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A REVIEW OF HYDROLOGIC AND GEOLOGIC CONDITIONS RELATED TO THE RADIOACTIVE SOLID-WASTE BURIAL GROUNDS AT OAK RIDGE NATIONAL LABORATORY, TENNESSEE

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ABSTRACT

Solid waste contaminated by radioactive matter has been buried in the vicinity of Oak Ridge National Laboratory since 1944. By 1973, an estimated six million cubic feet of such material had been placed in six burial grounds in two valleys. The practice initially was thought of as a safe method for permanently removing these potentially hazardous substances from man's surroundings, but is now questionable at this site because of known leaching of contaminants from the waste, transport in ground water, and release to the terrestrial and fluvial environments.

This review attempts to bring together in a single document information from numerous published and unpublished sources regarding the past criteria used for selecting the Oak Ridge burial-ground sites, the historical development and conditions of these facilities as of 1974, the geologic framework of the Laboratory area and the movement of water and water-borne contaminants in that area, the effects of sorption and ion exchange upon radionuclide transport, and a description and evaluation of the existing monitoring system. It is intended to assist Atomic Energy Commission (now Energy Research and Development Administration) officials in the formulation of managerial decisions concerning the burial grounds and present monitoring methods.

Sites for the first three burial grounds appear to have been chosen during and shortly after World War II on the basis of such factors as safety, security, and distance from sources of waste origin. By 1950, geologic criteria had been introduced, and in the latter part of that decade, geohydrologic criteria were considered. While no current criteria have been defined, it becomes evident from the historical record that the successful containment of radionuclides below land surface for long periods of time is dependent upon a complex interrelationship between many geologic, hydrologic, and geochemical controls, and any definition of criteria must include consideration of these factors.

For the most part, the burial grounds have been developed by a simple cut and fill procedure similar to the operation of a municipal landfill. Low permeability of the residuum, high rainfall, shallow depth to ground water, the excavation of trenches below the water table, and other practices, have contributed to a condition of waste leaching in probably all of the burial grounds. Despite these conditions, only very small concentrations of radionuclides have been found in wells or otherwise attributed to the initial three, small sites in Bethel Valley. This fact, however, may be due in part to the scant extent of site monitoring of those burial grounds for transport of radionuclides in ground water, and to the discharge of liquid radioactive waste to the drainage in concentrations that probably would have masked the presence of contaminants derived from these burial grounds. In comparison to the Bethel Valley sites, larger amounts of radioactive contaminants have been found in wells, seeps, trench overflow, and the drainages that drain Burial Grounds 4 and 5 in Melton Valley. The movement of radionuclides from the trenches to the drainages show that the latter sites are not suitable for the retention of all contaminants under existing conditions, and invalidates the operational concept of long-term or permanent retention of all radionuclides in the geologic environment.

The transport of many radioactive ions leached from the waste has been retarded by the very high sorptive and ion exchange capacity of the residuum with which the radionuclides have had contact. Not all radionuclides, though, will be retained in the subsurface by adsorption, absorption, or ion exchange. Among those radioactive contaminants that may be problematical with respect to trench burial at Oak Ridge are tritium and other negatively-charged nuclides, positively-charged radionuclides included in some of the complexed molecules, radioactive ions that have chemical properties similar to those of the stable ions present in local ground water, and radionuclides of very long half life.

The Bethel Valley sites are underlain by limestone in which small solution cavities are present. The Melton Valley sites are underlain by interbedded shale, siltstone and limestone that have fractures and solution openings. Some rather general patterns of ground-water movement, and hence radionuclide movement, through these media can be inferred from the reports of previous studies, but present knowledge of the hydrogeology is inadequate to define the flow system in three dimensions. Such definition will be necessary to predict the movement of radionuclides, to implement means for controlling or inhibiting contaminant transport, and to develop a network of wells for surveillance purposes.

The present (1974) monitoring system, by which water in the surface drainage only is monitored, is intended to measure the quantity of radionuclides released by the Laboratory to the Clinch River in order to fulfill regulations imposed by the Atomic Energy Commission Manual upon contractor sites. Realistically, a monitoring system designed to maintain surveillance of radionuclide movement from the burial grounds simply does not exist. While the present system is adequate for meeting the AEC's legal requirement, it is inadequate for monitoring radionuclide transport in ground water from the burial grounds or for providing information necessary to manage these areas for the long-term retention of their contaminants.

The appearance of formerly-buried radioactive contaminants on the ground surface of the disposal areas and in the streams draining these areas raises questions about whether burial grounds developed in a hydrogeologic environment typical of Oak Ridge can be managed for long-term contaminant retention. Recommendations are made, therefore, for an intensification of hydrogeologic studies of the area, development of an integrated surface water-ground water monitoring program, and implementation of remedial measures that would appear to have potential for minimizing radionuclide transport.

INTRODUCTION

Oak Ridge National Laboratory is a nuclear-energy research center, located in eastern Tennessee about 25 miles west of Knoxville and 150 miles east of Nashville. The Laboratory, or "X-10" as it is still known, is one of three major facilities in the Oak Ridge Reservation that have produced large amounts of waste contaminated by radioactive substances since the mid-1940's. Because of the potential hazard resulting from radioactivity, the waste has required disposal in a manner that would permanently preclude concentrations of radionuclides from entering pathways leading to man. Common practice has been to inter the solid-waste fraction in areas called burial grounds, or "solid-waste storage areas."

The practice of burying radioactive waste in the X-10 area began during the World War II effort to develop a nuclear weapon. At that time simple burial in trenches, similar to the burial of municipal waste in sanitary landfills, was conceived of as a safe and permanent method of isolating the radionuclides from the biosphere. Later study showed that interred contaminants could be leached and transported by ground water and might later appear in surface streams. Nevertheless, the practice of burial has continued with little modification in the belief that most, if not all, contaminants are retained in the ground. In view of the current national emphasis on preserving environmental quality, it is believed that the long-term safety of this practice warrants closer scrutiny. The Atomic Energy Commission (AEC; now Energy Research and Development Administration), therefore, requested an independent evaluation of certain aspects of the burial grounds by the U.S. Geological Survey.

This report constitutes a review of the history and the geologic and hydrologic conditions related to the burial grounds and of the monitoring system, as of 1974. It is intended to assist ERDA officials evaluate criteria used for burial-ground selection, and to help them assess the adequacy of monitoring techniques, types of waste appropriate for long-term storage, and the suitability of existing burial grounds at Oak Ridge for long-term storage of waste presently buried. Towards this goal, this document summarizes the historical development of the local burial grounds and explores the criteria that have been used in site selection. It discusses the geologic and hydrologic framework of the X-10 locale, and particularly the patterns of ground-water and surface-water movement through that area. Further, it describes the physical conditions at and the hydrology of the burial grounds. It discusses the sorptive character of local soils for radionuclides, and presents a description and evaluation of the system for monitoring radionuclide transport. Lastly, recommendations are offered for additional study, for the development of a more comprehensive monitoring system, and for ways of reducing the amount of future radionuclide transport from the burial grounds.

The report is largely a compilation of information and data from many sources. New data as such were not generated for this effort, but recent data developed in present studies at the Laboratory are incorporated where appropriate. Consideration of the burial grounds in the Y-12 area (Emlet, 1959, pp. 522, 526) or in other areas of the Reservation is not included in this review.

The author is grateful to many persons at the Laboratory for information contributed to this investigation. Appreciation is particularly expressed to Dr. J. O. Duguid who has provided much information about his current burial-ground studies, and Mr. J. R. Gissel, present engineer-in-charge of burial-ground operations, who has helped obtain information about the burial grounds that were formerly used.

This investigation was made in cooperation with the Oak Ridge Operations Office of the AEC.

