Initial Site Characterization and Evaluation of Radionuclide Contaminated Solid Waste Burial Grounds

February 1977

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GROUNDS

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SUMMARY

This report is an initial statement of work performed to characterize and evaluate radioactive solid waste disposal grounds. The resulting information will be used to develop the plans for decontaminating and decommissioning radioactive waste facilities.

A survey of historical records and literature containing information on the contents of 300 Area and North Burial Grounds was completed. Existing records of radioactive waste location, type, and quantity within each burial ground facility were obtained and distributed to cooperating investigators. In some instances these records appeared to be inadequate for estimating the physical characteristics of burial grounds, locating specific disposal sites, or determining waste distribution.

A study was then initiated to evaluate geophysical exploration techniques for mapping buried waste materials, waste containers, and trench boundaries. Results indicate that a combination of ground penetrating radar, magnetometer, metal detector, and acoustic measurements will be effective but will require further study, hardware development, and field testing.

Drilling techniques for recovering radionuclide-contaminated materials and sediment cores were developed and tested. Samples collected by these techniques will be evaluated by radiochemical analysis.

Laboratory sediment characterization and fluid transport and monitoring analyses were begun by installation of in situ transducers at the 300 North Burial Ground site. Data from these studies will permit calculation of fluid transfer rates using logging techniques and thermodynamic fluid potential monitoring methods. This study provides data required to determine long-term trends in radionuclide flux in unsaturated sediments.

Biological transport mechanisms that control radionuclide movement at contaminated sites were also studied. Flora and fauna presently inhabiting specific burial ground areas were identified and analyzed. Future monitoring of specific mammal populations will permit determination of dose rate and pathways of contaminated materials contained in and adjacent to burial ground sites.

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INTRODUCTION

Plans are in preparation for decontaminating and decommissioning burial facilities that were established during production operations on the Hanford Project. At some time in the future it may be desirable to relocate or place each contaminated site or facility in a stable condition with the minimum possibility of affecting the local environment. This will assure that the sites can be safely used in the future and that Hanford resources are allocated most effectively. Decommissioning requires that each burial site be characterized and evaluated to assess the location, quantity, and type of radionuclide present. Achievement of these objectives requires a thorough knowledge of the site hydrology, geology, biologic relationships, and waste material distribution, all of which are subjects of this study.

Historical records of the 300 Area and Wye Burial Grounds were first reviewed as a prerequisite to determining program objectives. All available historical documents, agency communications, and engineering drawings related to the study areas were located and analyzed. An inventory of recorded location, type, and quantity of radionuclides and associated materials in each burial ground was completed and distributed to cooperating investigators.

After the background material was reviewed, the following activities were defined and initiated: 1) Field tests of available geophysical techniques were conducted in the 300 North Burial Ground as a basis for developing technology to determine composition, size, distribution, and depth of buried waste materials and for characterizing the sediments in which they are buried. Acoustic, radar, thermal infrared, magnetic, and metal detection surveys were conducted and their applicability evaluated. 2) Drilling techniques and equipment for recovering and characterizing sediments and radioactive material were developed and tested. Drilling will also determine the amount and dimensional extent of radionuclide migration. 3) Methods and instrumentation for monitoring sediment-fluid interaction and fluid migration through the unsaturated zone were developed. This study will delineate fluid (vapor and/or liquid) and radionuclide transport through sediments. 4) A study to determine biological transport

of radionuclides was also initiated. This study involved a preliminary survey of present flora and fauna inhabiting the burial grounds. Plant tissue was chemically and radiochemically analyzed to determine radionuclide migration. Possible dose effects and population dynamics of burrowing animals that could potentially be exposed to buried waste materials were also investigated.

CONCLUSIONS

Basic conclusions derived from this preliminary study are listed as follows:

- Geophysical methods tested during this study period proved to be potentially effective for mapping buried waste materials and burial structures. Further work, including hardware development, is needed on all of these methods to achieve an operational capability. A survey program using a ground penetrating radar system, a magnetometer, a metal detector, and possibly an acoustic reflection system is expected to provide a comprehensive capability for waste detection and mapping in all 300 Area Burial Grounds.
- Potential radionuclide transport can be monitored by the drilling techniques and contaminant handling procedures developed and tested during this investigation. As research continues, drilling of buried waste materials and potentially contaminated sediments will be initiated.
- Characterization of burial ground sediments and fluid transport mechanisms indicated short-term trends in meteorological fluid flux rates and direction which occurred during the spring of 1975. In situ and laboratory sediment characterization delineated several geologic boundaries which may impede transport of radionuclides to the ground-water system. Preliminary sediment fluid potential and fluid content measurements have shown no significant transport of contaminants toward the saturated zone of the ground-water system. An interactive computer program has been developed to define and graphically illustrate fluid transport characteristics of the burial ground sediments. Continued monitoring of transport parameters will allow evaluation of long-term radionuclide transport.
- The data collected from vegetation and animal habitats within the burial grounds show that the potential for the spread of contaminants by burrowing rodents may exist. However, within the burial grounds

studied, no dissemination of contaminants by rodents has been found. Vegetation species that could potentially bring contaminants to the ground surface through their root systems were analyzed by chemical and radiochemical techniques. Transport of radionuclides from buried waste materials through plant systems to the ground surface was not detected. However, several radionuclides, probably derived from atmospheric weapons testing, were detected within various plant species.

RECOMMENDATIONS

Future development and implementation of geophysical drilling, sediment fluid transport, biological contaminant transport, and modeling studies during continuing phases of this study will result in a complete investigation procedure. These investigations will assist in formulation of decontamination and decommissioning recommendations for 300 Area and North Burial Grounds on the Hanford Reservation.

Detailed continuing studies and development of the following items are recommended:

- Development of a ground penetrating radar system for detecting waste materials buried to a depth of approximately 7 m.
- A computer-based system for acquisition, real-time processing, and digital recording of geophysical data is necessary for conducting efficient and effective field surveys.
- Detailed drilling of each site is necessary to evaluate and estimate the near-surface inventory of radionuclides.
- Radiochemical analysis of sediments collected by drilling is essential for quantifying contaminant-sediment chemical relationships and fluxes.
- Continued monitoring of fluid flux and development of laboratory characterization and analytical techniques is important for determining long-term radionuclide transport relationships.
- Development of hydrologic computer models for predicting radionuclide transport is also important.
- Additional studies to evaluate radioactive dose rate and pathways to man are necessary to complete the assessment.

These improvements in characterization and monitoring and computer modeling technologies will prove cost effective in continuing evaluations of burial ground decontamination and decommissioning.

HISTORICAL RECORDS PERTAINING TO SOLID WASTE DISPOSAL

During Hanford operations, radioactive or contaminated materials were removed from production or laboratory facilities to locations where the potential for personnel exposure was minimized. These materials are stored underground in trenches, tanks, and caissons within burial grounds. Disposal of these radioactive wastes required specific conditions: 1) The quantity of radioactive materials migrating from the disposal site should not represent a significant radiation exposure to personnel and 2) The locations of the radioactive materials were to be positively identified and records kept for such time as significant quantities of contaminated materials remained. The record review portion of this study was to investigate these requirements.

