i.e., using a single antenna. Tests of the system in a bistatic mode were not successful. The measured attenuation coefficient was 54 db/m.

FIGURE 49. Ground Penetrating Radar Reflection Profile in the 300 North Burial Ground

Another radar system was later tested. This system was a commercially available impulse radar designed for time-domain reflectometry. A single dipole antenna, suspended approximately 8.0 cm above the ground, was used for both transmitting and receiving. This system utilizes a short electromagnetic pulse, approximately 10 nanoseconds in length transmitted into the ground (Figure 50). Figure 51 illustrates an example of a two-dimensional planar surface projection of radar data collected at the 300 North Burial Ground.

FIGURE 50. Amplitude-Time and Power-Frequency Relationships of Ground Penetrating Radar

FIGURE 51. Two-Dimensional Planar Surface Projection of Radar Data Collected at the 300 Area North Burial Ground

Holographic Imaging

The potential application of acoustic holographic imaging for burial ground mapping was also experimentally tested. The configuration of this geophysical survey is shown in Figure 52. A test hole was drilled to a depth of 9.2 m on each side of a trench of known dimension and known buried material. A set of three geophones was inserted in the bottom of each hole which was then backfilled with sand. Another set of geophones was placed on the ground surface. The three geophones in each set were oriented to respond to three orthogonal directions. The outputs of the geophones were amplified, digitized,

FIGURE 52. Geometry of Holography Experiment at Test Site

and recorded on magnetic tape by a computer. The acoustic source consisted of a 4.5 kg weight struck against a steel plate on the ground surface. Wires attached to the weight and the steel plate constituted the start switch. The closing of the start switch circuit initiated computer recording such that a time-of-flight calculation would be possible. Delineation of buried material which attenuated the acoustic signal was computed by evaluation of acoustic signal phase relationships.

A backward wave reconstruction algorithm to obtain an image from time of flight and phase data between acoustic source and geophone sets was used (Kong et al., 1974). This required a spatial Fourier transform of the phase and amplitude distribution on the ground surface in order to obtain a plane wave decomposition. Each plane wave was then multiplied by a propagation factor

that adds the appropriate phase required to propagate the wave to a new plane. An inverse Fourier transform was used to resolve phase and amplitude distribution. An acoustic holographic image was then obtained by plotting the square of the absolute value.

Figures 53a and 53b show examples of acoustic holography imagery collected at a geophysics test site near the 300 Area for holes 1 and 2, respectively. Note the clearly defined outline of the trench in these figures, which indicates that the velocity was increased by the backfilling and packing within the test trench.

FIGURE 53a. Phase Plot of Acoustic Signals Received from Source Array

Results

Of the geophysical survey methods tested in this program, ground penetrating radar measurements offer the greatest potential capability for detecting both metallic and nonmetallic waste materials. A trade-off between resolution and depth of penetration is required because the ground in the Hanford area is a strong absorber of electromagnetic energy at radar frequencies. However, this trade-off can be accomplished by selecting the frequency content of

1.2 m

3.7 m

4.9 m

6.1 m

FIGURE 53b. Intensity Plots of Wavefront Shown in Figure 53a
Back-Propagated to Four Depths

the transmitted signal. The range of surface materials and textures in the 300 Area Burial Grounds will not restrict the operation of a radar system.

The metal detector and magnetometer survey systems used in conjunction with the ground penetrating radar provided necessary information to detect, map, and characterize buried waste on the Hanford Site. The information derived from these geophysical surveys, however, is voluminous and was found to require automated data collection and processing. Thus, an integrated geophysical survey system was designed, assembled, and tested. The principal components of the system are: 1) metal detectors, 2) radar and magnetometer units and related instrumentation, 3) survey vehicle to transport radar and magnetometer units, and 4) truck-mounted computer system for processing and storing radar and magnetometer data.

Survey Vehicle and Computer System

The survey vehicle was developed during this project to maximize the efficiency of the radar and magnetometer measurements. The vehicle is capable of transporting geophysical survey systems and an operator. Figure 54 shows the survey vehicle during its assembly. The frame of the vehicle is constructed of bolted and welded aluminum channels. Figure 55 is a front view of the vehicle, showing a radar antenna mounted on aluminum rails extending forward. The antenna is oriented between the rails on a fiberglass skid plate which is attached to the rails. This arrangement allows the antenna to be carried at a nominal height of 5 cm above the ground and yet ride smoothly over a rough ground surface. The 5-mm thick fiberglass plate is essentially transparent to the radar signal. The antenna housing is also constructed of fiberglass.

The operator's seat is mounted on a box containing the main electronics for the radar unit. It also contains a microprocessor, a telemetry unit, and associated power supplies. The rectangular fiberglass box under the operator's feet contains four 12-volt batteries which provide electrical power for all of the electronic instrumentation on the vehicle. Figure 56 is a block diagram of the electronic instrumentation, or data acquisition system, on the survey vehicle.

FIGURE 54. Assembly of Survey Vehicle

FIGURE 55. Survey Vehicle Showing Radar Antenna Mounted on Aluminum Rails

FIGURE 56. Block Diagram of Data Acquisition System on Survey Vehicle

The central data acquisition system on the survey vehicle is a microcomputer system. The microcomputer system is configured and programmed to perform three main tasks: 1) receive, digitize, and sum radar data; 2) read and store magnetometer data; and 3) transmit data to the telemetry unit. The system uses single-board computer containing an 8-bit CPU, system clock, read-write memory, nonvolatile read-only memory (ROM), I/O ports and drivers, serial communications interface, interval timer, interrupt controller, and bus control logic and drivers. Sixteen-line address and eight-line bi-directional data busses are used to facilitate interfacing to memory and I/O. As shown in Figure 59, the microcomputer system consists of the microcomputer module and three interface modules. Each of the interface modules consists of a single circuit board which, together with the computer board, share a common card cage.

The function of the radio telemetry link is to transmit digital data from the survey vehicle to a computer contained in a nearby truck. It eliminates the need to provide a connecting cable between the survey vehicle and the truck. The difficulty of manipulating a dragged cable among the rocks and plants that exist in the 300 Area Burial Grounds is thereby avoided.

A large military instrumentation truck was acquired for the purpose of transporting the field computer system and for serving as a mobile field laboratory (Figure 57). This truck required modifications including installation of electric wiring for the computer equipment and other power needs, storage cabinets and desks, and air conditioning and heating equipment. Figure 57 shows the interior of the truck and the major components of the computer system. This vehicle was selected largely because it has the desired mobility in the burial grounds in that all 10 of its wheels can provide driving power.

As shown in Figure 57, the computer mainframe, the disk drives, and the magnetic tape unit are mounted in an enclosure inside the truck. This enclosure provides protection against dust and allows independent heating and cooling systems to be used to control the temperature of the enclosed computer components. Other features of this enclosure include: external power and

FIGURE 57. a) Truck Used to Transport the Field Computer System.
b) Interior of the Truck and the Computer System.

sensor connections, power cable runs for easy movement, sliding front doors for easy access, air flow vent controls, shock-mounted instrumentation wheels, enclosure tie-downs, and internal temperature and humidity gages.

Summary of Geophysical Survey Results from the Hanford 300 North Burial Ground

After initial development and testing of each geophysical survey technique, surveys using combined systems were performed at the Hanford 300 North Burial Ground. Conducting combined surveys on this actual burial site provided an opportunity to test the developed operational system, as well as to map certain areas of buried waste.

To systematically map the burial ground, several sequential operations were conducted including: 1) acquisition and evaluation of engineering records of the site, 2) metal detector surveys, 3) magnetometer and ground penetrating radar surveys, and 4) comparison of results and preparation of illustrations showing the distribution of buried waste. Engineering records were evaluated, and a preliminary assessment of the location of buried waste structures, such as trenches and caissons, was performed.

An initial map of waste structures (Figure 58) was constructed from engineering drawings (Atomic Energy Commission Engineering Drawings H-3-9982). This map was then used as a base for conducting additional geophysical surveys. As shown in the figure, 12 burial trenches were identified from the engineering drawing as outlined by solid or dashed rectilinear bodies. Two arrays of vertical caissons consisting of 208- $\frac{1}{2}$ barrels were also identified as shown in the center and southwestern sections of the figure.

The next activity involved metal detector surveys of the burial site. Metal detector surveys were performed and locations of buried metallic objects were marked on the ground surface. Immediately after the metal detector survey aerial photographs of the burial site were taken.

The results of the metal detector survey delineation of buried metallic locations are shown in Figure 59. Comparisons of metal detector versus aerial image versus engineering drawing base map data were made. Several discrepancies

FIGURE 58. Map of the 300 North Burial Ground from AEC
Drawing Number H-3-9982 (1962)

FIGURE 59. Aerial Photograph of the 300 North Burial Ground Showing Metal Detector Survey Results (White Lines). The black lines are trench boundaries as shown on the available burial ground map.

are obvious in comparing the survey results with the existing engineering drawing, the most obvious of which are found at the north and south ends of the burial ground where large masses of buried metal extend well outside the trench boundaries as shown on the figure.

The next step in the identification and location of buried waste involved magnetometer surveys. Magnetometer surveys were conducted over specific areas within the Hanford 300 North Burial Ground. These surveys identified the ambient magnetic field and anomalous magnetic fields induced by buried waste. The locations of large masses of nonmetallic waste materials, i.e., trench boundaries, were found in the 300 Area Burial Grounds by means of magnetometer measurements. Trench boundary locations could be found because the magnetite-bearing sediments are replaced by nonmagnetic waste consisting of cellulose or other matter which causes a weak negative magnetic anomaly. This anomaly may be detectable and interpretable if it is not masked by strong anomalies produced by steel waste materials.

Figure 60 is a digitized, computer-produced, contour map of the magnetic field anomalies in a 61 m x 56 m rectangle in the northwest corner of the burial ground. The contour interval is 200 gammas. Figure 64 is a magnetic contour map of a 61 m x 30.5 m area in the east-central part of the burial ground. In this figure, the contour interval is 100 gammas. In both maps, the ambient field has been subtracted from the data. The same magnetic data as illustrated in Figures 60 and 61 are shown in computer-produced photographs in Figures 62 and 63. Intensity modulated plots of data augment the analysis of the digitized data by graphically distinguishing between small changes in magnetic fields.

In Figure 64 the magnetic data are shown in contour form superimposed on the map of the burial ground. As was shown in the metal detector survey results, relatively large discrepancies between the location of buried waste as mapped by magnetic surveys versus engineering records are shown.