GEOLOGIC FRAMEWORK OF THE X-10 AREA

Topography

The Oak Ridge Reservation lies in the Tennessee section of the Ridge and Valley Province (Fenneman, 1938). This province is characterized by multiple, northeasterly trending, elongate valleys separated by ridges that locally are 200 to 500 feet high. In the vicinity of the Laboratory, the succession of alternating ridges and valleys from the Clinch River to the northwest is: Copper Ridge, Melton Valley, Haw Ridge, Bethel Valley, and Chestnut Ridge (pl. 1). The X-10 facilities are located in Bethel and Melton Valleys.

Whiteoak Creek, one of several small streams in Bethel Valley, drains the Laboratory area. After passing through a water gap in Haw Ridge, the creek receives the drainage of Melton Valley and then discharges to the Clinch River. The Clinch in turn empties into the Tennessee River, the master drainage of the region.

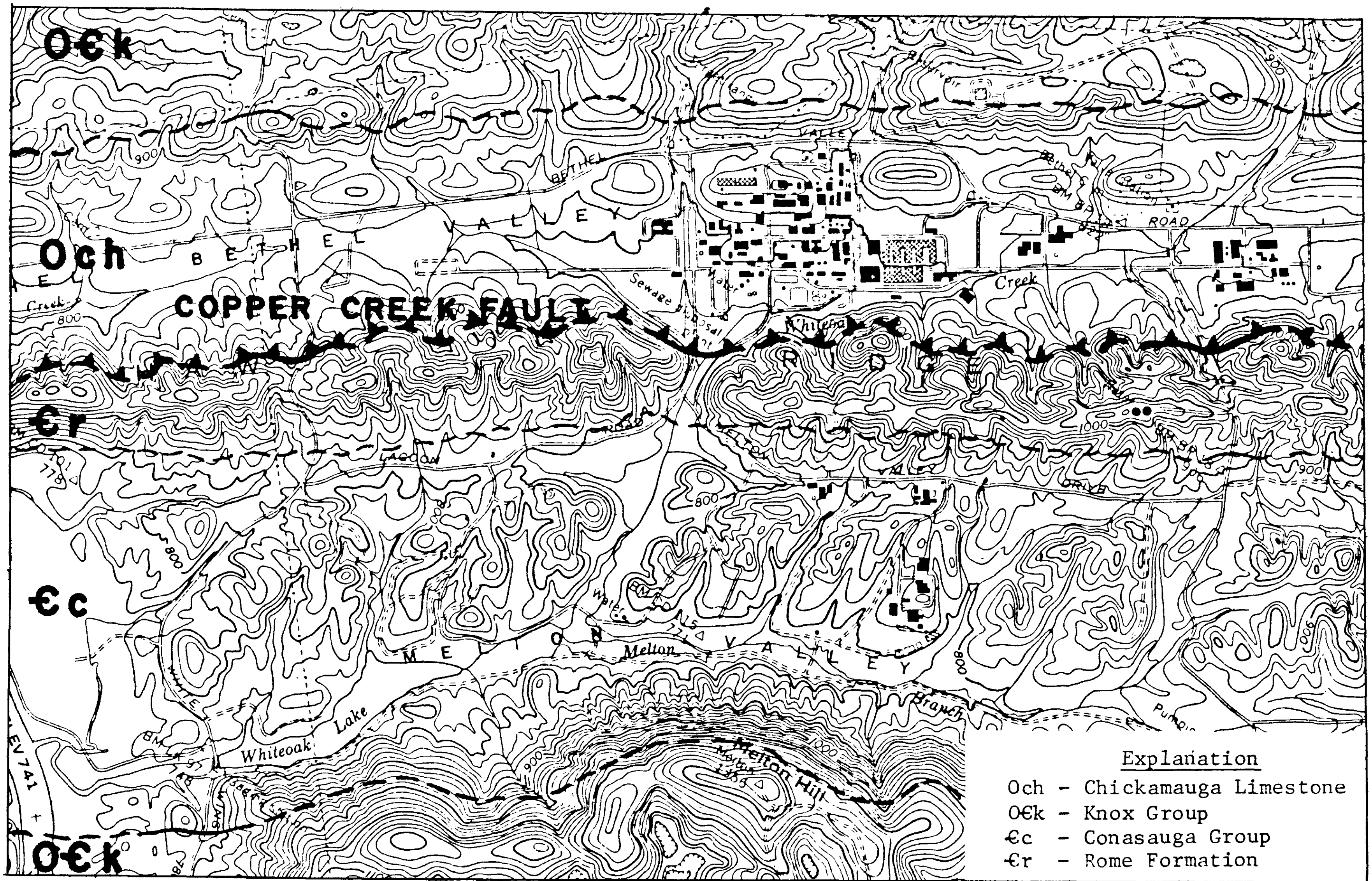
Stratigraphy and Structure

Of the nine major geologic units that have been mapped within the Reservation, four underlie the Whiteoak Creek drainage basin. These are, from northwest to southeast, the Knox Group of Cambrian and Ordovician age, the Chickamauga Limestone of Ordovician age, and the Rome Formation and the Conasauga Group of Cambrian age (fig. 1). The geologic units have been described by Stockdale (1951), McMaster (1963), and McMaster and Waller (1965); in addition, the Conasauga in Melton Valley has been mapped in detail by Barnett (1954) and described in several Laboratory reports.

The Knox Group underlies much of Chestnut and Copper Ridges, the two ridges that bound the drainage basin to the north and south. The group is composed largely of cherty dolomite in which sinkholes and caverns have developed; in some places the openings are of considerable size. The Knox is considered an unsuitable unit for the disposal of waste because the avenues by which water moves in cavernous rock, particularly at depth, are unknown, unpredictable, and virtually unmonitorable. Nevertheless, the Knox is beneficial to waste disposal at the Laboratory, for in this drainage basin the Knox's reservoir of water discharges to the Whiteoak Creek drainage and thus dilutes the concentrations of radioactive contaminants discharged directly to the creek or indirectly in ground water.

The Chickamauga Limestone underlies Bethel Valley, much of the Laboratory area, and Burial Grounds 1, 2, and 3 (B-1, B-2, and B-3, respectively, on pl. 1). It is composed predominantly of limestone, although shales, siltstones, and bedded chert comprise a significant minor part of the formation. The strata generally are thin- to medium-bedded. Fractures and solution openings occur between the beds of the Chickamauga, but the rock is believed free of large openings such as those found in the Knox. Nevertheless, the presence of cavities, even though of smaller dimensions, presents the same problems regarding deep ground-water movement and radionuclide monitoring; thus, this unit, too, is now considered undesirable for waste disposal.

The Rome Formation in the Whiteoak Creek basin is exposed along Haw Ridge. Locally, the bulk of the formation consists of soft, argillaceous shale containing occasional thin, siltstone layers less than an inch thick. The Rome is considered unsuitable for trench-type disposal because of its exposure along moderately steep slopes, shallow depth of soil weathering, and difficulty of excavation.



Base from TVA=USGS Bethel Valley, Tenn.
7.5-minute quadrangle map, dated 1968
Contour interval 20 feet.
Datum is mean sea level.

SCALE
1000 0 1000 2000 FEET

Geology by W. M. McMaster (1963)

ORNL NORTH
TRUE NORTH

Fig. 1. Geologic map of the x-10 area.

The Conasauga Group, commonly referred to as the Conasauga shale, underlies Melton Valley, including Burial Grounds 4, 5, and 6, (B-4, B-5, and B-6, respectively, on Plate 1), and the pits and trenches formerly used for liquid-waste disposal. The lithologic character of the rock is variable, both along strike and in superposition. The general sequence through the formation is gradational from shale at its base to bedded limestone at its top. In the waste-disposal areas, the unit contains many interbeds of shale, siltstone, and limestone. Local subdivision of the Conasauga is largely subjective, owing to gradational variations of the rock.