LOCATIONS OF SOLID WASTE BURIAL GROUNDS

The 300 North Burial Ground is located 15 km northwest of Richland, Washington on the Hanford Reservation (Figure 1). It is reported to consist of 12 backfilled trenches and 2 arrays of 94 vertical caissons (Figure 2). The total areal extent is approximately 2.5 ha with approximate dimensions of 150 x 175 m. The facility was operated from 1953 to 1963 and retired in 1964.

The Wye Burial Ground (Figure 1) is located 18 km northwest of Richland, Washington, on the Hanford Reservation directly west of the Washington Public Power Supply System No. 2 reactor site. The burial ground is reported to contain three backfilled trenches, one large buried culvert, and three large underground tanks (Figure 3). The burial ground areal extent is approximately 305 x 114 m with a total area about 3.5 ha. This facility was in service from 1962 to 1967 and retired in 1968.

WASTE TYPE

The potential hazard of waste materials transported to the environment depends in part on the type of radionuclides disposed to each burial ground. Three categories of wastes including low-level, intermediate-level, and high-level materials (classified as such for operational transport and handling purposes) have been buried in significant amounts in the 300 North Wye Burial Grounds.

FIGURE 1. Generalized Location Map of the 300 Area, 300 North, and Wye Burial Grounds Within the Hanford Reservation

FIGURE 2. Engineering Drawing of the 300 North Burial Ground

These materials have been defined as "High Level Waste" Solid Radioactive Waste, "Transuranium-Contaminated Solid Waste" and Radioactive Waste" as specified under U.S. AEC, AEC Manual Appendix 0511 Part 1, Nos. 14 and 18.

Low-Level Waste

Low-Level wastes generally include contaminated and potentially contaminated materials originating from general laboratory and processing areas. These wastes were primarily disposed of in square cardboard containers marked with appropriate radiation warning symbols. Radiation levels from these wastes generally varied from 5 to 200 mr/hr at 30 cm from the sealed cartons at the time of burial; however, much higher readings were experienced occasionally. These cartons were disposed in open trenches in controlled burial grounds.

Intermediate-Level Wastes

Intermediate-level wastes include radiometallurgy grindings, discs, solutions and associated materials. Large quantities of these wastes were collected in aluminum cylindrical containers. The cylinders were placed in lead casks for transport and were discharged from a truck-mounted cask through a chute into buried vertical caissons in an appropriate burial ground. The radiation levels of the waste-containing cylinders were approximately the same as those of waste cartons. When irradiated material within the caisson reached 1.5 m from the top or the radiation level became prohibitive, the caissons were sealed with concrete.

High-Level Wastes

High-level wastes include irradiated solid and liquid plutonium production process and reprocessing material. These wastes were sealed in 1-l cans and placed in lead casks for transport. No radiation exposure data concerning these wastes are available. The disposal method was similar to that for intermediate-level waste. Each caisson or tank containing these disposed wastes was retired on the basis of the same criteria used for intermediate-level wastes.

WASTE VOLUME AND RADIONUCLIDE CONTENT

The 300 North and Wye Burial Grounds contain volumes of approximately 5600 m³ and 340 m³, respectively, of buried waste. These approximations are based on a review of past operational programs and burial site utilization records. Waste materials disposed to 300 North and Wye Burial Grounds primarily contain a broad spectrum of fission products and plutonium. For the most part these wastes were generated under the direction of the Manhattan Project.

DEVELOPMENT OF WASTE DETECTION TECHNIQUES

The location of buried and stored waste materials in the 300 North and Wye Burial Grounds was not, in some instances, accurately recorded at the time of burial. Therefore, geophysical techniques are needed to determine exact locations, types, and quantities of contaminated materials in buried caissons, culverts, storage tanks, and trenches.

The waste materials have been buried in a thick layer (greater than 50 m) of alluvial sand and gravel. Numerous cobbles are scattered throughout the sand and gravel. The sediment and surface characteristics are generally unfavorable for geophysical exploration methods combined with the wide range of waste materials and disposal methods, they constitute a significant experimental problem. For efficient and accurate surveys to detect and map the buried wastes, special geophysical methods and survey techniques must be developed.

Five geophysical exploration methods were considered to be potentially useful: 1) metal detector, 2) magnetometer, 3) acoustics, 4) ground penetrating radar, and 5) thermal infrared imaging. Field tests to evaluate these methods were conducted in the 300 North Burial Ground.

METAL DETECTOR

A metal detector was acquired, tested, and used in a survey of the 300 North Burial Ground. A survey grid was established in the burial ground before the survey was conducted. The grid spacing was 15.2 m with secondary lines every 1.52 m. The intersections of the major grid lines were marked by wooden stakes.

The results of the metal detector survey are shown in Figure 4. This figure was made by overlaying the available map of the 300 North Burial Ground (AEC drawing H-E-9982) on an aerial photograph of the burial ground. The white lines were painted on the ground to delineate buried metal objects as observed by the metal detector. The black lines taken

FIGURE 4. Aerial Photograph of Magnetometer Survey Results Within the 300 North Burial Ground. (Boundaries Superimposed from Engineering Drawing)

from the map show the trench boundaries, storage drum locations, and the perimeter fence. Several discrepancies are obvious in comparing the survey results with the existing map, the most striking 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 map.

The metal detector was particularly effective in locating the buried oil drums and pipes in the southwest corner of the area. It also effectively determined the presence of large metal objects or masses in trenches. However, this instrument failed to detect a large fraction of the metal objects buried in the 300 North Burial Ground. This was demonstrated by a subsequent magnetometer survey of parts of the same area.

Controlled preliminary tests have shown that the metal detector is insensitive, even at short range, to elongated objects of small cross section, such as a metal rod. More generally, the sensitivity and the effective penetration depth depend in a complicated manner on the shape, size, and orientation of the buried object. For example, in one test, a cylindrical 19-l can was buried with its top 91.0 cm below the ground surface. It was easily detected. A solid steel cylinder approximately 25 cm in diameter and 10 cm thick was buried with its flat surfaces horizontal. This object could not be detected at a depth of 91.0 cm, although at shallower depths of burial it was detectable. In general, current results indicate that the minimum horizontal dimensions of an object mapped by a metal detector of the type tested can equal from half to full depth of burial.

MAGNETOMETER

Magnetic field measurements can be used to locate buried ferromagnetic objects such as tools, steel containers, steel scrap, etc. This method is based on the fact that an induced magnetization is produced in any magnetic

material 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 anomaly or an aberration in the ambient field.

For a buried object, the induced magnetization per unit volume is given by: $I = \Delta k B_0$, where Δk is the difference in volume magnetic susceptibilities of the object and the surrounding material, and B_0 is the intensity of the earth's magnetic field. The value and direction of B_0 are functions of location on the earth; most importantly they are functions of latitude. On the Hanford Reservation, B_0 is approximately 0.564 gauss, or 56,400 gammas (1 gauss = 10^5 gammas). The inclination of the field is approximately 68° and the declination is approximately 21° east. At this value of B_0 , the susceptibility, k , of iron or steel objects is typically in the range 1-10 cgs units. The susceptibilities of naturally occurring rocks and sediments are normally several orders of magnitude smaller. Strongly ferromagnetic minerals, such as magnetite and ilmenite, have susceptibilities in the range 0.1-0.8,⁽¹⁾ but these minerals comprise only a few percent of the sediment volume in the burial grounds. Their effect on the susceptibility of the sediments is negligible in surveys for buried steel objects.