FIGURE 60. Small-Scale Contour Plot of Magnetometer Field Survey Data from an Area in the Northwest Corner of the 300 North Burial Ground (the direction shown is magnetic north)

FIGURE 61. Large-Scale Contour Plot of Magnetometer Field Survey Data from an Area in the Northwest Corner of the 300 North Burial Ground (the direction shown is magnetic north)

FIGURE 62. Level Sliced Images of Magnetic Data from the Northwest Corner of the 300 North Burial Ground. Clockwise from the upper left, the images are: total field, second derivative, upward continued second derivative, and downward continued total field.

FIGURE 63. Level Sliced Images of Magnetic Data from the East Side of the 300 North Burial Ground. From top to bottom, the images are: total field, second derivative, and downward continued total field.

FIGURE 64. Contour Plots of Magnetic Data Superimposed on the Map of the 300 North Burial Ground

The next sequential survey of the burial site was performed by ground penetrating radar. Ground penetrating radar measurements were made in four contiguous subareas within the 300 North Burial Ground. The total area covered corresponds approximately to the larger of the two areas covered by the magnetometer survey. Ground penetrating radar results from these subareas are shown in Figure 65.

Figure 65 is a computer-produced map view of the combined radar data in the northwest corner of the 300 North Burial Ground. The ground penetrating radar is superimposed over the trench boundary locations as identified from engineering drawings as was done for the metal detector and magnetometer surveys. The intensity of the modulated ground penetrating radar signal is proportional to the reflected radar signal strength. From these data burial trench boundaries and buried waste within trenches can be identified.

By combining all geophysical data onto one map and visually integrating results, interpretation of waste burial structures and the buried waste contained in the structures was made. An example of comparative results is illustrated in Figure 66. This figure is a map of the northwest corner of the 300 North Burial Ground showing the common area covered by the metal detector, magnetometer, and radar surveys. The combined results of those surveys has been interpreted as shown by the shaded portion of the surveyed area. The shading indicates that at least one of the three geophysical methods used gave evidence of buried waste materials at that location.

The results of the combined geophysical survey have shown the location of waste burial structures and identified the gross composition of waste within these structures. The results also have shown that existing data, for example, engineering drawings, are, in several instances, in error as to the location of burial structures. The selection of decontamination and decommissioning alternatives for the 300 Area Burial Grounds should consider the location and composition of buried waste. For example, if the waste is to be exhumed an accurate survey of the exhumation burial site should be conducted. Thus, the level of geophysical surveys will depend on the of the safety and operational requirements specified by the alternative selected.

FIGURE 65. Map View of Level Sliced Radar Data in the Northwest Corner of the 300 North Burial Ground. The black lines show the perimeter fence and trench boundaries as indicated on AEC drawing number H-3-9982.

FIGURE 66. Map of the Northwest Corner of the 300 North Burial Ground. The shaded area shows the distribution of buried waste materials interpreted from metal detector, magnetometer, and radar data.

GEOCHEMISTRY

The physicochemical interactions of radionuclides and sediments in part control the transport of radionuclides potentially entering the biosphere. If transported through the geohydrologic system radionuclides from buried waste sites may have a potential to adversely impact onsite occupational workers or the general public. Thus, a methodology was required to evaluate radionuclide/sediment interactions in order to formulate a further understanding of radio-contaminant migration. The methodology consists of the following analyses: sediment core collection and preparation, optical microscopy, neutron-enhanced autoradiography, X-ray fluorescence, scanning electron microscopy, electron microprobe, X-ray diffraction, distribution coefficient, and leaching. The following is a summary of the methodology development and application.

Description of Technique

Uranium is considered to be the predominant radionuclide (volumetric basis) disposed to the Hanford 300 Area Burial Grounds. Uranium has also been found in groundwater systems below several 300 Area waste burial sites and as such was considered to be of importance for this study. Therefore, a need was identified to evaluate occurrences of uranium in sediments below waste burial sites. Preliminary drilling adjacent to and below nuclear waste disposal burial trenches reported to contain uranium in liquid form and subsequent radio-chemical analyses showed no uranium concentrations above background levels. From preliminary evaluations, uranium did not appear to migrate from waste burial structures or else it was of negligible magnitude. Thus, because uranium migration was not encountered, it was decided to evaluate migration of uranium from a crib (a liquid radioactive waste disposal structure) located directly adjacent to the 300 North Burial Ground. This structure, identified as the 316-4 Crib, was thought to contain significant concentrations of uranium derived from process development and nuclear fuels fabrication activities in the 300 Area. Groundwater monitoring reports (Brown et al., 1975) have identified above background uranium concentrations in ground water emanating from this crib.

The crib structure consists of a buried, inverted, bottomless, stainless steel tank. Liquid radiocontaminated waste was discharged into this crib from tank trucks, and flushing of transport vessels was accomplished by injecting ground water derived from a nearby groundwater well. Core samples were collected at this structure by hand augering a drill directly into the bottom of the crib.

Core samples were retrieved from the bottom of the crib at 25-cm increments to a depth of 75 cm. Field radiological surveys conducted at the time of collection determined an average gamma count rate of 800 and a maximum count rate of 1000 counts per minute at the surface of the retrieved cores. The collected radiocontaminated waste was then submitted to a radiochemical laboratory for radionuclide identification and determination of concentrations. Subsamples of core materials were also taken for further analytical work. The technique to determine uranium/sediment interaction involved the following procedures.

Subsamples of uranium-contaminated sediments from the 316-4 Crib were dried at 105°C and vacuum impregnated with an epoxy resin. Following resin impregnation and heat curing, the mounted samples were cut across the sediment grains to give a cross-sectional surface area that contained the uranium contamination. The surface was ground and polished to a thickness of 5.0×10^{-1} mm. Optical photomicrographs were taken at several magnifications of the surface features with ordinary light and plane-polarized reflected light.

Following the optical photomicroscopy, a Lexan sheet was attached to the surface of the mount and the mount sealed into a canister. The canister was then subject to a high neutron flux ($1 \times 10^{15} \text{ } \mu\text{cm}^{-2} \text{ sec}^{-1}$) from an operating nuclear reactor. After 15 min of neutron irradiation, the canister was removed and the sample recovered in order to allow neutron-induced radioactivity in the sample to decay to a reasonable level. The Lexan was removed and developed with dilute sodium hydroxide to give a uranium alpha autoradiograph. Optical photomicrographs of the developed Lexan were found to show the location of uranium particles that fissioned in the high neutron flux in proportion to

their concentration in the sediment sample. Comparisons of optical photomicrographs to the same areas of the original surface of the Lexan-mounted sample and the autoradiograph permitted a qualitative spatial estimate of uranium concentrations. This method is referred to as neutron-enhanced autoradiography.

Following the neutron-enhanced autoradiography and location of high uranium concentrations in the sediment mounts, certain high concentration uranium particles were extracted under a binocular microscope and the particles mounted on a glass capillary for X-ray diffraction analysis. A small-particle method allowed X-ray identification of particles down to 2 μm in diameter.

Other sediment mounts were vacuum-coated with gold and used in electron microprobe and scanning electron microscopy examinations. The electron microprobe was used to obtain chemical analyses of uranium and other constituents down to 1 μm in size. Another use of the microprobe was to qualitatively determine the spatial distribution of elements present in a specific area in the interstices of sediment grains. This also permitted elemental identification of sediment grain minerals. An element such as silicon is excited by electron bombardment and the characteristic X-rays emitted are recorded and subsequently superimposed at the same scale over the original photograph of the area. As a result, for example, silicon location and concentration are known. Other elements spatially determined included aluminum, calcium, potassium, iron, phosphorus and uranium. The above investigative procedures are similar to those used in a study of plutonium in the soil (Price and Ames, 1975).

Results

Results of neutron-enhanced autoradiography, photomicroscopy, and electron microscopy of uranium-contaminated sediments are given below as an example of application of the technique developed to assess radionuclide/sediment interactions.

A low magnification photomicrograph of a portion of a radiocontaminated soil (Soil 1), with a matching autoradiograph, is given in Figure 67. Magnified areas are outlined in black squares and labeled A, A', C and D. Two pebbles are shown in Figure 67 surrounded by smaller fragments cemented on their exterior surfaces. All four areas which were subsequently examined on the electron microprobe are located in the smaller fragments cemented on the pebble exteriors.

In area A (Figure 67), the uranium particle looks dark in the optical photo and light in the magnified electron scattering photo. The same small uranium particle is also the dark body left of center in the autoradiograph. The image appears much larger here because the Lexan on which the image is developed is about 1 mm in thickness. Under neutron bombardment, the ^{235}U fissions in three dimensions around the particle in the shape of a sphere. The autoradiograph is thus represented on the Lexan surface as a section through a sphere. The X-ray emission photo for the element silicon (Si) showed that both of the large fragments in the electron scattering photo were quartz (SiO_2).

The remaining X-ray emission photomicrographs of area A for the elements, potassium, iron, aluminum, calcium, uranium, and phosphorus, are given in Figure 68. The high concentration uranium particle can be seen in the uranium X-ray emission photomicrograph. The only other element coincidental with the uranium as a major constituent was phosphorus. This was confirmed by electron microprobe chemical analyses.

Area A' includes a longitudinal concentration of uranium-contaminated silicon, as well as several uranium particles, as seen in the autoradiograph and silicon X-ray emission photos of Figure 69. The contaminated silica is not a natural material but is part of the waste constituents. Note that at a magnification of 200X, the individual alpha tracks can be distinguished in the Lexan autoradiograph.

FIGURE 67. Optical Micrograph and Autoradiograph of Uranium-Contaminated Sediment

FIGURE 68. X-ray Emission Photomicrographs of the Same Sediment Section Analyzed for K, Fe, Al, Ca, U, and P

A'

(A')

200 X

(A')

200 X

Electron Scattering

200X

Si

200X

FIGURE 69. Optical, Neutron Autoradiograph, Electron Scattering and X-ray Emission Photomicrographs of the Same Sediment Section Used to Evaluate Radiocontaminant Species

The remainder of the macro element distributions can be seen in Figure 70. The uranium is distributed in discrete particles rather than homogeneously throughout the soil. The uranium particles shown in Figure 70 are difficult to locate in the electron scattering or optical photos. The main uranium particles in the C area can be seen in the 200 and 500 magnifications of Figure 71.

The uranium in area D, however, is easily seen in both the optical and electron scattering photos in Figure 72. The uranium is dark in appearance within the circle on the optical photo, and light-colored to white due to its higher density in the electron scattering photo. Phosphorus is the only element associated with the uranium in an appreciable amount as seen in Figure 73.