Burial Ground 4, in the stratigraphically lower part of the unit, is developed on non-calcareous shale interbedded with calcareous shale and thin, silty limestone (Lomenick and Cowser, 1961). Burial Ground 5 is developed on an area that grades from siltstone with interbedded shale and lenses of limestone at its northern limit to bedded limestone as much as 10 inches thick with interbeds of shale at its southern limit (Cowser, Lomenick, and McMaster, 1961). Burial Ground 6 is being developed on calcareous shale interbedded with thin, silty limestone and thin, pure limestone lenses (Lomenick and Wyrick, 1965). The Four-Acre Site and Pits 1 through 4 are underlain by jointed shale and limestone, with increasing lime content to the southeast. Whiteoak Lake and the lower part of Whiteoak Creek rest on limestone or shaly limestone (Barnett, 1954). Much of the carbonate within the weathered zone of the interbedded strata has been removed by leaching. In general, the weathered limestone layers have been reduced to silty clay and the shale layers to a fine, silty sand (De Laguna, Cowser, and Parker, 1958, p. 105).

All the formations in the drainage basin strike northeast at about 56 degrees and dip southeast at angles commonly between 30 and 40 degrees. The major structural feature in the area is the Copper Creek thrust fault which appears on the northwest flank of Haw Ridge and extends across the entire width of Tennessee. Millions of years ago the Rome and overlying formations in the basin were displaced northwesterly over the younger Chickamauga Limestone for a distance of about 7,200 feet, and the originally flat-lying beds in the region were deformed into multiple northeast trending folds. The shales, siltstones, and thin limestones of the Conasauga, and particularly the thin-bedded, less silty shales of that unit, were highly deformed, and many small structures and variations of strike and dip were imparted. Small anticlines and synclines are common; in places they have smaller folds on their flanks and are cut by a number of steeply dipping faults of small displacement. Excavation of Pit 4 showed that beds in that locale are intensely and irregularly folded and crumpled. The response of water levels in wells during pumping tests has suggested that this belt of crumpled rock is bordered on the south by a fault that could be related to the Copper Creek thrust fault. Structures have been reported to persist along strike for as much as 1,000 feet, and could extend for even greater distances (De Laguna, Cowser, and Parker, 1958, p. 106).

These geologic features largely control the movement of fluids through the rocks. The inhomogeneity of the strata, the irregularity of openings, and the complexities of structure make the movement of water devious and not entirely predictable. The movement of radionuclides dissolved in water is further complicated by hydrodynamic dispersion, reactions which take place between the water and soil or surrounding rock, and the retardive effects of sorption and ion exchange.

Soils

The soils of the Oak Ridge area belong to the Red-Yellow Podzol and Reddish-Brown soil groups that are found extensively in parts of the southeastern United States. Soils in these groups typically have developed under a forest canopy, and are characterized by being strongly leached and low in organic matter. The soils in the Laboratory area are further characterized as silty, although considerable clay may be present, and acidic in reaction with a pH from about 4.5 to 5.7 (Carroll, 1961).

Two local soil characteristics of significance to radioactive-waste disposal are the depth of weathering and type of clay developed. In areas underlain by the Chickamauga, the weathered zone is thin, commonly extending to a depth of less than 10 feet. In areas underlain by the Conasauga, the depth of weathering is related to topography, and may be described as thin in low-lying areas and thicker on the ridges. The thickness of the weathered zone ranges from about 4 to 16 feet at Burial Ground 4 (Lomenick and Cowser, 1961); "a few feet" to 40 feet at Burial Ground 5 (Cowser, Lomenick, and McMaster, 1961); and generally 5 feet or less to as much as 40 feet at Burial Ground 6 (Lomenick and Wyrick, 1965). A few studies of the Conasauga have reported that greatest permeability is associated with the transitional zone between the fresh and weathered rock. It is in this zone that the water table commonly occurs.

The clay component of the soils commonly consists of a mixture of several clay minerals. The principal clay mineral developed by weathering of the dolomite of the Knox Group is kaolinite. The Chickamauga weathers to form a mixture of kaolinite and illite, and some units of that formation have significant amounts of montmorillonite. The Rome decomposes to provide only a small amount of unidentified clay, and the Conasauga, where the largest burial grounds are located, decays to form illite and vermiculite (McMaster and Waller, 1965).

Physically, the clays are a mass of very small particles that, collectively, have a very large total surface area. Because of this property, the clays may have a large capacity to remove ions, including radioactive ions, from solution by processes termed sorption and ion exchange, provided that the fluid has intimate contact with the individual particles of clay -- that is, if the fluid can move between the grains rather than through some small portion of the mass -- and if other controlling factors allow. The sorptive properties of each of the clay minerals vary for specific radionuclides. These properties are discussed in greater detail in a later section.

HYDROLOGIC FACTORS AFFECTING WASTE DISPOSAL AND MONITORING

Climate

Annual precipitation at Oak Ridge National Laboratory averages about 54 inches and occasionally exceeds 70 inches. Precipitation falls throughout the year, with monthly maxima normally occurring from January to March and a secondary maximum occurring in July (Air Resources Atmospheric Turbulence and Diffusion Laboratory, 1972).

Mean annual pan evaporation at stations in eastern Tennessee with approximately similar conditions as at Oak Ridge ranges from about 41 to 43 inches. Because annual precipitation exceeds annual evaporation, contaminated salts resulting from evaporation do not accumulate in the soil. However, there may be temporary deposition of salts resulting from evaporative stress during periods of hot, dry weather.

The relatively large amount of rainfall at Oak Ridge has several effects. It causes the water table to occur at shallow depths and it is responsible for seasonally large stream flow; it contributes to the development of a high drainage density, thereby reducing the distance between points of ground-water recharge and discharge and the length of time of ground-water residence; it lowers soil p^H and influences the development of clay minerals that can control or modify the migration of radioactive ions; and in less direct fashion it governs the composition of the natural biological community (Richardson, 1963). Thus, the ultimate behavior and safety of the burial grounds are related to climate.

Ground Water

Occurrence

Ground water is found in the four formations underlying the Whiteoak Creek basin. The dolomite of the Knox Group and Chickamauga Limestone are the principal water-bearing units: the Rome Formation and Conasauga Group are thought to contain only meager ground-water supplies.

Water occurs in the residuum or weathered rock of all the units. In the Knox and Chickamauga, water also occurs at greater depths in fractures and enlarged openings developed by dissolution of the carbonate rock. The secondary openings in the Chickamauga are generally smaller than those in the Knox because of the limestone's more thinly bedded, shaly nature. In the siltstone and shale of the Rome Formation and Conasauga Group, water occurs in small openings or partings along joints and bedding planes. Because these rocks are relatively insoluble, the openings in them have not undergone substantial enlargement (McMaster, 1967).

The circulation of water below the weathered zone is limited by the occurrence of secondary openings. Pressure tests of a few wells in the interbedded silt, shale, and limestone strata of the Conasauga in Melton Valley indicate that secondary openings in that rock are restricted largely to the upper 100 feet; only rarely have they been found as deep as 200 feet. Hence, there appears to be little significant circulation of water below that depth. A pressure test of one well in the Chickamauga Limestone at X-10 and examination of cores from several wells in that unit indicated that the solution channels decrease in number and size with increasing depth; this suggests that these channels and the circulation of ground water in the Chickamauga may be restricted to the upper several hundred feet. The extent of secondary openings and depth of ground-water occurrence in the limestone unit of the Conasauga underlying Whiteoak Lake and the Whiteoak Creek estuary have not been investigated.

Water-table contour maps, based on water-level measurements in wells, have been constructed for limited areas within the basin (figs. 2 and 3). These maps indicate that the configuration of the water surface is a subdued replica of the topographic surface, a relationship suggestive of ground-water occurrence under water-table conditions. Water levels in some wells in Melton Valley, however, are not truly indicative of the water table. Significant differences have been found in water levels in wells only a short distance apart (W. M. McMaster, oral commun., 1974), and likely reflect differences in permeability within the Conasauga, the erratic communication between fractures and joints and, in places, confinement of water under slight pressure.1/ Moreover, according to an unpublished manuscript of the USGS, written about 1957, an artesian zone with sufficient pressure to cause flow from a well for four months was found at the Four-Acre Site, and perched water has been found in parts of Burial Grounds 5 and 6 (Cowser, Lomenick, and McMaster, 1961; Lomenick and Wyrick, 1965, respectively). Because of conditions causing anomalous water levels in wells, contour maps of the water table in Melton Valley should be considered approximate.