Analytical solutions for induced magnetic fields are possible for only a few special object shapes such as spheres or cylinders. The object is usually further required to have a specific orientation in the ambient field. This requirement is a result of the vector nature of the magnetic field. The induced field depends not only on the orientation of the object but also on its size, shape, depth of burial, and susceptibility. Nevertheless, it is often possible, given the parameter values, to compute the induced field to a good approximation. However, in the inverse calculation, which is the case of primary interest in geomagnetic surveys, no unique set of these parameters can be determined from a measurement of the magnetic field patterns. In other words, an indefinitely large number of combinations of parameter values will produce the observed magnetic anomaly. This indeterminacy is characteristic of most geophysical methods. It is one of the factors that motivates a multifaceted approach to geophysical exploration programs.

A semi-empirical approach to magnetic interpretation is usually taken. Simple models are used to describe an object; and reasonable bounds, based on other available data, can often be placed on the parameter values. If a buried object is not too elongated, and if its magnetic field is observed at a distance several times greater than the width of the object, the field will be approximately the same as if the object were spherical. A spherical shell model for the calculation of magnetic anomalies is useful because only a simple coordinate transformation is required to take into account the inclination of the earth's field.

For a ferromagnetic spherical shell in a uniform magnetic field, the magnetic potential is:⁽²⁾

$$\phi_m = - B_0(z-z_0) + \frac{\alpha(z-z_0)}{r^3}, \quad (1)$$

where

r = the distance from the center of the sphere to the observation point

z_0 = the coordinates of the center of the sphere in the magnetic (unprimed) coordinate system

and

α = magnetic dipole moment

$$= \left[\frac{(2\mu + 1)(\mu - 1)}{(2\mu + 1)(\mu + 2) - 2 \frac{a^3}{b^3}(\mu - 1)^2} \right] (b^3 - a^3) B_0, \quad (2)$$

$\mu = 1 + 4\pi k$ = magnetic permeability of the sphere,

a = inner radius of sphere,

b = outer radius of sphere.

The total (ambient plus induced) vector magnetic field, written in rectangular coordinates, is:

$$\begin{aligned}\vec{B} &= -\vec{\nabla}\phi_m \\ &= \frac{3\alpha(x-x_0)(z-z_0)}{r^5} \hat{i} + \frac{3\alpha(y-y_0)(z-z_0)}{r^5} \hat{j} \\ &\quad + \left(B_0 - \frac{\alpha}{r^3} + \frac{3\alpha(z-z_0)^2}{r^5} \right) \hat{k}.\end{aligned}\tag{3}$$

where

x_0 and y_0 = the x and y coordinates of the center of the sphere in the magnetic (unprimed) coordinate system.

The magnitude of $\vec{B}$ is:

$$\begin{aligned}B &= \left[\left(\frac{3\alpha(z-z_0)}{r^5} \right)^2 \left[(x-x_0)^2 + (y-y_0)^2 \right] \right. \\ &\quad \left. + \left(B_0 - \frac{\alpha}{r^3} + \frac{3\alpha(z-z_0)^2}{r^5} \right)^2 \right]^{1/2}.\end{aligned}\tag{4}$$

The coordinates of the observation point are first specified in the earth (or primed) coordinate system. Then, since the computation is performed with coordinates in the magnetic coordinate system, a rotational transformation is needed:

$$\begin{aligned}
 x &= x' \\
 y &= y' \cos \theta - z' \sin \theta \\
 z &= y' \sin \theta + z' \cos \theta
 \end{aligned}
 \tag{5}$$

where

$\theta = 90^\circ$ - magnetic inclination.

Figure 5 shows the geometry for the spherical source computation. The Y' axis is oriented along the N-S magnetic axis in the earth coordinate system. Rotation of the coordinate system by the angle θ to account for the magnetic inclination is about $X=X'$ axis which is directed west and into the page. The point $P = (x,y,z) = (x',y',z')$ is the observation point which can be anywhere in the three-dimensional space external to the sphere.

FIGURE 5. Geometry for the Spherical Source Computation

Figure 6 shows three magnetic anomaly profiles calculated by means of the spherical source model. These profiles in the $x = 0$ plane were calculated for source depths of 3.0, 4.5, and 6.0 m, assuming a sphere with an outer radius of 61 cm, wall thickness of 3.2 cm, and a magnetic susceptibility of 15 cgs units. Four rules⁽³⁾ for the interpretation of anomaly patterns are illustrated in this figure:

FIGURE 6. Magnetic Profiles Calculated from the Spherical Source Model

1. The maximum of the anomaly lies to the south of the source. At the latitude of the Hanford Reservation, the displacement is approximately one-fifth the source depth.
2. The width of the anomaly at one half its maximum value is approximately equal to the source depth.
3. The maximum amplitude of the negative part of the anomaly is approximately 10 percent of the positive peak and occurs approximately one depth unit to the north of the source.
4. The anomaly is very small (less than 2 percent) at distances greater than three times the source of depth.

Field measurements were made in the 300 North Burial Ground to determine whether a magnetometer would provide useful data to determine trench boundaries. A proton precession magnetometer was used. Measurements were made on a 1.52 m grid in two rectangular areas in the burial ground. Figure 7 is a contour map of the magnetic field anomalies in a 56 x 60 rectangle in the east-central part of the burial ground. The ambient field, B_0 , has been subtracted from the data. In Figure 7, the contour interval is 200 gammas; in Figure 8 the contour level is 100 gammas.

An initial analysis of these anomalies was made based on the four rules listed above which describe the relationships between the anomaly shape and the source location. The results of this simple analysis are shown in Figure 9, where circles representing detected buried ferromagnetic objects are superimposed on the existing map of the burial ground. The numbers in the circles are estimated source depths (in gammas). Depth estimates were not made for some of the more complex anomalies.

Many of the objects shown in Figure 9 were also detected by the metal detector (Figure 4). As previously observed in the metal detector survey, the existing map of the 300 North Burial Ground is clearly in error in several places. (An outline map of the 300 North Burial Ground showing the rectangular areas in which magnetometer surveys were conducted is also given in Figure 9. The circles are buried ferromagnetic bodies. The numbers inside the circles are inferred depths of burial. The direction shown is true north.)