High concentration uranium areas in sediment mounts of soil 1 were evaluated by electron microprobe to distinguish the elemental composition uranium in proximity to soil-sediment particles. The results of electron microprobe analyses are shown in Table 7. Note that elemental compositions do not total 100 wt% partially because any element lighter in atomic weight than sodium generates an X-ray that is of insufficient energy for detection.

Statistical analysis (Snedecor, 1946) of the data shown in Table 7 was then used to determine if there was any significant correlation between uranium and any other identified elements. Of the elements identified a correlation was found between compounds of uranium and phosphorous with a correlation coefficient of 0.89. This coefficient suggests a positive correlation between uranium and phosphorus as determined by electron microprobe analysis. From this result, statistical regression was used to evaluate the correlation between UO_2 and P_2O_5 compounds. The regression results of P_2O_5 on UO_2 are shown in Figure 74. Utilizing this regression, the molar ratio of phosphorous to uranium was determined by dividing the weight percent of phosphorous by its molecular weight and subsequently dividing the value by the product of the weight percent of uranium by its molecular weight. From the above for soil 1 a ratio of approximately 3 to 2 (phosphorous to uranium) was determined.

FIGURE 70. X-ray Emission Photomicrographs of Additional Contaminated Sediments Used to Evaluate Uranium Interaction with Sediment Particles

FIGURE 71. X-ray Emission Photomicrographs of Additional Contaminated Sediments Used to Evaluate Uranium Interaction with Sediment Particles

D

(D) 50 X

Electron Scattering 200X

Si 200X

FIGURE 72. Uranium Contamination Seen in Optical and Electron Scattering Photomicrographs

FIGURE 73. X-ray Emission Analyses Showing Correlation of Uranium and Phosphorous (see Figure 72)

TABLE 7. Electron Microprobe Chemical Analyses of High Concentration Uranium Areas in Soil 1

Elements	wt%				
	1A				
SiO ₂	2.8	16.2	8.9	7.1	2.6
Al ₂ O ₃	0.1	9.9	5.0	7.4	0.3
MgO	0.3	---	---	---	---
CaO	1.3	8.7	1.2	0.9	1.5
FeO	1.4	3.5	2.1	1.5	2.3
TiO ₂	0.1	---	---	---	---
K ₂	2.9	1.4	2.8	1.7	1.4
P ₂ O ₅	22.2	21.7	25.5	27.1	27.1
O ₂	69.1	38.7	53.8	53.4	63.1

FIGURE 74. The Regression of X₂ (P₂O₅) on X₁ (UO₂)

The probable chemical composition of the phosphrous-uranium compound found on soil particles was then determined. The observed P/U ratio of 3/2 and charge balance relationships, assuming U(VI), suggested that the compound is very likely $(\text{UO}_2)_2 [(\text{H}_2\text{PO}_4)_2(\text{HPO}_4)]$. With the added constraint of a measured 6.9 pH, a net negative charge per phosphorus ion of -1.33 is also satisfied by this compound. Although the original uranyl nitrate and phosphorus compound may have been more acidic, the buffering capacity of the soil would tend to return it to a near-neutral pH condition. Thus, soluble uranyl nitrate solution injected into the groundwater system during discharge operations possibly migrated from the 316-4 Crib under slightly acidic conditions. As the pH of the groundwater system was effectively buffered by the soil, the solubility decreased and migration subsequently was retarded. Uranyl phosphate, $\text{UO}_2\text{HPO}_4 \cdot 4\text{H}_2\text{O}$, is reported to be insoluble in water at pH 7.0 and in acetic acid, but soluble in nitric acid and sodium carbonate solutions (Weast, 1977).

The most chemically similar material to $(\text{UO}_2)_2 [(\text{H}_2\text{PO}_4)_2(\text{HPO}_4)]$ is UO_2HPO_4 . The solubility product for the reaction $\text{UO}_2\text{HPO}_4 \rightleftharpoons \text{UO}_2^{2+} + \text{HPO}_4^{2-}$ was given by Palei (1962) as 2.14×10^{-11} or $10^{-10.67}$. At pH 7.0 and a soil solution phosphate content of 10^{-7} moles/l, the UO_2 content of the soil solution was suggested to be about 10^{-9} moles/l.

In addition to the high concentration uranium particles on sediment grains, other lower concentration uranium occurrences were found which were homogeneous over a relatively large area. Chemical analyses of the solid phase on which the uranium was apparently adsorbed are given in Table 8. This material was extracted from a sample mounted and subjected to X-ray analysis using small particle X-ray diffraction technique. The resulting X-ray diffractogram identified nontronite, $[\text{Fe}^{3+}]_{2.00}[\text{Al}^{0.33}\text{Si}_{3.67}]_{10}[\text{OH}]_2\text{X}_{0.33}$, in which $\text{X}_{0.33}$ represents the exchangeable cations as the sedimentary material concurrent with the low concentration uranium. The X-ray analyses also demonstrated that the formulation contains excess hydrated iron oxides mixed with the nontronitic clay and that the clay is predominantly potassium based. Nontronite is a member of the smectite group of clay minerals which are natural soil constituents present in most Hanford soils.

X-ray diffraction and X-ray emission results then were compared. Ion uptake, i.e., surface adsorption and ion exchange by nontronite or similar smectite clay minerals, was found to be responsible for retaining low concentrations of uranium throughout the sediment matrix.

Column Leaching Tests

Once the chemical compound of phosphorous and uranium was identified and the occurrence of ionic uranium in clay minerals in radiocontaminated core sediments was determined, leachability of the uranium was studied. The preliminary concentration of uranium in the samples was determined by alpha counting (Table 9). For comparative purposes an uncontaminated undisturbed sample was included.

TABLE 8. Microprobe Chemical Analyses of Low Concentration Uranium Particles in Mount 3B

<u>Constituents</u>	<u>A, wt%</u>	<u>B, wt%</u>
SiO ₂	38.5	38.2
Al ₂ O ₃	13.1	12.5
TiO ₂	4.0	3.8
Fe ₂ O ₃	21.6	21.8
CaO	0.5	0.4
MgO	7.7	8.1
K ₂ O	7.9	8.4
Na ₂ O	---	---
P ₂ O ₅	1.2	1.0
UO ₂	1.2	1.2

Column leaching studies were initiated in order to determine the leachability of uranium from the 316-4 Crib and to qualitatively evaluate the potential for uranium migration within the saturated groundwater system at other 300 Area Burial Grounds. Small columns of uranium-contaminated soil were used.

TABLE 9. Uranium Concentration in Core Samples and a Background Soil Sample

<u>Soil Sample</u>	<u>Depth, cm</u>	<u>U, g/g Soil</u>
1	0-25	444 $\pm$ 155
2	25-50	623 $\pm$ 220
3	50-75	912 $\pm$ 320
Uncontaminated	---	9.24 $\pm$ 3.2

Distilled water, 0.1 N HNO_3 and methyl isobutyl ketone, respectively, were used as leaching agents. The leaching agents were added slowly to the top of the soil columns, with flow rates determined by soil column packing. The column flow rates averaged about $0.8 \text{ cm}^3/\text{min}/\text{cm}^2$.

The total amounts of uranium eluted by each reagent from soil 1 are given in Table 10. In general, the 0.1 N HNO_3 solution ($\text{pH} = 1.0$) eluted the most uranium while the organic solvent, methyl isobutyl ketone, eluted the least. The leaching results are consistent with uranium present as a sparingly water-soluble uranyl phosphate. Curves for cumulative uranium leaching versus column volumes of throughput are given in Figure 75 as an example for water, methyl isobutyl ketone and dilute nitric acid.

The elutant concentration with respect to uranium for each leaching agent was then determined and compared to radiation standards. From this comparison it was found that leaching of uranium-contaminated buried waste with natural ground water or with certain organic solvents would probably not result in significant migration. Leaching with acidic solutions would, however, potentially cause accelerated radionuclide migration in ground water.

FLUID TRANSPORT CHARACTERIZATION AND MODELING

The potential transport of radionuclides from buried wastes to the biosphere depends on numerous factors involving the waste form, the geological containment matrix and environmental mechanisms controlling mass and energy

FIGURE 75. Cumulative Leaching of Uranium from Soils 1, 2, and 3 0.1 N HNO_3 .
 Total U was 7733 pCi 14, 529 pCi and 17, 805 pCi, respectively.
 Column volume was 5.42 cm^3 , 4.51 cm^3 , and 4.96 cm^3 .

TABLE 10. Total Uranium Eluted from Soil 1, by Approximately Three Column Volumes of Distilled Water, Methyl Isobutyl Ketone and Nitric Acid

<u>Leaching Agents</u>	<u>Column Volumes</u>	<u>Total U Eluted, pCi</u>
Distilled Water	3.0	1.98
Methyl Isobutyl Ketone	3.1	1.59
0.1 <u>N</u> HNO ₃	2.8	224.3

balance within the hydrogeologic and atmospheric domains. Typically, radionuclides in the liquid phase originating from buried waste are transported within geologic material by water. This water originates through either of two general sources: 1) from the waste material disposed during burial in the hydrologic system or 2) in the form of rainfall, ground water, connate water, etc. Many radionuclides may be transported by water occurring at waste disposal sites, where they may possibly migrate within the groundwater system and ultimately to the surface-water system. Radionuclides may also be transported by migration directly upward to the burial matrix/atmosphere interface.

The rate and magnitude of radionuclide migration and the resultant exposure is additionally controlled by the affinity of the radiocontaminant containment matrix for each radioactive element. Thus, radionuclides are not uniformly transported by water in the hydrologic system and may be selectively retarded from migration through radionuclide/sediment physicochemical interactions. However, many radionuclides, e.g., tritium, and organically complexed cobalt, are effectively directly transported from waste burial sites by water.

For the 300 Area Burial Grounds, the following methodology was developed to:

1. evaluate burial site lithology
2. collect lithologic samples
3. analyze water retention and flux of lithologic samples in the laboratory
4. evaluate climatological data and climatological models
5. develop a computer data base
6. develop a computer model for the partially saturated zone
7. simulate and predict waste migration
8. perform sensitivity analysis of the model.

Water Flow and Potential Transport

Buried wastes in the 300 Area Burial Grounds are wholly contained within the partially saturated groundwater zone above the saturated groundwater zone. The partially saturated groundwater zone typically consists of well-drained coarse sediments of glaciofluvial origin. Due to the coarse texture of these sediments, the volumetric water retention capacity is low which results in a sparse arid vegetation occurring at the ground surface.