The depth to the water table varies both temporally and spatially. For a given area in the drainage basin, the depth is generally greatest during September and October and least during the period January through March. In Bethel Valley the depth to the water table has been found to range from as little as 1 foot near the sewage treatment plant to as much as 35 feet near a ground-water divide. In Melton Valley water has been found at a depth of less than 1 foot near drainages and as deep as 67 feet beneath the line of low hills along the northwest side of the valley. Seasonal fluctuations generally are small at the low-lying areas and somewhat greater beneath hillsides. In studies of the Melton Valley burial grounds, measured seasonal declines of water levels in wells have ranged from 1 foot to as much as 15 feet. A generalized map showing range in depth to ground water in the Whiteoak Creek Basin during March 1963 is given in figure 4.

1/ Well depth also can be an important factor influencing water levels. However, data showing well depths are not available.

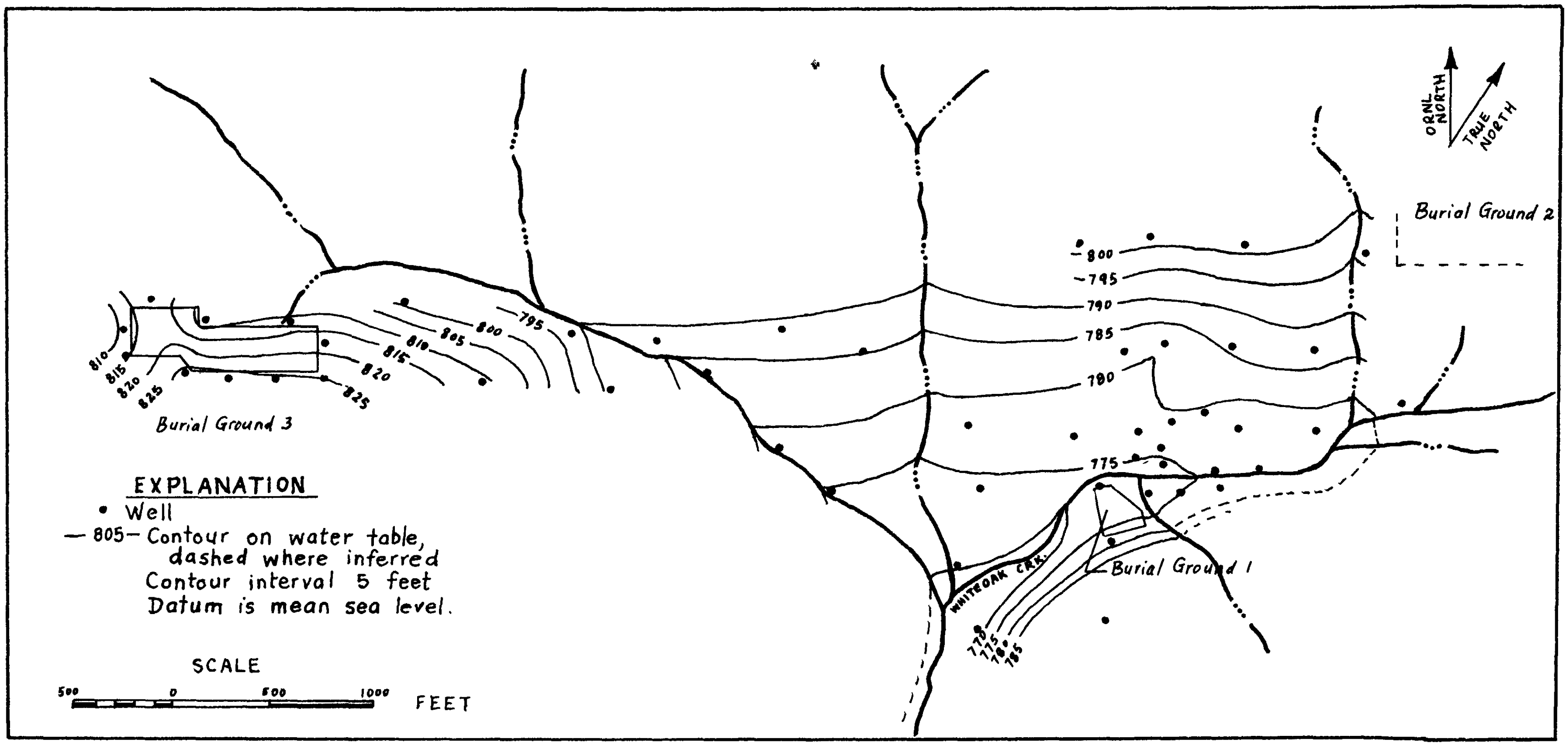
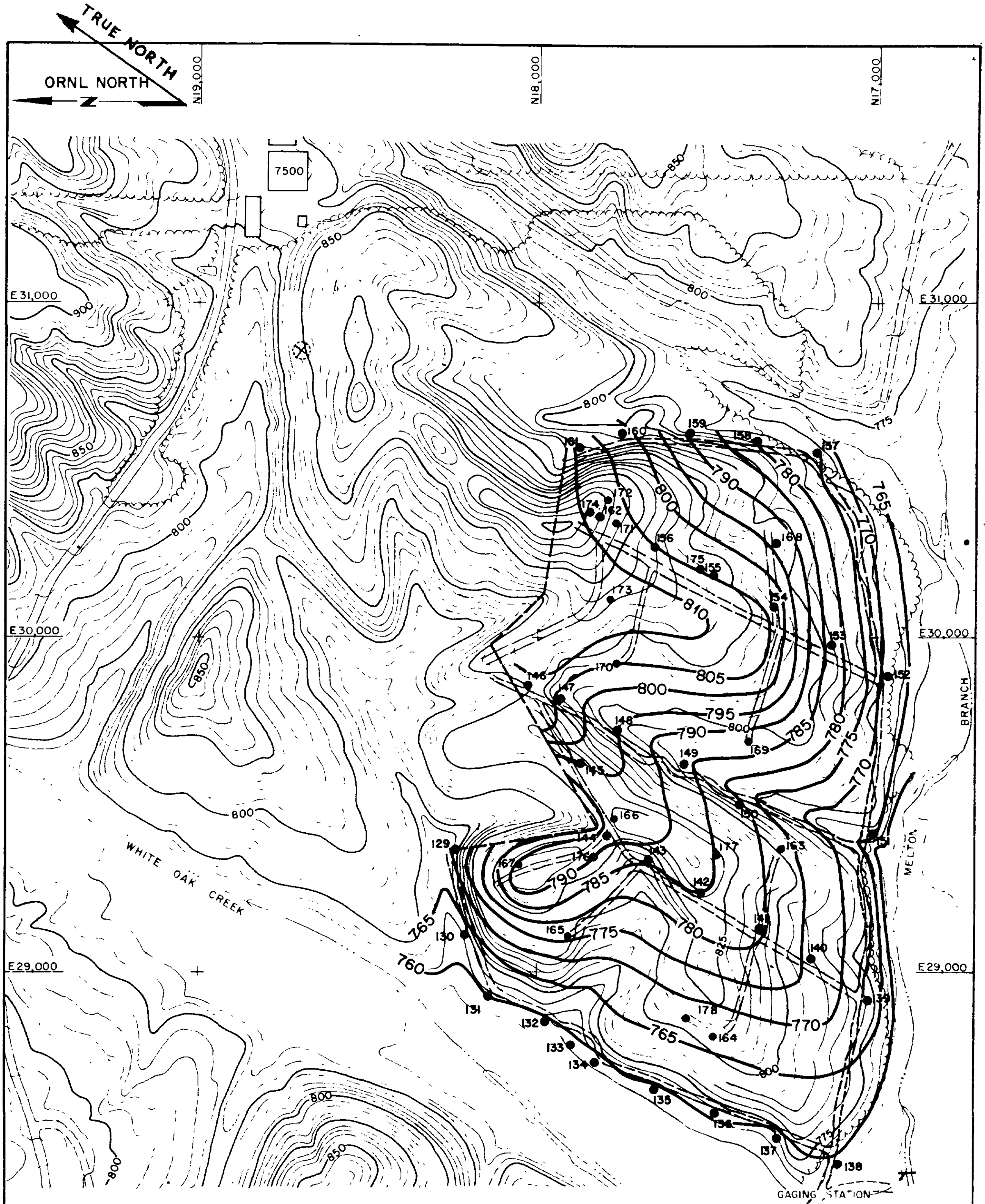


Fig. 2. Water-table map for part of Bethel Valley during June 1950 (After DeBuchananne, in Stockdale, 1951).