FIGURE 7. Contour Map 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 8. Contour Map of Magnetometer Field Survey Data from an Area in the East-Central Part of the 300 North Burial Ground (The direction shown is magnetic north)

FIGURE 9. Locations and Inferred Depths of Ferromagnetic Objects in the 300 North Burial Ground

Several other techniques, more sophisticated than the one used in this preliminary study, are available for the analysis of magnetic survey data. The most useful are computer-oriented and are basically schemes for filtering the data to enhance features of interest. Examples include upward or downward continuation of the field,^(4,5) computation of second vertical derivatives,⁽⁵⁻⁸⁾ and Fourier analysis and filtering. Direct measurement of

the components of the magnetic field gradient would yield additional detail and provides new options for analysis. Further study will be required to develop analysis procedures that are designed specifically for this application, and which will more fully develop the information contained in the survey data.

ACOUSTICS

Acoustic techniques offer the possibility of directly observing trench boundaries and buried material within the trenches. Variations in the acoustic properties of the ground are from differences in material, sediment porosity, particle orientation, moisture content, etc. These variations are observable, in principle, as acoustically reflective interfaces, changes in acoustic velocity, and variations in mechanical impedance. But practical techniques for using these effects to detect and map buried wastes on the Hanford Reservation are beyond the state-of-the-art mainly because the sand and gravel comprising the ground material in the Hanford burial grounds exhibit highly unfavorable energy transmission and coupling characteristics. Combined with unusually short acoustic travel times and a need for relatively high resolution, these characteristics cause significant difficulties. Nevertheless, it may be possible to develop an acoustic technique that could effectively detect and map buried wastes.

Preliminary acoustic transmission, refraction, and reflection measurements have been made in the 300 North Burial Ground to determine acoustic velocities, to identify reflecting and refracting layers, to test sound sources and receivers, and to develop survey and data processing techniques.

Acoustic techniques potentially useful for waste materials include reflection (or pulse-echo) profiling,⁽⁹⁾ refraction profiling,⁽¹⁰⁾ travel-time measurements acoustic holography,⁽¹¹⁻¹³⁾ and mechanical impedance mapping.⁽¹⁴⁻¹⁵⁾ However, because the scope of this initial phase of the program was limited, the work reported here has focused on the reflection profiling method. This method was chosen for several reasons: 1) it is less affected by lateral inhomogeneities in the sediments than are the other methods; 2) data interpretation is more direct, in principle, than in the

other methods; 3) measurements do not require the drilling of holes in the burial ground; 4) a minimum amount of field equipment is required; and 5) the nature of the waveform of a signal reflected from buried waste materials can provide information about the composition of the material. Specifically, if the acoustic impedance (density x acoustic velocity) of the material is less than that of the sediment, the phase of the signal will be shifted 180°. A material of higher acoustic impedance will not produce this phase shift.

The near-surface compressional wave velocity in the burial ground sediments is highly variable with respect to location. Measured values range from 140 to 450 m/sec. The variation is from differences in the grain size and packing density of the surface material. At a depth of approximately 1.5 m, the acoustic velocity appears to be less variable and to have a value of about 400 m/sec. This effect may be related to soil moisture variations; a maximum in the measured moisture versus depth curve occurs at a depth of about 1.5 m.

Figures 10 and 11 are travel-time plots showing the results of refraction lines along the east and south edges, respectively, of the 300 North Burial Ground. The signals were bandpass filtered at 500 Hz. Assuming horizontal layering in the sediments, the layer velocities are the inverses of the slopes of the travel-time line segments. Two layers are clearly shown in both figures; a third layer is suggested in Figure 10 by one point at the upper end of the curve. The layer thicknesses are given by⁽¹⁶⁾

$$Z_1 = \frac{t_2 v_1 v_2}{2\sqrt{v_2^2 - v_1^2}}$$

and

$$Z_2 = \frac{1}{2} \left(t_3 - \frac{2Z_1 \sqrt{v_3^2 - v_1^2}}{v_1 v_3} \right) \frac{v_2 v_3}{\sqrt{v_3^2 - v_2^2}}, \quad (6)$$

FIGURE 10. Travel-Time Plot of Acoustic Refraction Data (Eastern boundary of the 300 North Burial Ground)

FIGURE 11. Travel-Time Plot of Acoustic Refraction Data (Southern boundary of 300 North Burial Ground)

where

t_i = the intercept of the i th line segment on the time axis, and

V_i = the velocity of the i th layer.

The calculated velocities and depths are shown in the figures.

A steel plate struck by a sledgehammer was an effective and convenient sound source.^(17,18) Three types of detectors were tested: 1) geophones; 2) accelerometers; and 3) hydrophones. The geophones and accelerometers both have spike-shaped bases that are pressed into the ground. The hydrophones are simply placed on the ground surface and covered with a small weight. Detailed sensitivity measurements were not made for these devices, but in operation they all performed well. Signal amplitudes depend on the quality of the mechanical coupling with the ground.

Figure 12 shows computer-plotted acoustic reflection signals along a north-south traverse across the buried metallic mass in the southeast corner of the 300 North Burial Ground (see Figure 4). The signal traces shown in Figure 12a are raw data except that each trace has been multiplied by a normalizing constant to compensate for variations in the source energy. In Figure 12b each trace has been multiplied by a time-varying gain (TVG) function of the form $f(t) = 1 + Kt^2$, where K is a constant. The dominant component in these unfiltered signals is a weakly damped, low frequency oscillation of the ground surface. A change in the character of the upper parts of the signal is apparent at about the mid-point of the traverse. This corresponds roughly to the point at which the traverse crosses the left edge of the buried mass. However, this location also corresponds to a distinct change in the texture of the surface sediments, and the observed differences in waveform are probably due to the change in surface material.

The beamwidth of the sound produced by the sledgehammer/plate source is very broad. Reflected signals are thus received from many directions, resulting in a complex record. In an attempt to discriminate between non-vertical reflections, two geophones were used in a coincidence mode. The

(a)

(b)

FIGURE 12. Computer-Plotted Acoustic Reflection Profile Signals Normalized for Source Energy Variations [(a) raw signals after normalization (b) signals with time-varying gain]

geophones were placed 2 feet apart with the source centered between them. Figure 13 shows a reflection profile obtained with this arrangement. Only those signals that arrive simultaneously at both geophones have been plotted. This record was obtained along the line A-A' as shown in Figure 9. Although this record is relatively simple, it is still difficult to interpret without additional data. Except for an indication of a shallow, persistent interface in the upper part of the figure, no interpretive results are shown.

FIGURE 13. Acoustic Reflection Profile with Coincidence Detectors

The coincidence method appears to offer the possibility of providing useful data and should be studied further. With a three- or four-detector array, it may be possible to computer process the data, using both vertical and nonvertical reflections to plot reflector locations within a large volume. If successful, this approach would reduce the number of times that the source/detector array must be moved during a survey. This is a vital

consideration in the design of acoustic detection and mapping methods. If a dense array of observation points is required, the time and effort required for repositioning the source and detectors can easily become prohibitive.

A major factor affecting the design and efficient use of acoustic sources and detectors in the Hanford burial grounds is the variability of the texture of the surface sediments. Acoustic coupling between the sound source and the ground, and also between the detectors and the ground, is difficult and highly variable. This is a major problem in acoustic system design.