Water transport in the partially saturated zone may occur both in the liquid and vapor phases (evaporation). Liquid transport in soils is governed by the hydraulic properties of the system. Water is lost from the surface by evaporation into a drier atmosphere, primarily by diffusional processes. Evaporation from near ground surface sediments on the Hanford Site or similar arid environments has been independently determined by utilization of an evaporation model (Wallace, 1978). Precipitation calculated on an annual basis as reported was found to exceed evaporation. Calculations showed a mean increase in meteoric water of 11.6 mm stored in the partially saturated groundwater zone. Thus, the water stored in this zone, where precipitation exceeds evaporation, may be capable of drainage through waste burial sites. Consequently, radionuclides could be leached and subsequently transported to the biosphere.

The lithology of the sediments which extend from the ground surface to the water table at the 300 Area Burial Grounds is extremely diverse. This diversity is a basic function of the material, i.e., sediments and the mode of sediment deposition. For example, the sediment stratigraphy profile at Burial Ground 4 is typically interlayered coarse sands and gravels deposited by high-velocity fluvial processing overlain by a relatively thick mantle of aeolian-derived sand; while the stratigraphic profile at the 300 Wye Burial Ground consists of interlayered moderate to coarse-textured sands and gravels laid down by numerous successive fluvial depositional regimes of lower velocity and sediment transport capacity, overlain by a moderate thickness of aeolian-derived sand. The spatial distribution of sediments in these areas constitutes numerous isotropic and nonisotropic heterogeneous configurations. As a result, the lithologic configuration of 300 Area sediments is extremely varied within and between each of the burial grounds. Thus, definition of a unique profile of sediments through which water could conceivably flow and transport radionuclides is conceptually unobtainable. Therefore, an idealized (simplified) lithologic profile was used for further assessment. The lithologic profile consisted of a trimodal configuration of sand overlying a gravel layer which in turn was overlying a sand layer.

A radionuclide migration test site was constructed adjacent to the 300 North Burial Ground (Figure 76) to provide a basis for monitoring the flow of water through an idealized nuclear waste burial site under somewhat similar conditions to those existing in the 300 Area Burial Grounds. The site is comprised of two large, 2.75 m x 7.6 m, closed bottom lysimeters which contain uniform sand material to a depth of 7.6 m, and a 0.3-m layered gravel discontinuity at a depth of approximately 6 m. The hydrological characteristics of the material at this site were used in a simulation model to predict the water transfer in the 300 Area Burial Grounds during periods of normal and excessive precipitation.

The water retention and flux characteristics of the sediments in the field model site were then determined by laboratory evaluation of sediment samples collected in the region of the 300 Area and data analysis computer

FIGURE 76. Radionuclide Migration Test Site Located Adjacent to 300 North Burial Ground

programs. Figures 77 and 78 show examples of the measured water retentivity of the sand material with its corresponding calculated hydraulic conductivity. Figures 79 and 80 show the same relationships for the gravel layer discontinuity.

Micrometeorological/climatological data for the Hanford Site were assembled and utilized as computer input to evaluate evaporation/ evapotranspiration models. The models were selected and evaluated to determine the model producing the most reasonable results for the study area. The models included examination of potential and actual evaporation/ evapotranspiration by the following methods: 1) Blaney-Criddle (1962); 2) radiation (Makkink, 1957, Doorenbos and Pruitt, 1977); 3) Penman (1948); 4) modified Penman (Doorenbos and Pruitt, 1977).

In order to simulate and predict water flow at the 300 Area burial sites, the effects of evaporation/evapotranspiration, burial sediment lithologic configuration, and water retention and flux were compiled for conditions present and potentially existing within the study area. This information was systematically compiled for use as input for computer simulation.

Computer Simulation

A one-dimensional, finite difference computer model was developed to simulate isothermal water infiltration, vertical drainage, and water extraction, under given environmental conditions. The specific model was developed by modification of an existing computer code (Gupta et al., 1978). The salient features of this code are shown in Figure 81 which demonstrates the versatility of application of this model subjected to simulation of water migration under diverse environmental conditions.

The model was used to simulate actual, idealized water flow in the partially saturated zone at waste burial grounds on the Hanford Site and to predict water flow in this zone under different climatic conditions. The model was also used to parametrically evaluate the sensitivity of evaporation/ evapotranspiration, lithologic configuration, and retention as well as hydraulic characteristics of the lithologic material.

FIGURE 77. Soil-Water Characteristic Curve for Fine Sand

FIGURE 78. Hydraulic Conductivity Computed by the Millington-Quirk Method for Fine Sand

FIGURE 79. Soil-Water Characteristic Curve for Coarse Sand

FIGURE 80. Hydraulic Conductivity Computed by the Millington-Quirk Method for Coarse Sand

FIGURE 81. Salient Features of Computer Model "Field Simulation of Soil-Moisture Movement with Crop Water Extraction"

Source: Gupta et al., 1978

The developed simulation/prediction code was then applied to specific cases. Preliminary evaluation of model results showed that rainfall intensity, duration, and distribution were important factors in partially saturated groundwater flow. Therefore, climatological records were evaluated to define time intervals of equivalent cumulative rainfall and potential evaporation and nonequivalent rainfall distribution and intensity. The years 1947 and 1948 were found to have the above similarities with respect to total precipitation and dissimilarities, with respect to rainfall intensity duration, and distribution were used in further model cases.

Ground-Surface Desiccated Layer Sensitivity

A simulation was performed to determine the effects of a desiccated, i.e., a hydrophobic, sediment layer at the ground surface of burial sites. The results, using climatological data for 1948, are summarized in Table 11.

TABLE 11. Simulation of 1948 Climate With and Without a Hydrophobic Surface Layer. Blaney-Criddle Potential Evapotranspiration (PET) and standard initial conditions.

	<u>Infiltration (cm)</u>	<u>Evaporation (cm)</u>	<u>Drainage (cm)</u>	<u>Storage (cm)</u>
Without Layer:	24.09	26.28	-0.40	42.57
With Layer:	24.51	23.41	-0.25	45.90

- implies upward movement

The simulation suggests that a desiccated ground surface layer which typically occurs in arid environments such as the Hanford Site may be detrimental in that by retarding evaporation it may cause increased drainage. For the above case, however, insignificant differences are noted, and there is a small (2 to 4 mm) net upward movement from the water table under the specific climatic regime for 1948.

Hydraulic Conductivity Sensitivity

Effects of differences in hydraulic conductivity of the unsaturated sediments were valuated. The hydraulic conductivity function, K, was decreased by factors of 10 and 100 and the resultant annual water balance evaluated. The results of this simulation are shown in Table 12.

TABLE 12. Simulations Based on 1948 Climate, Without Hydrophobic Surface Layer

<u>Conductivity</u>	<u>Infiltration (cm)</u>	<u>Evaporation (cm)</u>	<u>Drainage (cm)</u>	<u>Storage (cm)</u>
K	24.09	26.28	-0.40	42.57
K/10	24.46	23.29	-0.21	45.70
K/100	24.51	22.66	-0.12	46.19

Results indicate that reduction in hydraulic conductivity causes infiltrated water to remain relatively near the ground surface and also reduces drainage. An interesting result is that of reduction in evaporation with reduced hydraulic conductivity. This is likely due to the reduced rate at which water can be transported to the evaporation sites at the soil surface. The net effect of lower conductivity is decreased evaporation and increased storage.

Water Flux Simulation

Figure 82 illustrates the cumulative flux of water at various depths in response to the climatic variables of precipitation and potential evaporation for 1948. The data show that the upper 200 cm are most responsive to the climatic inputs. The summer drying period is sufficiently long that there is negative seepage (upward flow) at all depths at the end of the test period (1948). The storage changes on the other show a slight increase at the end of the 1948 calendar year in the top 200 cm. These results reflect the sensitivity of drainage and storage to the daily climatic variable input.

Layering Sensitivity

Model sensitivity simulations were also performed to investigate the effect of a lithologic profile configuration, i.e., layering effects, and effects of water-table depth. Horizontal layering of adjacent sedimentary materials with different texture, hydraulic conductivity or water retention properties were shown to retard drainage. Simulations were performed using a layering configuration of sand-gravel-sand and only sand. The effects of depth to water table were also simulated in that evaporation and water storage in the lithologic profile was thought to somewhat affect the migration of water through burial site materials. Simulations were performed on the sand-gravel-sand configurations with a depth to water table difference of 1 m. Results of simulations of lithologic profile configuration and water table depth are summarized in Table 13. Differences in water content in the profile with and without a gravel discontinuity are shown in Figures 83 and 84 as examples.

FIGURE 82. Simulated Soil-Water Movement Using Penman PET and 1948 Climate; a) Cumulative Seepages at Selected Depths, b) Profile Soil-Water Storage Differences

TABLE 13. Simulations Using 1947 Climate and Blaney-Criddle PET Method, Assuming Presence of a Hydrophobic Layer for the Following Cases: (a) 800-cm water table including gravel and layer 600 to 650 cm; (b) 700-cm water table including coarse sand layer 600 to 650 cm; (c) 800-cm water table without gravel layer

Case	Infiltration (cm)	Evaporation (cm)	Drainage (cm)	Storage (cm)	
				Initial	Final
(a)	23.47	20.13	-0.05	44.62	47.95
(b)	23.47	20.41	-0.73	37.77	41.45
(c)	23.47	20.43	0.26	50.03	52.72

Rainfall Sensitivity

Annual rainfall was another factor evaluated by model simulation which permitted determination of potential migration of water through waste burial sediments. It was thought that increased rainfall could increase the amounts of water draining into the water table through waste burial grounds. Moreover, the likelihood of net drainage into the water table was thought to depend on the previous rainfall history. To study effects of rainfall amount, six consecutive years with rainfall equal to various multiples of 1948 rainfall were simulated. Each year the same pattern of potential evaporation and rainfall was repeated, but the rainfall was multiplied by a common factor each year. Each year's simulation used as initial conditions the final conditions of the previous year, except in the first year where the standard initial conditions were applied. The results of this simulation are presented in Table 14.

The effects of different applications of rainfall and the possible effects of rainfall application on evaporation, drainage, and storage can be seen in the above table.