R



EXPLANATION

⊗ STATE GRID SYSTEM – COORDINATE N 560,000 - E 2,500,000

129 OBSERVATION WELL AND NUMBER

—775 -Water-level contour
Contour interval, 5 feet
Datum is mean sea level

THIS DRAWING HAS BEEN DEVELOPED FROM A PHOTOGRAPHIC ENLARGEMENT OF A PORTION OF MELTON VALLEY TOPOGRAPHY SHEET I PREPARED BY THE TENNESSEE VALLEY AUTHORITY AUGUST, 1956.

Fig. 3. Water-table map for Burial Ground 5, December 1959 (from Cowser, Lomenick, and McMaster, 1961).

0 200 400 600 800
SCALE IN FEET

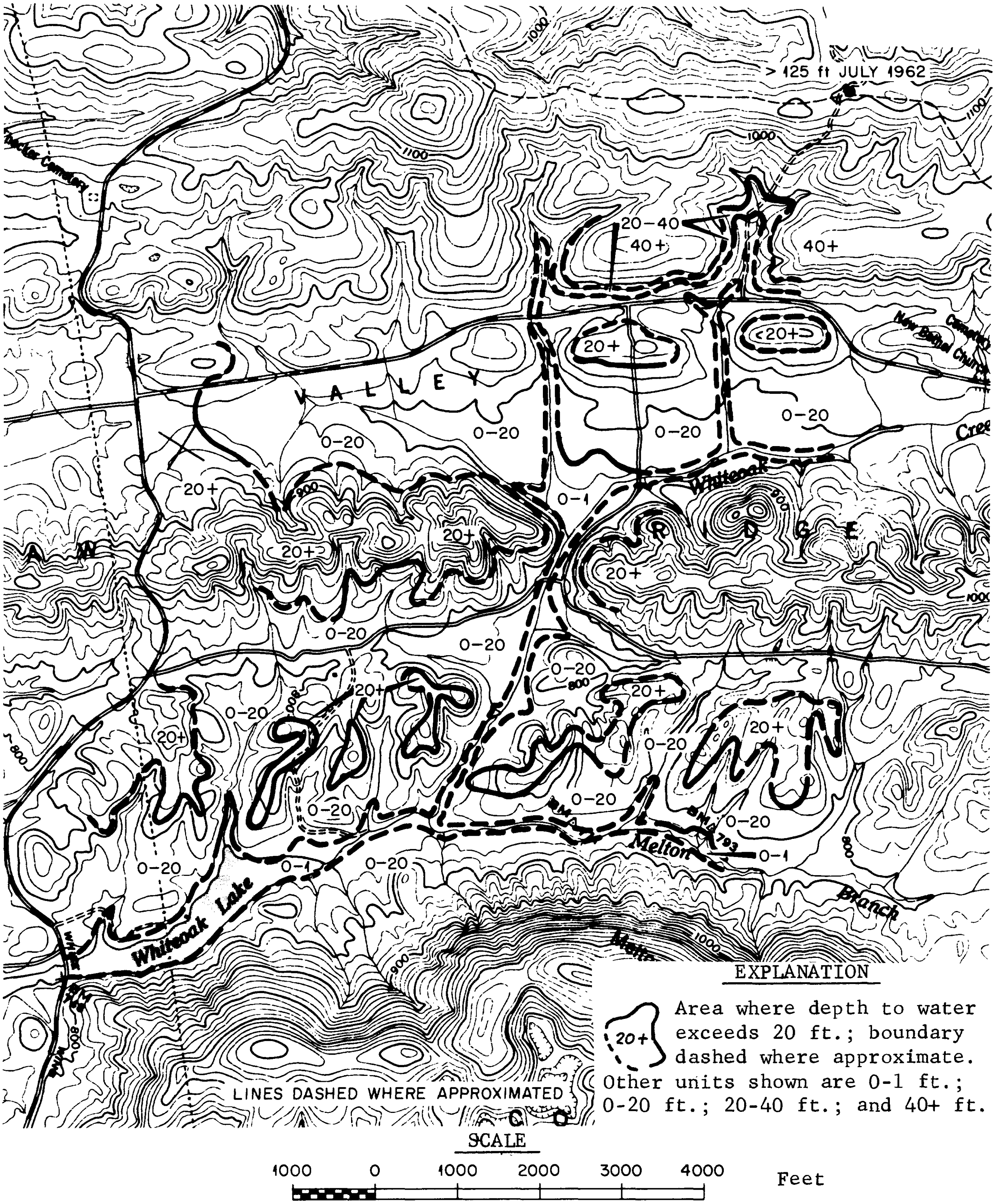


Fig. 4. Map showing general depth to ground water in the Whiteoak Creek drainage basin during March 1963 (from Lomenick and others, 1963a).

Recharge and Discharge

The ground-water reservoir of the basin is replenished naturally by the infiltration of precipitation through the soil mantle. Additional recharge is received seasonally from Whiteoak Creek when the water table recedes below creek level, and locally from the waste-water treatment ponds. All areas of recharge are entirely within the drainage basin.

Discharge from the ground-water reservoir occurs at springs and seeps, along the channel of Whiteoak Creek, and at or near ground surface by the evaporation and transpiration of water to the atmosphere. There is no discharge from the ground-water reservoir by pumping of wells, although minor amounts may be released seasonally in Melton Valley from a couple of flowing wells. The discharge areas of ground water that has passed through the burial grounds is considered in greater detail in subsequent sections.

Movement

Water-table contour maps can be useful for predicting the direction of ground-water flow. Although such maps lack the precision necessary to predict either the travel paths of individual water particles or localized flow patterns, they show the areal hydraulic gradient from which the overall trend in movement often can be inferred. Inference is based on the premise that in an unconfined aquifer system, ground water moves by gravity downgradient in a direction generally normal to the water-table contours. This interpretation must be restricted to movement in the residuum, however, because the direction of movement in the underlying limestone and interbedded strata is influenced most strongly by directional differences in permeability. Inspection of available maps (figs. 2 and 3, for example) thus indicates that ground-water flow in the residuum in mapped areas is towards Whiteoak Creek or its tributaries, except in a small area in and west of Burial Ground 3. The general similarity between the direction of water-table slope and topographic slope implies that in areas not mapped hydrologically, the trend in the direction of ground-water movement corresponds to the trend in the direction of surface slope. It can be reasoned, therefore, that the movement of and discharge of ground water above bedrock in this basin is towards and into this surface-drainage network.

In Bethel Valley ground water in the Chickamauga Limestone below the weathered zone moves through the small solution channels that have developed in that rock. The direction of fluid movement through such cavities is controlled by their three-dimensional geometry and their degree of interconnection with other cavities of lower hydraulic head. That direction may have little or possibly no relationship to the direction of movement inferred from water-table contours. Consequently, specific areas of discharge of water in the deeper rock of this unit are not known and conceivably could be outside the drainage basin. As of this time, however, there has been no reported evidence that would indicate subterranean movement of ground water from the X-10 section of Bethel Valley to other drainage basins.