GROUND PENETRATING RADAR

A ground penetrating radar system is a potential effective tool for detecting and mapping buried waste materials. The operation of such a system is based on the fact that an electromagnetic wave propagating through sediments will be reflected at interfaces corresponding to changes in the dielectric constant. Buried waste materials, including both metallic and non-metallic objects, generally produce abrupt changes in the dielectric constant and are highly reflective.

Unwanted reflections also occur because of variations in soil moisture, density, or composition. The major problem, however, is the attenuation of the signal by the ground. At the signal frequencies of interest, approximately 100 to 1000 MHz, attenuation coefficients in the burial ground sediments are typically 15 to 60 db/m, depending on the moisture content and composition of the sediment.

A prototype radar system developed by the Calspun Corporation of Buffalo, New York, was tested in the 300 North Burial Ground. The output signal was a single cycle at 1000 MHz. The effective pulse repetition frequency was 50 pulses per second.

Figure 14 is a radar reflection profile acquired along a 15 m traverse in the burial ground, again along line A-A' in Figure 9. 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. This high value is apparently due largely to magnetite in the sediments and can be reduced by using a lower transmitted signal frequency. Further work is required to define and develop an effective, operational radar system for waste detection and mapping.

FIGURE 14. Ground Penetrating Radar Reflection Profile
Within the 300 North Burial Ground

THERMAL INFRARED IMAGING

Under certain conditions it is possible to identify features such as filled trenches in thermal IR imagery. Distinctive temperature, thermal emissivity, or thermal inertial patterns may exist in excavated areas as a result of changes in soil properties and moisture content. In order to test this technique, aerial thermal IR scanner surveys were conducted over the 300 North Burial Ground on February 24 and 25, 1975, at various times during mid-day, evening, and early morning. Intensity-modulated pictures produced from imagery collected at 15:45 and 22:40 hours on February 24 are shown in Figure 15.

FIGURE 15. Thermal Infrared Imagery of the 300 North Burial Ground (Top image flown at 15:45 hours, bottom image flown at 22:40 hours)

The basic data collection system is an optical-mechanical scanner operated from a twin-engine aircraft. The thermal imaging system is equipped with a long wavelength mercury-cadmium-telluride detector which provides a temperature sensitivity of $<0.5^{\circ}\text{C}$. Data collected with this system is representative of the near surface ($<0.1\text{ mm}$) temperatures. A two-dimensional thermal image is collected as the aircraft traverses the target area. The spatial resolution depends on aircraft altitude; however, a system divergence of less than 2 milliradians is normally obtained.

The thermal patterns in Figure 15 conform roughly to the mapped distribution of trenches in the 300 North Burial Ground. Examination of the area has shown that the observed thermal patterns are mainly the result of differences in soil type and vegetation density. However, three rows of small objects are visible in the original imagery in the southwest corner of the burial ground. They do not appear to be from vegetation effects because their pattern is uniform rather than random. Close agreement is found between this imagery and the available engineering drawing and the metal detector survey data (see Figure 4). According to the engineering drawing, vertical metal pipes approximately 75 cm in diameter and 4.5 m altitude of the survey these objects approach the resolution spot size of the scanner.

A linear pattern, seen in the imagery taken at 15:47 hours on February 24, is similar in position and size to an array of vertical pipes buried in the center of the area, according to the engineering drawing. These tubes are smaller than the resolution spot size of the scanner at 304 m and are not individually distinguishable.

The quality of the thermal data can be improved by combining data from repeated surveys. For example, the effects of differences in surface composition can probably be reduced by using repeated surveys over a period of several months to map the thermal inertia of the ground. Information derived from this method would complement that available from ground-based geophysical surveys.

DATA ACQUISITION AND PROCESSING REQUIREMENTS

Subsequent work in this program will be to develop the hardware and analysis techniques needed to achieve an operational survey capability. The work will focus on ground penetrating radar, magnetometer, metal detector, and acoustic reflection systems. All of these instrument systems acquire large volumes of data in short periods of time. This is both a desirable and necessary characteristic because enormous quantities of data will be needed to accurately detect, identify, and map buried wastes in the large volume of ground encompassed by the 300 Area and Wye Burial Grounds.

A computer-based data acquisition system for field use has been requested. This system will provide a means for handling the data and for efficiently controlling the field surveys. The basis of the system will be a minicomputer and graphics console interfaced to a multiplexed analog-to-digital converter, a storage disk, a magnetic tape unit, and a hardcopy output device.

DEVELOPMENT OF DRILLING AND SAMPLE COLLECTION TECHNIQUES

A drilling technique was developed to investigate sediment potentially contaminated with radionuclides, and to characterize contamination patterns and radionuclide migration rates within burial grounds. Test drilling, however, has not delineated any contamination to a depth of 10 m outside the boundary of the 300 North Burial Ground where testing was conducted.

Small diameter, shallow test holes were drilled with a split tube core barrel technique using a modified impact-drive, cable tool. This method prevents contamination caused by mud, fluids, or other materials used in standard drilling operations. Changes in lithology were readily recognized by examining the sediment within the core barrel. Distinct sand and silt lenses and, in some cases, bedding features were also revealed by core barrel sediment inspection. Each sample collected by this technique was representative of in situ stratigraphy and remained relatively undisturbed.

SEDIMENT CHARACTERIZATION AND FLUID FLUX MONITORING

Fluid transport is the primary mechanism for radionuclide migration. In order to define the status of meteoric fluids and radioactive waste materials disposed to burial grounds, in situ instrument arrays were installed at the 300 North Burial Ground. In addition, field and laboratory sediment characterization studies were conducted.

Two sources of transport fluids were found: 1) fluids contained in disposed waste materials, and 2) meteoric fluid from above the sediment atmosphere interface. Investigation of transport mechanisms will potentially permit quantitative evaluation of radionuclide flux through burial grounds.

DESIGN AND INSTALLATION OF FLUX MONITORING SYSTEMS

The flux of fluids in sediments potentially transporting contaminants is governed by such factors as fluid content, fluid and matrix potential,

density, and temperature. These factors must be measured over a sufficient time interval within specific accuracy limits to permit calculating long-term fluxes. The potential gradients during diurnal, seasonal, and long-term periods change direction and magnitude, depending on the above factors and extraneous atmospheric forces. Thus, monitoring sediment-controlled transport rates and direction by buried instrument and logging arrays will allow prediction of transport of radionuclides. Various techniques were initiated to measure these factors and to characterize sediment-fluid relationships.

THERMOCOUPLE AND THERMOCOUPLE PSYCHROMETER ARRAY

A vertical array of 17 thermocouple psychrometer transducers and thermocouple temperature transducers was installed to a depth of 6.5 m at a location adjacent to the 300 North Burial Ground. The array was buried and backfilled, as illustrated in Figure 16.

The monitoring system access well was drilled through eolian sediments to a depth of approximately 10 m, where an indurated deposit of silica-cemented gravel and silt was encountered. Split tube core barrel drilling techniques were used to retrieve cores, and continuous samples of drilled material were collected for analysis. When drilling operations terminated, the instrument cable was put into place and the drill casing removed. The access hole was then backfilled with sediment previously removed.