Rainfall Distribution Sensitivity

The effects of rainfall distribution were simulated to evaluate model sensitivity. The sensitivity analysis was performed using 1947 and 1948 climatological data since the total rainfalls were similar for those years

FIGURE 83. Water Content Profiles for Selected Days in 1947.
Rainfall was 8.8 cm for the period.

yet the distributions were different. In 1947, the majority of rain occurred in the fall, whereas rainfall was distributed over spring and winter of 1948. Beginning with the chosen standard initial conditions, the natural climate sequence for 1947-48 was used to simulate a 3-year period by repeating the 1948 climate. To further demonstrate importance of the rainfall distribution, a 3-year sequence based on repeated 1947 climate was simulated. The 1947-1948 repetition case and the repeated 1947 case results are shown in Tables 15 and 16.

FIGURE 84. Water Content Profiles for Selected Days in 1947 with Coarse Sand Layer Removed

TABLE 14. Simulation of Six Consecutive Years Based on Multiples of Rainfall in 1948. Blaney-Criddle PET Method and Hydrophobic Surface Layer Assumed

Year	Infiltration (cm)	Evaporation (cm)	Drainage (cm)	Storage (cm)
1	49.07 (2.0 x)	34.87	7.49	51.04
2	36.81 (1.5 x)	31.51	6.81	49.35
3	8.14 (0.33 x)	13.08	0.57	43.90
4	24.51 (1.0 x)	23.22	-0.34	45.48
5	36.78 (1.5 x)	30.87	1.87	49.33
6	18.46 (0.75 x)	21.14	0.99	45.61

TABLE 15. Simulation of a Three-Year Rainfall Sequence Based on Consecutive 1947 and 1948 Climates with a Repeated 1948 Year. Blaney-Criddle PET and Presence of a Hydrophobic Surface Layer are Assumed.

<u>Year</u>	<u>Infiltration (cm)</u>	<u>Evaporation (cm)</u>	<u>Drainage (cm)</u>	<u>Storage (cm)</u>
1947 (1)	23.47	20.13	-0.05	47.95
1948 (2)	24.56	25.02	0.73	46.70
1948 (3)	24.54	24.56	0.15	46.44

TABLE 16. Simulation of a Three-Year Rainfall Sequence Based on Repeated 1947 Climate

<u>Year</u>	<u>Infiltration (cm)</u>	<u>Evaporation (cm)</u>	<u>Drainage (cm)</u>	<u>Storage (cm)</u>
1947 (1)	23.47	20.13	-0.05	47.95
1947 (2)	23.47	21.97	1.15	48.23
1947 (3)	23.47	22.10	1.31	48.23

Simulation results indicate that the distribution of rainfall clearly affects the amount of infiltration, evaporation, drainage and storage of water at the idealized burial site under consideration. For example, approximately 1.3 cm of water would pass through the lithologic profile if sequential rainfall distribution similar to 1947 is used, whereas negligible drainage through the profile would occur if 1948 rainfall distribution was used.

The data suggest that textural discontinuities produced by sediment layering results in a reduced drainage over specific time intervals when compared to cases without layering. These effects, however, depend on the specific layer configuration.

Summary of Results

The overall results of the model simulation and prediction efforts have shown that for 300 Area Burial Grounds, the migration of water through the hydrogeological system is a complex phenomenon dependent on many temporal and spatial factors. The most important ambient factor may be rainfall

distribution. The developed simulation/prediction model utilized above has shown that on an annual basis a range from 5 mm of water evaporation to 10 mm water drainage can occur from nonvegetated surfaces at the 300 Area Burial Ground sites under a realistic range of environmental conditions. Results of radiochemical analysis of sediments collected below 300 Area Burial Ground waste burial structures, however, suggests that little or no drainage has occurred. Factors including surface layering, hydraulic conductivity, and hydrologic profile configurations are thought to be somewhat controllable by modifying their characteristics, i.e. by selected nuclear waste management practices, such as installing barriers. Thus, if the potential for radionuclide migration is thought to be significant in the future, the burial sites may be modified to reduce that potential.

BIOLOGICAL TRANSPORT

Various techniques were implemented to assess the biological integrity of the 300 Area Burial Grounds. The study involved organisms potentially capable of radionuclide transport. These organisms included vegetation, ants, reptiles, small mammals, and birds.

Vegetation

Vegetation cover serves as a way to reduce soil erosion by wind and water, thereby helping to maintain sufficient depth of backfill over buried material. Furthermore, vegetation can, in part, prevent rainfall from percolating deeply into burial ground backfill by returning meteoric soil water to the atmosphere via leaf transpiration. This is important because water returned to the atmosphere is not available to percolate through buried waste. For this project, percent canopy cover was estimated by visual inspection (Daubenmire, 1959) on two 50-m transects for each burial ground.

Annual grasses, annual forbs, perennial grasses, perennial forbs, and shrubs constitute the categories of vascular plants found growing on portions of the 300 Area Burial Grounds. Cheatgrass, Bromus tectorum, an annual, is the most important single contributor to plant canopy cover. Perennial grasses are scarce and provide little canopy cover. Perennial forbs are represented by five species but provide very little in the way of canopy cover.

The herbaceous canopy cover may vary greatly from year to year depending upon climatic and other conditions. For example, total canopy cover varied from 8% to 76% and averaged 39% over all burial grounds in 1976. In 1977, measurements taken on Burial Grounds 7, 300 North and 300 Wye showed the total canopy cover varied from 42% to 68%. Results also showed that several plant species have a high affinity for burial ground backfill as indicated by 100% fidelity (occurring on all burial sites) (Table 17). These are cheatgrass; spring draba, Draba verna; jagged chuckweed, Holosteum umbellatum; Russian thistle, Salsola kali; and tumble mustard, Sisymbrium altissimum.

Radiochemical Analysis

Vegetation was analyzed for the presence of gamma-emitting radionuclides. Leaf and stem tissues from various species were collected, dried and analyzed for ^{137}Cs by gamma spectroscopy. Shrubs, perennial forbs and annuals were collected on burial sites and also from adjacent control sites outside the burial grounds (Table 18). Shrubby plants growing outside burial ground enclosures had amounts of ^{137}Cs attributable to fallout from atmospheric thermonuclear detonations. One sample of cheatgrass had 9 pCi/g ^{137}Cs which may have been derived in part from a surface soil contamination. Only one plant, snowy buckwheat, Eriogonum niveum, had accumulated ^{137}Cs at significant levels, i.e., 300 pCi/g which indicates that backfill can occasionally be penetrated by deep-rooted plants.

Secondary Plant Succession

Secondary plant succession was considered in order to evaluate the potential for establishing a vegetation cover which could possibly exhumate significant concentrations of buried radionuclides. The self-reestablishment of vegetation on disturbed ground was found to follow a more or less predictable pattern. Early plant invaders are annual plants. These annual plants over time were found to be replaced or suppressed in abundance by perennial species that occupy the ground indefinitely unless they in turn are destroyed by man, fire or disease. The climax species of the 300 Area are believed to be sagebrush, Artemisia tridentata, and bitterbrush, Purshia tridentata. The time required for these shrubs to reinvade disturbed ground can be very long.

TABLE 17. Canopy Cover (Percent) and Species Composition of the Vegetative Cover on 300 Area Burial Grounds

Taxa	Burial Ground Designation										Fidelity
	West	#5	#3	North	#7a	#7b	#4	2	WYEa	WYEB	
Annual Grasses											
Bromus tectorum	29	0.8	39	4.7	9.1	9.9	20	24	43	13	100
Festuca sp.	1.2	0	1.2	0.1	0.5	T	T	1.0	0	1.8	80
Total Ann. grasses	30.0	0.8	40.0	4.8	9.6	9.9	20	25	43	15	
$\bar{x} = 20\%$											
Annual Forbs											
Draba verna	2.4	0.7	2.2	5.3	2.2	2.5	3.1	3.2	2.5	1.2	100
Holosteum umbellatum	2.7	0.8	13	0.5	3.6	2.6	17	3.8	5.0	6.7	100
Salsola kali	0.1	3.8	1.4	3.5	3.8	1.8	0.2	1.7	0.4	2.3	100
Erodium cicutarium	0.5	0	3.6	0	0	0	0	T	0	0	30
Cryptantha circumscissa	0.6	0	0	T	1.2	0.3	0	0.3	1.5	0.6	70
Sisymbrium altissimum	0.5	2.1	T	1.0	2.0	9.3	0.4	0.5	2.5	0.5	100
Amsinckia lycopsoides	0	0	0	0	0.4	0	0	0	1.9	0	20
Lepidium sp.	0	T	0	0	0	0	0	0	1.3	T	30
Lactuca sp.	0	0.5	0	0	0	0	0	0	0	0	10
Plantago patagonica	0	0	0.1	0	0	0	0	0	0	0	10
Ambrosia acanthicarpa	0	0	0.1	0.7	0.4	0	0.1	0.6	0.1	0.2	70
Microsteris gracilis	0	0	0	0.1	0.2	0	0	0	1.0	0.7	40
Descurainia pinnata	0	0	0	0.1	0.2	0	0	0	0.2	0.3	40
Myosurus aristatus	0	0	0	0	0.1	0	0	0	0	0	10
Cryptantha pterocarya	0	0	0	0	0.2	0	0	0.1	0.1	0	30
Total Ann. forbs	6.8	7.9	20.0	11.0	14.0	16.0	21	10.0	16.0	12.0	
$\bar{x} = 13\%$											
Perennial Grasses											
Poa sandbergii	0	0	0.8	0	0	0	0	0.1	0	0.1	30
$\bar{x} = 0.1\%$											
Perennial Forbs											
Psoralea lanceolata	0.7	0	0	0	0	0	0	0	0	0	10
Phlox longifolia	0.2	0	0.2	0.2	0.1	0.2	0.1	0.3	0.6	1.1	90
Aster canescens	0	0	0.7	0	0	0	0	0	0	0	10
Rumex venosus	0	0	0	0	0	0	0	0	0	0.1	10
Astragalus sp.	0	0	0	0	0	0	0	0	0	0.8	10
Total Pern. forbs	0.9	0	1.7	0	0.1	0.2	0.1	0.4	0.6	2.1	
$\bar{x} = 0.6\%$											
Shrubs											
Eriogonum niveum	0.1	0	0	0	0.9	0	17.9	0.2	0	0	40
Chrysothamnus nauseosus	13.5	0	15.4	0	0	0	0.3	6.9	0	0	40
Total Shrubs	14.0	0	15.0	0	0.9	0	18.0	7.1	0	0	
$\bar{x} = 5.5\%$											
Total Canopy Cover	52	8.7	77	16	25	26	59	42	60	29	