Fluid movement in the Conasauga of Melton Valley has been investigated by four separate studies (reported in Morton and others, 1954; Struxness, 1955; an unpublished manuscript of the USGS, written about 1957; Cowser and Parker, 1958; De Laguna, Cowser, and Parker, 1958; an unpublished manuscript by Cowser, De Laguna, Parker, and Struxness, dated 1961; Lomenick, Gera, and Wyrick, 1964; Lomenick, Jacobs, and Struxness, 1967). The wells used in these investigations were drilled to various depths[2/] and frequently were cased to bedrock. Each study reported that within the area investigated the principal direction of ground-water flow in the Conasauga is parallel to the strike. This conclusion has been based collectively on pumping tests, pressure tests, tracer tests, and the appearance of seeps from the liquid-waste disposal pits at points that lie approximately along strike from them. There are several reasons, however, why the validity of the conclusion and its indiscriminate application to the entire column of saturated material should be treated cautiously. These include the facts that examination of flow in the residuum appears to have been largely precluded by extending casing in most wells as deep as the bedrock (an exception is the study of the unlined pit); movement in two studies (those involving the unlined pit and the movement of waste from Pit 2) was found to differ somewhat from strike for unknown reasons; movement normal to the water-table contours immediately south of Pit 4 is known to have been impeded by a fault that functions as a hydraulic barrier (see page 8, this report); and in the study of the unlined pit and the tracer study near Pits 2 and 3 the direction of strike was not greatly different from that of the hydraulic gradient and, hence, flow parallel to strike rather than normal to water-table contours could not be rigorously tested. Nevertheless, even though questions remain, these investigations have provided much valuable insight concerning fluid movement in the Conasauga. The findings indicate that greatest permeability beneath the weathered zone is associated with partings between the beds and perhaps with the residue of the more soluble beds; a lower permeability is associated with fractures and joints that cross the bedding. Given a condition of equal differences in hydraulic head, therefore, the largest component of ground-water flow could be expected to be oriented in a direction parallel to the bedding (which is parallel to strike) and a smaller component in a direction across the bedding. Consequently, ground water below the weathered zone appears to move preferentially in a direction parallel to strike when monitored with wells not far apart, although the specific paths of movement between any two wells could range from direct to tortuous and complex.

[2/]Wells used for tracing a contaminant from an unlined pit in what is now Burial Ground 6 were 12 to 19 feet deep, except one well was 61 feet deep; those used for tracing the path of tritiated water near pits 2 and 3 were 40 feet deep; many of those used for monitoring contaminant movement from pits 2, 3, and 4 were over 100 feet deep; and of five wells used in pumping, pressure, and tracer tests at the Four-Acre Site, four were 200 feet deep and one was 300 feet deep.

A composite picture of flow in the Conasauga through the total column of saturated material as suggested herein would show (1) a zone at and immediately below the water table where the largest component of flow corresponds to the direction of hydraulic gradient, especially during spring when the water table is high, although the probability of this zone being present may decrease as the depth to the water table increases; (2) an underlying transitional zone where significant components of flow are oriented parallel to both strike and hydraulic gradient; and (3) a thick zone in the fractured rock where the major component of flow parallels strike. A diagram illustrating such a flow system when the hydraulic gradient and strike are normal to each other is shown in figure 5.

This interpretation of information from prior studies implies that the significance of those factors controlling ground-water movement in the Conasauga change with depth. In the uppermost part of the saturated zone, the slope of the water table (or hydraulic gradient) is the principal factor controlling movement. With increasing depth, there is a change from control of the dominant flow direction by the areal hydraulic gradient to control by the local hydraulic head distribution within the partings, joints, fractures, or other slightly permeable zones in the rock.

The rate of ground-water movement is a function of the permeability of the rock and the hydraulic gradient between points of recharge and discharge. The rate of movement in the limestone terrain of Bethel Valley has not been determined quantitatively, but the smallness of solution cavities found in drill cores and the slowness of recovery of water levels after pumping, suggest that movement of significant volumes of water in the bedrock is relatively slow (De Buchananne, *in* Stockdale, 1951). The rate of movement in the Conasauga has been studied by monitoring the movement of liquid waste from the waste pits and by monitoring the movement of tracers from injection wells to observation wells. Because of the marked anisotropy of the rock, determinations by these methods are considered more reliable than those determined by hydraulic tests based on assumptions of an isotropic medium.

The rate of waste movement from Pits 2 and 3 was measured when the pits were operational and the fluid moved under a steep hydraulic gradient. At that time the velocity of fluid movement was found to range from 2 to 6 feet per day along strike[3/], and from Pit 4, 10 to 30 feet per day (De Laguna, Cowser, and Parker, 1958, pp. 112-113). Movement across strike was found to range from 0.4 to 0.8 ft/d from Pits 2

3/ In reporting the same study, Blanchard and others, 1957, p. 79, state that movement along strike is 2 to 4 feet per day. It is not known which report reflects the most accurate data.

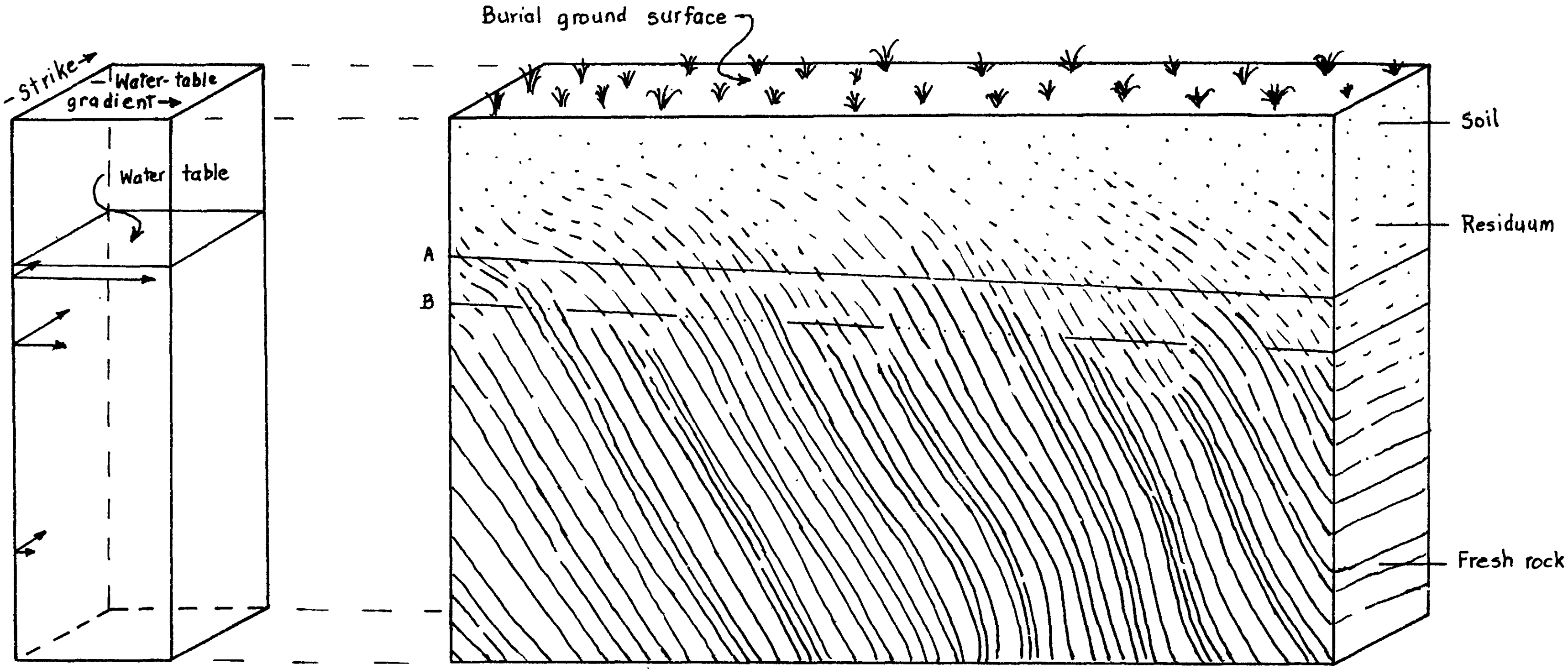


Fig. 5. Diagram illustrating suggested change in direction of ground-water flow in the interbedded strata of the Conasauga as depth below water table increases. In this diagram strike and water-table gradient are normal to each other. Vectors in left column show components of flow parallel to strike and to water-table gradient at three depths. Length of vectors is suggestive of relative amount of flow at each depth. Right column shows hypothetical section through the interbedded strata. Water table during seasonal high is shown by "A"; position later during year is shown by "B".