GAMMA-NEUTRON LOGGING ARRAY

Access tubes were installed at a depth of approximately 10 m in two locations adjacent to the 300 North Burial Ground for monitoring meteoric fluid flux through the sediment profile and determining sediment moisture density relationships. Drilling and sampling techniques were consistent with those used in the thermocouple psychrometer and thermocouple installation.

Fluid content and flux determinations were made using a subsurface ^{226}Ra - beryllium soil moisture probe. Sediment density determinations were made with 3 mCi ^{137}Cs cesium-gamma soil density probes.

FIGURE 16. Buried Instrument Cable at the 300 North Burial Ground

THEORETICAL AND EMPIRICAL EVALUATIONS OF FLUID TRANSPORT POTENTIAL

The potential of water, or the work required to remove water from porous media, can be equated to the sum of the volumetric water content and its change in state. This function can be expressed as the Gibbs Free Energy Equation, which is modified to account for water in the porous media fluid system by:⁽¹⁹⁾

$$d\mu_w = - S_w dT + V_w dP = \tau'_w dn \quad (7)$$

where

μ_w = the partial molar function (i.e., the chemical potential of the fluid to do work)

S_w = the specific entropy of water in the system

V_w = the specific volume of water in the system

τ'_w = the affinity of the porous media to the volumetric content of water

T = temperature of the system

P = pressure.

Each potential force is considered independently by various empirical methods.

Water Potential

The vapor pressure of moisture within porous media is influenced by the chemical potential of pure free water (μ_w°) related to the water potential of the porous media system under study (μ_w) and additional forces expressed as:

$$\mu_w - \mu_w^\circ = RT \ln e/e^\circ \quad (8)$$

where

R = ideal gas constant

T = the absolute temperature

e = vapor pressure of porous media system at a given T

e° = vapor pressure of pure free water at the same T.

The resulting net water potential (Ψ_w) expressed as a negative is related to physical constants within the system at various pressures and temperatures, including the relative humidity, e/e°. The net water potential then can be expressed in terms of pressure by equating Equation (8) with the partial molar value of water. Thus:

$$\Psi_w = \frac{RT \ln e/e^\circ}{V_w} \quad (9)$$

The water potential is measured by a psychrometer millivoltmeter system that monitors relative vapor pressure at depth at specific temperatures. The results of the psychrometer monitoring studies are shown in Figures 17 and 18. An increase in mean June 1975 potential from the ground surface to approximately 2 m demonstrates seasonal desiccation of sediments by evaporation. Precipitation recorded during June did not significantly change the trend in desiccation in this zone. For near surface sediments a net transport of fluid vertically through the sediment-atmosphere interface was determined during later spring and summer months.

Matrix Potential

The total potential can be subdivided into a unit of matrix potential (Ψ_m) which results from the adsorptive forces of the sediment matrix. This potential force, in effect, attracts fluid to particles and lowers their potential energy below that of free bulk water.

Matrix potential was determined by laboratory methods on selected sediments obtained during drilling operations at the study site. Results of these

FIGURE 17. Mean June 1975 Potential vs. Depth of Sediment Profile at the 300 North Burial Ground, SE Corner Array

FIGURE 18. June 1, 1975 Matrix Potential vs. Depth of Sediment Profile at the 300 North Burial Ground, SE Corner Array

measurements are similar to those of psychrometric determinations. Results suggest that for this location, the matrix potential component of the total potential is the predominant force controlling fluid transport.

Temperature Effects

Knowledge of sediment temperature is necessary to define nonisothermal conditions affecting fluid transport phenomena. The volumetric fluid content of the sediment at a given time greatly influences the temperature gradient, which in turn controls fluid flux.

The predominant mechanism of sediment heating and cooling is the transfer of solar energy through the atmosphere-sediment interface during the day and subsequent loss of adsorbed heat during the night through re-radiation. The amount of re-radiation is calculated from the Stefan-Boltzman Equation in $\text{cal cm}^{-2} \text{ min}^{-1}$ (S) as:

$$S = \alpha(T)^4 \quad (10)$$

where

$$\alpha = \text{a constant of } 8.25 \times 10^{-11}$$

T = the absolute temperature in degrees Kelvin.

Monitoring of ground surface mean-noon temperatures onsite showed re-radiation of heat during June 1975 to be from 0.53 to 0.696 $\text{cal cm}^{-2} \text{ min}^{-1}$. Figure 19 illustrates the mean temperature profile during June 1975 at the study site. Shallow diurnal and deeper seasonal temperature gradients were easily delineated.

FIGURE 19. Mean June 1975 Temperature vs. Depth of Sediment Profile at the 300 North Burial Ground, SE Corner Psychrometer and Thermocouple Transducer Array

FLUID CONTENT MONITORING

In order to measure the flux of fluid through the sediment profile, an evaluation of fluid content at depth was conducted. Figures 20 and 21 graphically depict measurements of fluid content in sediments within the study area. Mean June monthly moisture determinations show a trend toward desiccation in the total flow system. This trend is caused by a natural drying in the sediment profile as well as a drying of the backfill material around the access well.

FIGURE 20. Mean June 1975 Fluid Content - Bulk Density vs. Depth of Sediment Profile at the 300 North Burial Ground, SE Corner Array

FIGURE 21. Mean June 1975 Fluid Content - Bulk Density vs. Depth of Sediment Profile at the 300 North Burial Ground, NW Corner Array

The bulk density of the sediments was evaluated (Figures 20 and 21) in order to determine their volumetric fluid content at depth. The density of the bulk sediment and the packing configuration volume in part determine the amount of moisture held at a specific potential. Thus, if the sediment were homogeneous and isotropic, the moisture content values derived from neutron probe analysis would relate directly to the potential values and the linear flux could be measured. Bulk density measurements, however, have shown a stratified profile or varying density, and consequently a varying moisture content capacity.

LABORATORY SEDIMENT CHARACTERIZATION

Various flow system parameters were characterized, using standard laboratory methods, to check field data and to determine variables not readily identified under field conditions. Tables 1 and 2 delineate results from two sampling wells located adjacent to the 300 North Burial Ground. Table 1 shows low water content values at a depth of approximately 8 to 10 m, i.e., a zone of relatively low conductivity, high bulk density. This suggests an indurated layer which may impede flow. Table 2 suggests that another layer may be impeding flow at a depth of approximately 6 to 8 m.

COMPUTER SEDIMENT ANALYSIS

A computer program was written to assist in determining the unsaturated hydraulic conductivities of burial ground sediments. The program assumes that contributions in the sediment pore system, from specific pore sizes up to and including maximum saturation, are summed in order to obtain the hydraulic conductivity for a given moisture content.