T = Trace, #7a and #7b = two transects, WYEa and WYEB = two intersects

TABLE 18. Radionuclide Analysis (gamma scan) for ^{137}Cs in Plant Tissues Collected from 300 Area Burial Grounds and from Adjacent Land

Taxa	Burial Ground Designation							Adjacent Land	
	North	2&3	4	5	6&7	West	Wye	West	Wye
Shrubs									
<i>Eriogonum niveum</i>	NS	--	NS	--	NS	--	*300 pCi/g	*1.07	--
<i>Chrysothamnus nauseosus</i>	NS	--	NS	NS	NS	NS	--	NS	NS
<i>Lycium halimifolium</i>	--	NS	--	--	--	--	--	--	--
<i>Purshia tridentata</i>	--	--	NS	--	NS	NS	--	*0.2	--
<i>Artemisia tridentata</i>	--	--	--	--	--	NS	NS	*0.5	--
<i>Chrysothamnus viscidiflorus</i>	--	--	--	--	--	--	--	NS	--
Perennial Forbs									
<i>Aster canescens</i>	--	NS	NS	NS	NS	NS	NS	--	NS
<i>Achillea millefolium</i>	NS	NS	--	--	--	--	--	--	--
Annuals									
<i>Bromus tectorum</i>	NS	NS	NS	NS	NS	NS	*9.4	--	--
<i>Ambrosia acanthicarpa</i>	NS	NS	--	NS	NS	NS	NS	--	--
<i>Salsola kali</i>	NS	NS	--	NS	--	NS	NS	NS	NS
<i>Sisymbrium altissimum</i>	NS	NS	NS	NS	NS	NS	--	--	--
<i>Amsinckia lycopsoides</i>	NS	NS	--	NS	NS	NS	--	--	--

NS = Count not statistically significant

- = No sample taken

* pCi/g dry weight

Abandoned agricultural fields in the Hanford Site have not been invaded by shrubs even after 35 years. Thus, climax community shrubs may not reinvade 300 Area Burial Ground backfill over extended periods of time.

Ants

Ants were studied to provide a preliminary assessment concerning what effects, if any, they might have while living within the fenced enclosures of the 300 Area Burial Grounds. The ant population was characterized by searching out colonies and by collecting specimens attracted to baits. Species occupying burial grounds were *Solenopsis molesta* and the harvester ant, *Pogonomyrmex owyheei*. Two additional species, *Formica subpolita* and *Formica manni*, were collected from areas adjacent to the enclosure but were not found on the burial ground itself.

Harvester ants were found to be dominant at burial sites at lower elevations. These ants are relatively large and typically invade disturbed soil, thus inhabitation of the 300 Area Burial Grounds is of particular interest. Colony densities were obtained from several burial grounds. Results of colony densities are shown in Table 19 for equivalent-sized areas located within and adjacent to the burial grounds. The data suggest that harvester ants prefer to establish their colonies within disturbed areas such as the 300 Area Burial Grounds.

TABLE 19. *Pogonomyrmex owyheeii* Colony Densities in Burial Grounds

<u>Location</u>	<u>Total Number Colonies</u>	
	<u>Inside Enclosure</u>	<u>Control</u>
Wye	358	90
300-North	86	38
300-7	244	8
300-West	0	0
300-4	<u>20</u>	<u>15</u>
Total	708	141

Ant excavation potential was studied in order to estimate the quantity of potentially contaminated radionuclides which could be exhumed from burial structures and transported to the ground surface. The nest construction habits of harvester ants are much better known than for other ant species. Tunneling depths of harvester ants extend to 3.0 m. The total amount of soil excavated by the harvester ant was estimated to average 3.8 kg over the life of the colony. Extrapolating soil excavation volume estimates from Table 20 with the colony densities shown in Table 19 permits an estimation of total soil movement (Table 21). About 11% of this soil is thought to be moved from depths greater than 1.5 m. Thus, harvester ant colonies located on the Wye Burial Ground, for example, transport about 8.4 kg of soil material each year from depths exceeding 1.5 m. Harvester ants were then concluded to possess the potential for moving small particles of contaminated material to the surface where it could be further distributed by wind and by biota.

TABLE 20. Maximum Depths and Volumes of Soil Excavated by Five P. owyheei Colonies

<u>Colony</u>	<u>Amount (cm³)</u>	<u>Maximum Depth (m)</u>
1	2468	2.7
2	3147	2.5
3	1518	2.5
4	713	2.0
5	1027	1.7
x $\pm$ S.E.	1774 $\pm$ 453	2.3 $\pm$ 0.2

TABLE 21. Total Soil Movement by Harvester Ants on 300 Area Burial Grounds

<u>Burial Ground</u>	<u>Soil Movement/Year(a)</u>	
	<u>Volume (cm³)</u>	<u>Mass (kg)(b)</u>
WYE	63,509	76.2
300 North	15,256	18.3
300 6 and 7	43,286	51.9
300-West	0	0
300-4	3,548	4.3
TOTAL	125,599	150.7

(a) Assumes colony life span = 10 years

(b) Assumes soil bulk density = 1.2 g/cm³

Reptiles

Since lizards and snakes associated with the burial sites are carnivores, they may be valuable indicators of the bioavailability of radionuclides in local ecosystems. Unlike birds and many mammals, most reptiles are sedentary in nature and seldom move more than a few kilometers in their lifetimes (Fitch, 1949; Hirth et al., 1969). Any radionuclides found in individuals

living on or adjacent to a burial site would therefore provide an indication that the source of radionuclides was the burial site itself. For example, burrows or crevices formed from caveins may provide pathways to buried waste and serve as hibernation sites for lizards.

Reptiles associated with burial sites can also serve as vectors of radioactivity. For example the Swainson's hawk, Buteo swainsoni, feeds heavily on snakes.

To study reptile and amphibian populations, a survey path immediately adjacent to four burial sites (4, 7, 300 North, 300 Wye) was walked during two mornings in each of the months of March, April, May, June, and July 1978. All reptiles observed were recorded to species. Table 22 lists the species encountered at the four study sites. Amphibians were never observed during the burial site studies.

TABLE 22. Reptiles Observed at the 300 Area Burial Sites

Species	Burial Site			
	4	7	300 North	300 Wye
Western Yellow-bellied Racer (<u>Coluber constrictor</u>)	X		X	X
Gopher Snake (<u>Pituophis melanoleucus</u>)		X		X
Side-blotched Lizard (<u>Uta stansburiana</u>)				X
Sagebrush lizard (<u>Sceloporus graciosus</u>)	X	X	X	

Small Mammals

Small mammals were studied on four sites: 300 North, 300 Wye, Burial Ground 7 and a control. On each of the study sites, a trap grid containing 100 Sherman live traps was established. The traps were spaced at 10-m intervals in a 10 x 10 pattern oriented in part over waste burial trenches. These

traps were utilized to collect small mammals living in or near the burial grounds. The trapping process yielded species of small burrowing rodents. Captured rodents were then evaluated for gamma exposure and biological uptake.

Two species of mice were consistently trapped on all four study sites. These were the Great Basin pocket mouse, Perognathus parvus, and the deer mouse, Peromyscus maniculatus.

When a rodent was initially captured it was marked by using a series of toe amputations, giving it a unique identification number. The data collected per each trapped rodent included trap location, species, sex, reproductive condition, relative age, and weight. In addition, each animal was surgically subcutaneously implanted with a 7 mm x 10 mm packet containing 2 LiF thermoluminescent dosimeters. The animal was anesthetized while the packet was inserted under the loose dorsal neck skin (Figure 85). The incision was sutured to help prevent infection and promote healing. Following surgical implantation, identification, etc., the animal was returned to its capture location and released. When an animal was recaptured, the old dosimeter packet was removed and replaced with a new one. All returned dosimeters were analyzed for exposure and reported in milli-Roentgens.

Analysis of the dosimeters showed that the average exposure for all areas including the control plot was less than 2 mR/wk (Table 23). The highest exposure received by a pocket mouse was 8.7 mR/wk on 300 North Burial Ground. This is slightly higher than the highest pocket mouse exposure on the control plot which was 4.0 mR/wk. Deer mice trapped on Burial Grounds 300 North and 7, however, had average exposures significantly higher than the controls with 28.5 mR/wk and 38.1 mR/wk, respectively. Comparatively, the deer mouse exposures on the control plot matched the pocket mouse exposures with less than 2 mR/wk. The highest exposure rate to a deer mouse came from Burial Ground 7 with 476 mR/wk, and that received by a deer mouse on 300 North was 112 mR/wk. There were 28 deer mice on Burial Ground 7 and 5 on 300 North with exposure rates greater than 19.2 mR/wk or 1 R/yr (Table 24).

FIGURE 85. Implantation of Dosimeter Packet in Pocket Mouse

TABLE 23. Mean Gamma Exposure Rates to Mice Captured on 300 Area Burial Grounds (mR per week)

Study Site	Pocket Mouse			Deer Mouse		
	n	$\bar{x} \pm S.E.$	Range	n	$\bar{x} \pm S.E.$	Range
WYE Burial Ground	21	1.11 $\pm$ 0.10	0.42 to 1.75			
300 North B.G. (a)	40	1.96 $\pm$ 0.18	1.23 to 8.66	14	28.5 $\pm$ 11.1	1.21 to 112.0
300 #7 B.G. (a)	30	1.89 $\pm$ 0.07	1.47 to 3.00	57	38.1 $\pm$ 9.31	1.30 to 476.0
Control Plot	34	1.57 $\pm$ 0.11	0.63 to 4.04	3	1.96 $\pm$ 0.09	1.81 to 2.12

(a) Burial Ground

TABLE 24. Exposure Rates Greater than 19.2 mR/wk for Deer Mice Captured on 300 Area Burial Grounds North and Number 7

Number 7 Burial Ground			North Burial Ground
19.3	35.0	58.1	30.0
19.7	35.0	74.6	42.0
20.0	35.0	79.6	95.5
22.0	38.3	100.7	96.5
22.1	38.6	101.6	112.0
22.3	42.0	117.2	
24.1	46.5	236.6	
24.3	49.7	476.0	
24.6	51.6		
28.5	54.8		

Occasionally an animal would die during the dosimeter implant operation as a result of anesthesia overdose, which provided tissue samples for radiochemical analysis. Two tissue types were used for this analysis. The hide including the fur, feet, and tail made up one sample representing an exterior tissue, and the remaining carcass represented an interior tissue sample. These tissues were dried in an oven at 75°C for at least 48 hr and then analyzed by gamma spectrometry.