and 3, and 0.1 to 1.5 ft/d from Pit 4 (Blanchard and others, 1957, p. 79). A study made 3 to 4 years after the pit operation was terminated and the water table had receded to what probably approximated its natural position showed the velocity of ground-water movement under a more normal hydraulic gradient. Using tritiated water, the rate of movement was then found to be about 0.56 ft/d along strike for the first 5 feet and only slightly less out to a distance of 10 feet (Lomenick, Jacobs, and Struxness, 1967, p. 902). This remains as the best current estimate of rate of ground-water flow in the Conasauga under natural conditions.

Little is known about the upward movement of ground water and contaminants in or near the burial grounds. Where the water table is shallow, it can be expected that water is discharged to the atmosphere by evaporative stress during periods of hot weather. This probably is of significance only to tritium-contaminated water because other radionuclides in solution would be deposited as salts in the soil and subsequently leached by infiltrating precipitation. However, the upward movement by evaporative stress, either to the capillary fringe or above, may bring contaminants in solution to the root zones of trees or other vegetation. Studies near the waste pits showed that ^{106}Ru has been accumulated by trees from ground water, translocated to the leaves, and deposited on the ground in fallen leaf litter (Auerbach and others, 1958). A study elsewhere in the Laboratory area revealed that a tree had assimilated ^{60}Co, ^{137}Cs, and ^{90}Sr from the soil and also shed contaminated leaves to the ground (Struxness, 1962). Current studies have shown that the uptake of ^{90}Sr by a sapling has been so great that the level of radiation emitted from its leaves is about one million disintegrations per minute (dpm) per gram of dry weight (J. O. Duguid, oral commun., 1974). It is apparent that vegetation has the potential to move both ground water and dissolved contaminants upward, returning to the surface or above that which was intended to be buried.

Chemical Quality

The ground water in the drainage basin has a pH usually between 7 and 8, and is of a calcium bicarbonate type, reflecting the limestone and dolomite terrain through which the water has moved. The natural radium content of ground water in Bethel Valley is generally less than 1×10^{-12} grams per liter (De Buchananne, *in* Stockdale, 1951, p. 79). The natural beta radiation from ground water in Melton Valley is close to zero at the five percent level of significance (Cowser, Lomenick, and McMaster, 1961, p. 19). The natural radium content and gamma activity in Melton Valley ground water have not been reported.

Surface Water

Drainage Characteristics

Whiteoak Creek rises from several sources on Chestnut Ridge. In its four-mile journey to the Clinch, the main stem receives the discharge of two principal tributaries, Melton Branch, which drains the reactor area and Burial Ground 5 in Melton Valley, and an unnamed tributary in the northwest part of Bethel Valley, which receives surface drainage from Burial Ground 3. In Melton Valley the creek is impounded 0.6 mile upstream from its mouth by Whiteoak Dam. The body of water thus formed, Whiteoak Lake, serves as a settling basin for the deposition of contaminated sediment, and as a holding pond, if necessary, for the detention of discharge for a short period of time. During the early period of the Laboratory's existence, the creek was additionally impounded by earthen dikes on the flood plain immediately south of Burial Ground 4 (at mile 2.0) and across the water gap through Haw Ridge (Setter and Kochtitzky, 1950). Both impoundments failed during the flood of September 29, 1944. Behind the dike at mile 2.0 is a deposit of contaminated sediment that may influence the chemistry of ground water draining to the flood plain from Burial Ground 4.

The movement of water downstream from Whiteoak Dam is complex due to the thermal stratification of water and to the operation of power-generation dams. It is beyond the scope of this review to consider the movement of radionuclides and that part of the monitoring system downstream from Whiteoak Dam; however, the reader interested in these aspects is referred to reports by Parker (1964), Morton (1965, 1966), Struxness and others (1967), and Carrigan (1965).

Factors Influencing Composition, Transport, and Monitoring

The creek is both the natural drainage and an integral part of the Laboratory's waste distribution system, conveying contaminants from various parts of the X-10 complex to points beyond the Reservation. Its natural flow consists of precipitation, overland runoff, and discharge from the ground-water reservoir, which could become contaminated at numerous places within the Reservation. The natural flow is augmented by water piped to the Laboratory from outside the drainage basin and subsequently discharged to the creek as treated process waste water, laundry water, sanitary sewage, and reactor cooling water effluent, all of which are known to contain or to have contained radioactive contaminants. During prolonged periods of dry weather, the discharge from these sources often comprises the major component of flow.

The transport of radionuclides in the creek occurs both by ionic and molecular solution and sorption on sediment in suspension. Lomenick and others (1963b) have shown that an important part of the contaminant load is carried by sediment. Suspended sediment is the principal vehicle for the movement of ^{137}Cs regardless of variations in flow; on the other hand, much of the ^{90}Sr is transported in solution, although the percentage carried in solid versus liquid phase varies with flow.

The rate of contaminant transport in the creek is related to discharge. The mean velocity of the creek between miles 2.6 and 1.8 (essentially monitoring stations 1 and 3, plate 1) under contrasting flow conditions (base flow and flood flow) is shown below (Lomenick and others, 1963c):

Discharge, in ft^3/sec	Mean Velocity, in ft/sec
4.5	0.40
200	2.30

The mean time of travel across the length of Whiteoak Lake under a condition of average flow is about six days (Health, Physics Division, 1951, p. 8). By comparison, it can be seen that water, and hence dissolved contaminants, could move in the stream under base-flow conditions as much as 70,000 times faster and in the lake 1,200 times faster than in the Conasauga shale, even without considering retardation due to sorption. However, in this humid environment the concentration of contaminants attenuates in a downstream direction because of the accretions to discharge as water from small tributaries and from the ground-water reservoir is added, and the dilution afforded by mixing with water in larger streams.

Data describing discharge near monitoring stations 3, 4, and 5 in Melton Valley are summarized in Table 1. As indicated, the annual range in discharge is great. The problem of accurate monitoring of the stream by automated devices is complicated by this large range in annual discharge, the natural and artificial fluctuations in daily discharge, and the transport of radionuclides in both liquid and solid phases.

Table 1. Discharge data of Whiteoak Creek and Melton Branch (U.S. Geological Survey, 1971).

Station	Discharge, in ft^3/sec			Period of record
	Average	Minimum	Maximum	
Whiteoak Creek 0.1 mi above Melton Branch	9.62	1.9	642	10 yrs.; 1950-52; 1955-63
Melton Branch 0.1 mi above Whiteoak Creek	2.50	no flow	242	8 yrs.; 1955-63
Whiteoak Dam	13.5	no flow	669	5 yrs.; 1953-55; 1960-63

Chemical Quality

The chemical quality of Whiteoak Creek upstream from the Laboratory generally resembles that of ground water in Bethel Valley. At Whiteoak Dam the creek reflects the many influences in Bethel and Melton Valleys that have affected its composition. The amount of discharge of radiochemicals in water sampled at the monitoring station at Whiteoak Dam, the point used by the Laboratory for determining contaminant release to the environment, for the years 1959-73, is shown in Table 2. Much of the radioactivity shown for the early 1960's came from the seepage pits into which intermediate-level liquid wastes were discharged. A much smaller amount of activity originated at the waste-water treatment plant and from accidental releases of activity discharged into that system. While some of the activity may have come from the burial grounds, the concentrations are thought to have been sufficiently small that they could not be differentiated from the larger concentrations already in the stream (Lomenick and Cowser, 1961). During the 1960's a significant decrease in contaminant release was effected. The reduction was accomplished largely by discontinuance of the pits (and later, trenches) and by improvements in the treatment of Laboratory effluent.