This program uses empirical expressions suggested by Campbell⁽²⁰⁾ to relate fluid potential to fluid content:

$$\psi = \psi_e (\theta/\theta_s)^{-b} \quad (11)$$

TABLE 1. Sediment Physical Data for Samples
from the NW Corner of the 300 North
Burial Ground

Sample	Depth (m)	Bulk Density (g/cm ³)	Particle Density (g/cm ³)	Saturated H ₂ O Content (%)	Saturated Hydraulic Conductivity (cm/day)
1	0-0.78	1.64	2.82	34.15	1289.7
2	0.78-1.60	1.61	2.84	40.35	3828.4
3	1.60-2.41	1.56	2.80	39.11	2401.2
4	2.41-3.22	1.62	2.88	38.99	2724.4
5	3.22-4.01	1.60	2.31	41.10	3263.5
6	4.01-4.82	1.55	2.42	40.52	3610.1
7	4.82-5.63	1.64	2.40	39.93	1229.0
8	5.63-6.45	1.64	2.40	41.06	2492.9
9	6.45-7.26	1.59	2.38	40.94	1923.1
10	7.26-7.92	1.65	2.97	44.37	3846.2
11	7.92-8.53	1.66	2.87	44.87	2824.1
12	8.53-9.14	1.70	2.98	38.52	1884.7
13	9.14-9.75	1.78	3.04	41.23	901.0
14	9.75-10.36	2.02	3.04	27.95	678.0
15	10.36-10.97	2.13	2.85	31.07	384.6
16	10.97-11.27	1.81	2.86	38.49	1186.9

TABLE 2. Sediment Physical Data for Samples
from the SE Corner of the 300 North
Burial Ground

Sample	Depth (m)	Bulk Density (g/cm ³)	Particle Density (g/cm ³)	Saturated H ₂ O Content (%)	Saturated Hydraulic Conductivity (cm/day)
1	0-0.61	1.72	2.30	36.21	467.47
2	0.78-1.60	1.76	2.64	35.59	208.7
3	1.22-1.83	1.59	2.56	42.41	1620.3
4	1.83-2.44	1.68	2.57	43.72	2192.3
5	2.44-3.05	1.68	2.62	41.49	1335.4
6	3.05-3.66	1.59	2.74	41.31	1534.5
7	3.66-4.27	1.70	2.59	44.78	1812.7
8	4.27-4.88	1.68	2.93	38.65	1400.7
9	5.49-6.10	1.66	2.58	38.15	1682.7
10	6.10-6.71	1.76	2.77	36.55	4558.4
11	6.71-7.32	1.98	2.94	24.47	203.7
12	7.32-7.93	2.05	2.94	19.80	170.5

where

ψ_e = the air entry potential

θ_s = the saturated fluid content

b = a determined constant.

This is combined with the equation describing capillary rise of fluids and solved for fluid content at the corresponding pore size to give:

$$r = -(2\gamma/\psi) (\theta/\theta_s)^b \quad (12)$$

where

γ = the surface tension of liquid in air.

Thus:

$$F(r)dr = d\theta \quad (13)$$

where

$F(r)$ = the pore size distribution

When the pore size distribution function is equated to its corresponding volumetric fluid content and integrated with fluid content values for limits of pore size, the expression describing hydraulic conductivity is given as:

$$K = M' \theta^{2b+2} \quad (14)$$

where

M' = a constant to be determined.

K is then determined at saturation (θ_s), giving:

$$M' = K_s / \theta_s^{2b+2} \quad (15)$$

and

$$K = K_s (\theta/\theta_s)^{2b+2} \quad (16)$$

Combining with Equation (11) gives:

$$K = K_s (\psi_e / \psi)^3 + 2b \quad (17)$$

The program then computes the fitting parameters from Equations (16) and (17) and generates displays, i.e., 1) fluid content versus capillary pressure (Figure 22); 2) capillary pressure versus relative hydraulic conductivity (K/K_s) (Figure 23); and 3) relative hydraulic conductivity (K/K_s) versus fluid content (Figure 24) for each specific sediment.

FIGURE 22. Example of Computer Display of Capillary Pressure vs. Moisture Content

FIGURE 23. Example of Computer Display of Relative Hydraulic Conductivity vs. Capillary Pressure

FIGURE 24. Example of Computer Display of Relative Hydraulic Conductivity vs. Moisture Content

BIOLOGICAL TRANSPORT MECHANISMS

Burrowing rodent populations within the Wye Burial Ground were investigated to evaluate their potential for contamination by buried waste materials. Vegetation studies were also conducted to examine radionuclide migration rates through specific plant systems, and to identify pathways by which buried wastes may reach the ground surface.

MAMMAL STUDIES

Buried waste is usually believed to be safe from animal dispersal. However, some mammals are efficient burrowers and spend a great deal of their life span below ground. The purpose of this study was to obtain a measure of the number of pocket mice actually living within the Wye Burial Ground enclosure.

A total of 100 Sherman live traps were arranged in a 10 x 10 grid pattern with 10 m spacing between traps. A trap grid was operated for 3 consecutive nights in each of 4 months: February, March, April, and May. Each animal captured was individually marked; its location of capture (i.e., trap number), species, sex, reproductive condition, age, and weight were recorded, and the animal was released.

During the same period, an identical grid was set up in an undisturbed "control" plot on the Arid Lands Ecology Reserve within the Hanford Reservation. A comparison of populations in the test plot and this control area indicates whether the disturbance of the soil and vegetation on the Wye Burial Ground effects the acceptance of the area by small mammals (Figure 25).

The most important animal in terms of total number and biomass is the Great Basin pocket mouse, Perognathus parvus. The only other small mammal captured was the deer mouse, Peromyscus maniculatus.

FIGURE 25. Trap Catches of Pocket Mice on the Wye Burial Ground as Compared to a Control Zone on the Arid Lands Ecology Reserve

Great Basin pocket mice are not active above ground during fall and winter. Reproductive activity begins in May and the first young-of-the-year are trapped in June and July. By mid-summer the adults begin to disappear from the trap catch as they retreat below ground and sub-adults remain active until late fall.

The peak adult population was trapped on the grids in April. The Wye Burial grid yielded a total of 30 pocket mice and 3 deer mice, while the control plot had 79 pocket mice and no deer mice.

Compared to the control area, the low population found on the Wye Burial Ground was somewhat expected. Pocket mice, being burrowing animals, prefer deep, sandy soils. When the burial ground was decommissioned, a layer of stony soil approximately 1.2 m thick was spread over the surface. This

layer of stony soil not only inhibits burrowing by small mammals, but it also changes the amount and kind of plant cover. Severe soil disturbances associated with the burial, however, have not made the habitat unacceptable to pocket mice, which tend to remain in the same area for long periods. The movements of an often trapped male are shown in Figure 26.

FIGURE 26. Travel of Pocket Mouse Number 1, Adult Male, During the Spring of 1975 on the Wye Burial Ground Trap Grid System

The backfill earth serves as an effective shield for ionizing radiation emitted from buried radioactive material. However, pocket mice may be exposed to radiation if mouse burrows are deep enough to bring the mice into close proximity to waste materials. The animals are strictly nocturnal, emerging from burrows at night and retreating to them during daylight hours. The animals are totally below the ground surface in winter.

VEGETATION STUDIES

The vegetation of the 300 North and Wye Burial Grounds was analyzed during May 1975 using the canopy-covered method. The method consists of placing a series of small plots at systematic intervals along a tape line. In this investigation the plots were $1/10 \text{ m}^2$ spaced at 1 m intervals along 50 m of tape laid in a used portion of each burial ground. One tape line is treated as a sample unit and the results are expressed as average canopy-cover values for the 50 plots examined. The results of vegetation analyses are summarized in Table 3.