Radiological analysis of small mammal tissues yielded very small concentrations of ^{137}Cs . Thirty-eight animals were analyzed for external and internal tissue concentrations of ^{137}Cs . A sodium iodide scintillation detector was used for the analysis. All values for external tissues (skin, fur, feet, and tail) were below detection limits, while in four of the internal samples (remaining carcass) concentrations ranged from 2.3 to 9.8 pCi $^{137}\text{Cs/g}$ dry weight. Three of these internal samples were pocket mice and one was a deer mouse.

Birds

Bird survey paths were located adjacent to four burial sites, 300 North, 300 Wye, 4 and 7. Surveys were taken twice each month during March, April, May, June, and July 1978. Table 25 lists the species observed in or adjacent to the burial sites.

Summary of Results

Results showed only a few biological vectors at the 300 Area Burial Grounds capable of transporting radionuclides. Recommendations were formulated to further reduce the potential for biological transport of radionuclides. These recommendations include establishment of: shallow-rooted plants rather than permitting succession of deep-rooted plants at waste burial grounds; barriers to suppress wind and water erosion; and barriers to effectively eliminate intrusion into buried waste by plants and animals.

CONTAMINANT MIGRATION DRILLING AND RADIOCHEMICAL ANALYSIS

Migration of radionuclides from Hanford 300 Area waste burial structures depends on numerous factors including the type, quantity, and rate of transport of radionuclides within the sedimentary material which comprises the primary waste containment barrier. In order to quantify the actual migration of specific isotopes from burial structures and to delineate their spatial concentrations, retrieval of radiocontaminated sediments was required.

TABLE 25. Breeding Birds of the 300 Area Burial Grounds^(a)

Species	Location			
	300 North	No. 4	No. 7	"Y"
Western Meadow Lark ^(b) (<u>Sturnella neglecta</u>)	C	C	C	C
Horned Lark ^(b) (<u>Eremophila alpestris</u>)	C	C	C	C
Sage Sparrow ^(b) (<u>Amphispiza belli</u>)	U	U	U	U
Long-billed Curlew ^(b) (<u>Numenius americanus</u>)	U	U	U	U
Ring-billed Gull (<u>Larus delawarensis</u>)	C	C	C	C
California Quail (<u>Lophortyx californicus</u>)	U	U	C	U
Black-billed Magpie (<u>Pica pica</u>)	C	C	C	C
American Kestrel (<u>Falco sparverius</u>)	U	U	U	U
Loggerhead Shrike (<u>Lanius ludovicianus</u>)	U	U	U	U
Mourning Dove ^(b) (<u>Zenaidura macroura</u>)	C	C	C	C
House Sparrow (<u>Passer domesticus</u>)	U	U	U	U
Killdeer ^(b) (<u>Charadrius vociferus</u>)	U	U	U	U
Swainson's Hawk (<u>Buteo swainsoni</u>)	U	U	U	U
Western Kingbird (<u>Tyrannus verticalis</u>)	U	C	C	C
Burrowing Owl (<u>Speotyto cunicularia</u>)	U	U	C	U
House Finch (<u>Carpodacus mexicanus</u>)	U	C	U	U

(a) Four surveys were conducted at each burial site. All surveys conducted during early morning hours on the following days---April 17, May 5, June 2, July 5.

(b) Species found or believed to be nesting on the burial grounds.

C = Observed on at least three surveys.

U = Observed on at least one survey.

Specialized drilling, core collection, and residual and radiochemical analysis were performed at the 300 North and Wye Burial Grounds, and Burial Grounds 4 and 5. Drilling and sample collection was conducted at the 300 North and Wye sites at locations where liquid or partially solidified wastes were disposed to bottomless caissons and where the potential for transport was highest. Drilling and sample collection at the remaining two sites was performed because these sites had higher hydraulic conductivity sediments which would possibly permit relatively higher rates of radionuclide migration and the potential for transport was high. The recorded radionuclide inventory of these two sets of burial grounds was also different. In other words, the 300 North and Wye Burial Grounds contain predominantly mixed fission products and plutonium, whereas the other burial grounds contain mostly uranium and thorium wastes. Thus, a broader range of leachable radionuclides could be studied.

To determine the amount and distribution of contaminants leached below 300 Area waste burial structures, core drilling was initiated in 1978. A drill rig and associated specialized drill string were procured. This equipment consisted of a trailer-mounted hydraulic-actuated auger drill capable of rapid drilling in shallow moderate to coarse textured unconsolidated sediments. This apparatus was of applicable design to permit drilling at low to moderate angles from the vertical which was required to intersect potential zones of contamination below waste burial trenches and caissons. A hollow stem auger was mounted hydraulically driven from the drilling rig such that continuous drilling from the ground surface to a maximum of 10 m in depth could be completed by successive additions to the drill string. A split tube core barrel was driven along with the auger such that the core barrel bit extended to a depth of approximately 2 cm below the bit affixed to the auger drill string. Thus, the auger drill string was intended to provide a casing for the core barrel drill. The enclosed core barrel provided a plug so that potentially contaminated sediments would not enter the auger casing during drilling.

Drilling of a specific well was initiated after preliminary geohydrological assessments. An initial prerequisite was locating a waste burial structure. Location of waste burial structures was typically determined by utilizing site engineering drawings in concert with geophysical survey measurements, as described previously. After locating a waste structure, structural records were reviewed to provide insight into the probable contents and dimensions of the structure. A decision to drill a sample collection well adjacent to the identified structure was then made if the probability for interception of radiocontaminants leached downward from the structure was sufficient to warrant further study.

When a burial site was identified as having some potential for leaching, a well location was selected. The wells were located to enable drilling beneath the structure where radiocontaminated leachate, if present, would be intercepted, rather than drilling into the burial structure. It was envisioned that if leachate moved out of a burial structure into the sediments it would migrate downward and laterally as a result of gravitational, matric, osmotic, and other soil potential, in addition to diffusion and dispersion phenomena. The leachate potentially containing radiocontaminants was thought to migrate with liquids derived from the buried waste through meteoric rainfall, snowmelt, etc.

After locating the well, the surficial material soil was removed to approximately 5 cm in depth radially from the well location to a distance of approximately 2 m. This soil was removed to limit the potential for surficial contaminated soil to enter the well annulus during drilling. Subsequently, a wooden drill platform with a hole located in its center was placed over the excavated area. The drilling apparatus was then placed over the drill pad so that the drill mast and casing collar were oriented to drill below the identified structure (Figure 86).

The well was drilled with hollow stem auger drill string containing a core barrel string as discussed above. When a predetermined depth was reached or where drilling was arrested by large textured materials, or indurated

sediments, the auger drilling was halted. The core barrel and associated drill string were then retrieved from the hollow steam auger, cleaned and filled with a mylar core barrel liner. The core barrel (Figure 87) was driven into the sediment below the depth of the auger bit to collect undisturbed potentially contaminated soil within the core barrel. The core barrel was retrieved from the well and disassembled. The mylar-lined core was secured, labeled, capped and double bagged in polyethylene for transport to and analysis at a radioassay laboratory. The core barrel and core and auger drill string were retrieved from the well and thoroughly cleaned and set aside for utilization of the next well.

Radiation monitoring with field instrumentation was performed continuously throughout drilling to assure radiation safety. Furthermore, radiation monitoring provided a screening of samples whereby, if greater than background levels or activity were detected, additional drilling and sample collection would be continued until the zone of contamination could be determined.

FIGURE 86. General Configuration of Drilling Below Waste Burial Structures

FIGURE 87. Auger Core Collection System Used to Retrieve Sediment Sample from Below Burial Structures

Collected core samples were submitted to an analytical laboratory (U.S. Testing Co., Richland, Washington) for gross alpha, gross beta and gamma X-ray spectroscopy analyses. These analyses were performed to quantitatively determine activity not readily identified during field monitoring.

Gamma spectroscopy was conducted on dry bulk soil samples for 100 min using a germanium-lithium drifted diode detector system. Pulse height analyses of electromagnetic spectra was completed automatically within the counting system (Lima and Atatta, 1974) by determining peaks, locating peak centroids, and calculating their corresponding energies and areas. Error estimates were also calculated automatically within the counting system.

Gross alpha analyses were completed by wet chemical extraction of bulk core samples using HNO_3 , evaporation, and subsequent plating on a planchet. The extracted plated material was counted in an alpha counting system. Gross beta analyses were conducted directly from subsamples of submitted bulk core samples by transferring 2 g of soil onto a planchet and counting in a beta counting instrument.

The activity of radionuclides emitting gamma, alpha, and beta radiation within core samples drilled adjacent to 300 Area burial structures is tabulated in Table 26. Relatively few radionuclides were identified within the core samples. The only radionuclide identified within all samples was potassium 40, a naturally occurring element. The remaining radionuclides identified include lead-214, radium-226, thallium-208, bismuth-214 and 212, actinium-228 and cesium-137. Of the above all of the radionuclides are naturally occurring as daughter products of uranium, with the exception of cesium-137.