Four different categories of plants are found on the 300 Area Burial Grounds: 1) winter annuals, 2) summer annuals, 3) shrubs, and 4) perennial herbs. Most species are classified as winter annuals. The two most successful shrubby species are rubber rabbitbrush, Chrysothamnus nauseosus, and snow eriogonum, Eriogonum niveum. These are both winter deciduous, autumn blooming species. Spring blooming herbaceous species are classified as perennials. Winter annuals contributed 11 species, the most abundant of which were Bromus tectorum, Holosteum umbellatum, Draba verna, Sisymbrium altissimum, and Festuca ocotoflora. Only two species of summer annuals, Salsola kali and Ambrosia acanthicarpa, occurred on the burial grounds but these were important contributors to canopy cover in the later summer.

Roots provide the main pathway of water entry from soil to plants and also the main pathway for mineral uptake. However, one of the least known aspects of plant communities is the vertical and lateral extent of living root systems. Some general observations, however, can be made concerning

TABLE 3. Percent Canopy Cover Provided by Plant Species on the 300 North and Wye Burial Ground

	300N	Wye	Avg.
<u>Winter Annuals</u>			
*Bromus tectorum	4.7	28.0	16.4
*Holosteum umbellatum	0.45	5.8	3.1
*Draba verna	5.2	1.8	3.5
Festuca octoflora	1.0	0.9	0.9
*Sisymbrium altissimum	1.0	1.4	1.2
Cryptantha circumscissa	0.05	1.0	0.5
Myosurus aristata	0	0	0.0
Amsinckia lycopsoides	0	0.93	0.5
Cryptantha pterocarya	0	0.03	0.02
Microsteris gracilis	0.05	0.80	0.4
Descurainia pinnata	0.05	0.17	0.1
Plantago patagonica	0	0	0.0
*Erodium cicutarium	<u>0</u>	<u>0</u>	<u>0</u>
Total	12.5	40.8	26.65
<u>Summer Annuals</u> ⁽¹⁾			
*Salsola kali	3.4	1.3	2.4
Ambrosia acanthicarpa	<u>0.70</u>	<u>0.88</u>	<u>0.8</u>
Total	4.1	2.2	3.2
<u>Shrubs</u>			
Eriogonum niveum	0	0	0.0
Chrysothamnus nauseosus	<u>0</u>	<u>0</u>	<u>0.0</u>
Total	0	0	0.0
<u>Perennial Herbs</u>			
Oenothera pallida	0	0	0.0
Poa secunda	0	0	0.0
Aster canescens	0	0	0.0
Psoralea lanceolata	<u>0.70</u>	<u>0</u>	<u>0.4</u>
Total	0.70	0	0.4
GRAND TOTAL	17.4	43.0	30.2

(1) Values here would be greater if analyses were conducted later in the season.

* Allian species.

the depth of root penetration by plants growing on burial grounds. Winter annuals have shallow root systems as compared to summer annuals. Perennial plants generally have deeper roots than annual plants. Shrubs have the deepest penetrating roots.

Mineral analyses were performed to identify those plants with a strong potential for the uptake of minerals from the soil substrate. Two general categories of plants were chemically analyzed, shrubs and summer annuals. Four species were associated with most of the burial grounds: rubber rabbitbrush (Chrysothamnus nauseosus), snow eriogonum (Eriogonum niveum), Russian thistle (Salsola kali), and bursage (Ambrosia acanthicarpa). These plants were harvested whole in the early fall of 1974 when plants were in flower or with ripening fruits. The results of elemental analyses of three species are summarized in Tables 4 and 5.

Summer annuals had higher average values for ash, phosphorus, potassium, magnesium, calcium, sodium, manganese, barium, boron, copper, zinc, and molybdenum than did the shrubs. The average value for calcium was 0.90 percent of dry weight in shrubs as compared to 1.71 percent in summer annuals. The average potassium value for shrubs was 0.80 percent as compared to 2.40 percent for summer annuals. These data suggest that summer annuals would concentrate strontium-90 and cesium-137 in their tissues if these radionuclides are present in the root zone.

Plants were collected from the populations growing inside burial ground enclosures for radionuclide analysis. The results are summarized in Table 6. Potassium-40, a naturally occurring radionuclide, was found in every sample but was especially abundant in Russian thistle (Salsola kali). Cesium-137 was measured in five out of seven samples. Cerium-144, ruthenium-106, and cobalt-60 were infrequently measured. The low amounts of all radionuclides (other than potassium-40) suggest that the source of radionuclides is airborne debris from weapons testing programs (fallout) rather than from buried waste materials.

TABLE 4. Chemical Analyses of Summer Annuals from the
300 North, Wye Burial Grounds and Control Area

Burial Ground	%						ppm					
	Ash	P	K	Mg	Ca	Na	Mn	Ba	B	Cu	Zn	Mo
<u>Salsola kali</u>												
300 N	11.46	0.18	3.70	0.44	1.50	0.02	100	35	34	9	33	0.22
Wye	10.85	0.24	3.38	0.70	1.70	0.06	37	42	29	10	21	0.10
C*	11.80	0.24	3.36	0.75	1.65	0.65	51	32	25	9	13	0.04

Ambrosia acanthicarpa

Wye	10.37	0.22	1.63	0.38	1.90	0.08	49	50	28	12	75	0.57
C*	11.24	0.30	1.75	0.35	1.95	0.02	80	57	57	13	83	0.40

* Control area not near burial grounds

TABLE 5. Chemical Analyses of Eriogonum niveum from the
300 North Burial Ground and the Control Area

Burial Ground	%						ppm					
	Ash	P	K	Mg	Ca	Na	Mn	Ba	B	Cu	Zn	Mo
<u>Eriogonum niveum</u>												
300 N	4.62	0.19	0.50	0.18	0.95	0.08	30	115	44	6.5	17	0.05
C*	4.45	0.16	0.78	0.24	1.40	0.05	30	160	35	6.5	13	0.05

* Control area not near burial grounds

TABLE 6. Gamma-Emitting Radionuclides Measured
in Deep-Rooted Plants from 300 North
and Wye Area Burial Grounds in the
Autumn of 1974^(a)

<u>Burial Ground</u>	<u>¹⁴⁴Ce</u>	<u>¹⁰⁶Ru</u>	<u>¹³⁷Cs</u>	<u>⁴⁰K</u>	<u>⁶⁰Co</u>
<u>Ambrosia acanthicarpa</u>					
Wye		*	3.9	16	*
Control	*	(4.0)	1.8	19	(0.40)
<u>Salsola kali</u>					
Wye	*	*	*	30	*
300 N	*	*	0.93	40	*
Control	*	*	*	34	*
<u>Eriogonum niveum</u>					
300 N	*	(2.2)	0.26	7.6	*
Control	*	3.0	0.21	7.8	*

(a) Reported as picocuries per gram dry weight

* Below detection levels.

() Not significant.

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