Lead-214 is a descendent of naturally occurring radium-226 with a bismuth-214 daughter and polonium-218 parent. Lead-214 is an isotope originating from the uranium-238 decay chain. Radium-226 is an isotope originating from spontaneous fission of uranium within the uranium-238 series decay chain. It is a daughter of thorium-230 and a parent of radon-222. Within the uranium decay chain series originating from uranium-238 is bismuth-214; this isotope is a descendent of radium-226, and is a daughter of lead-214 by beta decay or

TABLE 26. Activity from Core Samples Drilled from Various
300 Area Burial Grounds

Burial Ground	Sample Location	Depth (m)	Activity pCi g ⁻¹								Gross Alpha	Gross Beta
			214Pb	226Ra	208Tl	214Bi	40K	212Pb	228Ac	137Cs		
300 North	1	9.1	1.33 ± 0.30	---	0.29 ± 0.12	0.75 ± 0.22	110.76 ± 20.52	---	---	0.26 ± 0.09	0.38 ± 0.19	15.4 ± 2.6
300 North	2	7.0	1.90 ± 0.28	---	---	0.94 ± 0.23	106.68 ± 14.22	---	---	---	0.32 ± 0.21	13.0 ± 2.4
300 North	3	8.5	2.57 ± 0.39	---	0.52 ± 0.16	0.94 ± 0.38	160.13 ± 21.59	9.92 ± 3.97	---	---	0.61 ± 0.25	17.7 ± 2.8
300 North	4	6.7	1.49 ± 0.19	---	---	0.53 ± 0.20	106.78 ± 9.11	---	---	0.21 ± 0.09	1.19 ± 0.32	15.0 ± 2.6
300 North	5	9.1	1.26 ± 0.18	---	---	---	78.83 ± 9.27	---	19.48 ± 7.79	---	0.65 ± 0.27	14.5 ± 2.6
300 North	6	7.9	0.97 ± 0.17	---	---	0.46 ± 0.15	78.50 ± 8.65	---	17.44 ± 7.38	---	0.78 ± 0.29	16.2 ± 2.7
300 North	7	9.1	1.18 ± 0.16	---	0.20 ± 0.08	0.45 ± 0.18	82.40 ± 8.93	---	19.39 ± 6.92	---	0.80 ± 0.27	15.4 ± 2.6
300 North	9	6.4	1.00 ± 0.14	---	0.19 ± 0.07	---	77.87 ± 8.01	---	---	0.13 ± 0.04	0.44 ± 0.23	14.2 ± 2.5
300 North	10	9.1	1.45 ± 0.20	---	0.24 ± 0.10	0.46 ± 0.22	92.86 ± 9.46	---	37.68 ± 7.80	---	0.56 ± 0.24	16.7 ± 1.9
300 North	11	8.5	1.02 ± 0.20	---	0.28 ± 0.07	0.52 ± 0.15	75.92 ± 8.70	6.10 ± 2.62	20.70 ± 10.35	---	0.36 ± 0.19	16.0 ± 1.9
300 North	12	8.5	1.49 ± 0.18	---	0.18 ± 0.08	0.41 ± 0.19	88.85 ± 9.04	---	18.22 ± 9.11	---	0.75 ± 0.28	17.4 ± 2.0
300 North	13	8.5	1.19 ± 0.21	---	0.34 ± 0.10	0.62 ± 0.17	105.44 ± 10.88	---	33.70 ± 9.43	0.28 ± 0.08	0.40 ± 0.22	17.6 ± 2.0
300 North	14	9.1	1.22 ± 0.16	---	0.30 ± 0.06	0.50 ± 0.16	81.20 ± 8.90	---	---	---	0.50 ± 0.22	16.8 ± 2.0
300 North	15	9.1	1.17 ± 0.16	---	0.18 ± 0.07	0.62 ± 0.15	99.61 ± 9.30	---	17.41 ± 7.36	---	0.60 ± 0.26	15.2 ± 1.9
300 North	16	6.0	1.32 ± 0.20	---	0.22 ± 0.09	0.60 ± 0.17	103.41 ± 11.31	---	21.15 ± 8.95	---	0.17 ± 0.17	17.0 ± 2.0
300 North	17	8.2	1.53 ± 0.17	---	0.24 ± 0.07	0.66 ± 0.15	68.77 ± 7.98	---	---	0.14 ± 0.07	1.48 ± 0.39	14.4 ± 2.6
300 North	18	8.8	1.26 ± 0.14	---	0.26 ± 0.06	---	78.44 ± 7.84	---	---	---	0.50 ± 0.29	13.9 ± 2.5
300 North	19	7.6	1.10 ± 0.17	---	---	0.45 ± 0.16	96.49 ± 9.91	---	19.18 ± 7.54	---	0.78 ± 0.30	14.5 ± 3.9
300 North	20	7.6	1.24 ± 0.20	29.43 ± 13.98	---	0.52 ± 0.18	107.35 ± 9.07	---	25.15 ± 9.15	0.34 ± 0.9	1.38 ± 0.41	15.0 ± 2.7
300 North	21	7.6	1.09 ± 0.18	---	0.33 ± 0.08	0.58 ± 0.19	96.80 ± 9.10	---	38.32 ± 10.83	0.26 ± 0.10	1.11 ± 0.37	13.0 ± 3.5
300-4	1	5.4	1.02 ± 0.21	---	0.37 ± 0.09	---	124.04 ± 10.10	5.57 ± 1.59	24.69 ± 9.44	---	1.19 ± 0.47	20.2 ± 3.0
300-4	2	5.6	1.09 ± 0.15	---	0.25 ± 0.07	0.61 ± 0.14	87.39 ± 8.53	---	27.40 ± 6.98	---	1.69 ± 0.44	21.5 ± 3.2
300-4	3	5.1	1.16 ± 0.17	---	0.31 ± 0.07	0.64 ± 0.16	135.98 ± 10.23	---	23.05 ± 9.10	---	1.32 ± 0.36	21.9 ± 2.8
300-5	1	4.5	1.26 ± 0.17	---	0.17 ± 0.08	---	109.08 ± 9.20	---	26.46 ± 7.28	---	1.69 ± 0.44	19.8 ± 3.1
300-5	2	2.4	1.20 ± 0.15	---	0.46 ± 0.07	0.12 ± 0.13	95.05 ± 7.78	4.92 ± 1.84	24.68 ± 6.72	---	38.2 ± 1.9	20.0 ± 3.0
300-Hye	1	9.4	0.91 ± 0.17	0.01 ± 0.17	0.21 ± 0.07	0.50 ± 0.17	84.47 ± 7.92	---	---	---	0.65 ± 0.32	15.7 ± 0.37
300-Hye	2	8.8	1.04 ± 0.18	---	0.17 ± 0.08	---	95.57 ± 8.28	4.21 ± 1.46	22.59 ± 6.64	0.16 ± 0.07	0.94 ± 0.34	13.0 ± 0.25
Background Soil (600 Area)	--	1.0	0.88 ± 0.18	---	0.28 ± 0.08	0.78 ± 0.15	90.15 ± 8.45	6.99 ± 2.33	---	---	4.31 ± 1.0	17.6 ± 0.28

alternatively astatine-218 by alpha decay. Bismuth-214 is conversely the parent of polonium-214 by beta decay or thallium-210 by alpha decay.

Thallium-208 is a member of the naturally occurring thorium series decay chain produced by spontaneous fission of thorium-232 with a principal means of production as a descendent of thorium-228. This isotope is a daughter of bismuth-212 and a parent of lead-208. Bismuth-212 is also a member of this series. The principal means of production is descendent from thorium-228. Bismuth-212 is a daughter of polonium-216 by alpha decay and lead-212 by beta decay and a parent of thallium-208 by alpha decay and polonium-212 by beta decay. The remaining isotope within the thorium series decay chain is actinium-228. This naturally occurring isotope has a radium-228 parent and a thorium-228 daughter.

Potassium-40 is also a naturally occurring radionuclide present in core samples from Hanford 300 Area Burial Grounds. Potassium-40, however, differs from those above in that it is a singly occurring unstable natural radionuclide. It decays to calcium-40 by beta emission.

The only radionuclide identified in core samples that was not a product of naturally occurring decay chains was cesium-137. Cesium-137 is a fission product occurring as a daughter of xenon-137 and a parent of barium-137m. For radium-226, and potassium-40, the mean activity in units of pCi g^{-1} are reported as 0.71 and 65, respectively. The permissible concentrations for the radionuclides are controlled as reported by the Nuclear Regulatory Commission's Code of Federal Regulations (10 CFR Part 20) (Appendix B) for restricted and unrestricted areas. These concentrations were used to compare those results obtained in Table 26. The radionuclides identified as occurring in collected 300 Area Burial Grounds from core drilling and their permissible concentrations are listed in Table 27. It should be noted that the concentrations listed in Table 26 are distinctly formulated for concentration in air and water not specifically for concentration in bulk sedimentary material.

TABLE 27. Concentrations of Radionuclides Collected in the 300 Area Burial Grounds by Core Drilling

Radionuclide	Solubility	Activity pCi ml ⁻¹			
		Restricted Area		Unrestricted Area	
		Air	H ₂ O	Air	H ₂ O
Pb-210	---	---	---	---	---
Ra-226	Soluble	3×10^{-5}	4×10^{-1}	3×10^{-6}	3.0
	Insoluble	5×10^{-5}	9×10^2	2×10^{-6}	3.0
Ti-208	---	---	---	---	---
Bi-214	---	---	---	---	---
K-40	---	---	---	---	---
Bi-212	Soluble	1×10^{-1}	1×10^{-4}	3×10^{-3}	4×10^2
	Insoluble	2×10^{-1}	1×10^4	7×10^{-3}	4×10^2
Ac-228	Soluble	8×10^{-2}	3×10^3	3×10^{-3}	9×10^1
	Insoluble	2×10^{-2}	3×10^3	3×10^{-4}	9×10^1
Cs-137	Soluble	6×10^{-2}	4×10^2	2×10^{-3}	2×10^3
	Insoluble	1×10^{-2}	1×10^3	5×10^{-4}	4×10^3

Radium-226 in one sample from the 300 North Burial Ground was found at concentrations of 29.43 ± 13.98 pCi g⁻¹. This sample was collected from a depth of over 7 m in a controlled area and as such is thought to connote negligible hazard in its present location. Additionally, as this activity value was the only value identified for radium-226, it may be spurious as a result of counting error and/or interpretation.

The concentration of bismuth-212 was recorded in core samples collected from the 300 North and Wye Burial Grounds, Burial Grounds 4 and 5, and from a background soil sample collected 1 km south east of the 300 North Burial Ground. Bismuth-212 in no instances was found to exceed permissible limits for air or water in other restricted or nonrestricted areas.

Actinium-228 was detected in all burial sites in most core samples. The concentration as determined with activity ranging from 17.41 ± 7.36 to 38.32 ± 10.83 pCi g⁻¹ may exceed soluble permissible concentrations in air by about four orders of magnitude and is lower than permissible concentrations by about one order of magnitude in water for unrestricted areas. No significant health hazard from bismuth-212 was identified.

Cesium-137 was found above detection limits in the 300 North and Wye Burial Grounds. The range in activity of samples from these locations occurred between 0.13 ± 0.05 and 0.34 ± 0.09 pCi g⁻¹. These values may exceed soluble permissible concentrations in air by three orders of magnitude for restricted areas. Concentrations of cesium-137 in water in restricted areas are not exceeded by determined activities. Again, no significant health hazard was identified.

As a result of drilling, sample collection, radiochemical analysis, and comparison of analyzed data to radiation standards, no significant evidence was found to support the premise of radionuclide migration from below burial grounds. With the combined data and modeling results derived from the Fluid Transport and Modeling Section and the drilling results, it appears that the migration of radioactive waste from the Hanford 300 Area Burial Grounds into the geohydrologic system is presently nonexistent or at least negligible.

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