In recent years ^{3}H (tritium) and ^{90}Sr have been the principal contaminants in the discharge (Table 2). These two nuclides are of interest because nearly all of the tritium and a part of the strontium are believed to emanate from the burial grounds. The maximum acceptable concentrations of these and other nuclides in effluent discharged from AEC-contractor sites to uncontrolled areas are set forth in the AEC Manual (U.S. Atomic Energy Comm., 1968) where they are referred to as "Concentration Guides" (or CG's).[4] Using these values as a basis for calculation, the average annual concentration of tritium in

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[4] The AEC has adopted the term, "Concentration Guide", in preference to the older term, "Maximum Permissible Concentration" (MPC), which is still widely used in the literature. The term Concentration Guide perhaps is less misleading inasmuch as there is no definite limit below which immunity from radiation damage is assured and above which harmful effects will result, as suggested by the term "Maximum Permissible Concentration."

Table 2. Annual discharge of radionuclides, in curies, at Whiteoak Dam, 1959 - 1973 (Compiled from Health Physics and Safety Annual Reports, 1965-67; Applied Health Physics and Safety Annual Reports, 1968-74; and unpublished data)

Year	Transuranic alpha emitters	^{137}Cs	^{106}Ru	^{89}Sr	^{90}Sr	Trivalent rare earths, less Ce	^{144}Ce	^{95}Zr	^{95}Nb	^{131}I	^{60}Co	^{3}H
1959		76	520	0.28	60	94	48	27	30	0.5	77	
1960		31	1900	1.9	28	48	27	38	45	5.3	72	
1961		15	2000	2.0	22	24	4.2	20	70	3.7	31	
1962		5.6	1400	1.7	9.4	11	1.2	2.2	7.7	0.36	14	
1963		3.5	430	0.98	7.8	9.4	1.5	0.34	0.71	0.44	14	
1964		6.0	191	0.79	6.6	13	0.3	0.16	0.07	0.29	15	1,929
1965	0.50	2.1	69	0.59	3.4	5.9	0.1	0.33	0.33	0.20	12	1,161
1966	0.16	1.6	29	0.85	3.0	4.9	0.1	0.67	0.67	0.24	7	3,090
1967	1.0	2.7	17	0.73	5.1	8.5	0.2	0.49	0.49	0.91	3	13,273
1968	0.04	1.1	5	0.55	2.8	4.4	0.03	0.27	0.27	0.31	1	9,685
1969	0.2	1.4	1.7	0.31	3.1	4.6	0.02	0.18	0.18	0.54	1	12,247
1970	0.4	2.0	1.2	0.27	3.9	4.7	0.06	0.02	0.02	0.32	1	9,473
1971	0.05	0.9	0.5	0.2	3.4	2.9	0.05	0.01	0.01	0.21	0.8	8,945
1972	0.05	1.7	0.5		6.5	5.2	0.03	0.01	0.01	0.34	1.25	10,600
1973	0.08	2.3	0.69		6.7	0.0	0.2	0.05	0.05	0.46	1.06	15,040

the discharge has ranged from about 28 to 56 percent of CG value[5] during the 5-year period from 1969 to 1973, inclusive. In 1973, when a very large amount of tritium was released, the average annual concentration was only 28 percent of CG. In contrast, much smaller quantities of ^{90}Sr have been released, but the average annual concentration of this nuclide has ranged from about 114 to 173 percent of CG during that same 5-year period. In 1973 the average annual concentration of ^{90}Sr was about 126 percent of the CG value. It must be noted, however, that the concentration of each contaminant released in the discharge is reduced by dilution with water in the Clinch, either in the Whiteoak Creek estuary or in the river itself. The mean annual dilution factor for the years 1962-73 is about 375.[6] Thus, even though the average annual ^{90}Sr concentration near the mouth of Whiteoak Creek has exceeded CG value, the concentration in Clinch River water downstream from Whiteoak Creek has been reduced far below that level.

5/ The CG values in the AEC Manual (Ch. 0524, Table II) are based on dose standards for individuals in uncontrolled areas who are exposed to radiocontaminants in their drinking water 168 hours per week. The Manual permits release of contaminants in concentrations up to these values when averaged over a period of a year. However, the International Commission on Radiological Protection has recommended a more stringent standard for population exposure, in view of the wide variance of individuals within a population group. Accordingly, Chapter 0524, Part II C.1 of the Manual states that the CG values in Table II shall be reduced by a factor of three when applied to a suitable sample of the exposed population. The percentages describing ^{3}H and ^{90}Sr concentrations as given in this paragraph should, therefore, be multiplied by 3 to relate them to derived CG values for a population group.

6/ Various statistical methods may be used to compute dilution factors. Carrigan (1968), for example, calculated a mean dilution factor (the ratio of flow in the Clinch River to that of Whiteoak Creek) of 390 for the years 1951-60, but using the same data calculated a mean daily dilution factor (the sum of the daily dilution factors divided by the number of days involved) of 670 for the same 10-year period.

BURIAL-GROUND DEVELOPMENT, CONDITIONS, AND HYDROLOGY

General

The need for a safe method for disposing of radioactively-contaminated waste arose during World War II when small quantities of radioactive substances became available. Disposal of the solid-waste fraction by burial in the ground nearby appears to have been chosen as a convenient expedient. In view of the then anticipated one-year life of the Laboratory, it is doubtful that persons of that era ever intended or envisioned the burial of large amounts of material or contaminants in the X-10 area. In the years following the war, however, the Laboratory's research mission continued, and the volume, concentration, sources, and diversity of contaminated solid waste grew. The area devoted to burials increased, and now, following the passage of three decades, five burial grounds have been filled and a sixth site opened. The initial three sites were established when the atomic energy program was under the Army's jurisdiction, and occupy only small areas in Bethel Valley. The latter three sites were established under AEC authority and include larger areas in Melton Valley. Throughout this period burial practices have undergone little change; there has been, however, a gradual evolution of criteria for selecting burial-ground sites as radionuclide transport has become better understood.

The records of most Oak Ridge burial grounds are scant. No records at all were kept of Burial Grounds 1 and 2 (Wirth, 1946), and those of Burial Grounds 3, 4, and a part of 5 were accidentally destroyed by fire in 1961. Existing records consist of raw data about disposals in Burial Ground 6 and a part of Burial Ground 5, and a study of Burial Ground 4 made shortly after its closure in 1959.

These sources of information, other published and unpublished reports, office memoranda, and inquiries made of persons knowledgeable of the burial sites have been used to compile the historical information contained herein. Trench features shown on maps of Burial Grounds 1 and 3 (figs. 6 and 8, respectively) are based on recollection and may not be entirely accurate. The conflict in information pertaining to the early sites may be attributed to a hazy remembrance of events that transpired two to three decades ago and to the general cloak of secrecy that prevailed under military security.

The Bethel Valley Burial Grounds

Burial Ground 1

Burial Ground 1 is located at the foot of Haw Ridge and beside the area formerly used for incinerating combustible waste. It is at the edge of the Laboratory complex, and at its closest point, about 25 feet south of Whiteoak Creek. The initial suggestion for burying waste at this location appears to be contained in a memorandum dated January 5, 1943[7] by Dr. S. T. Cantril of the Medical Department to the Central Safety Committee. He stated, "It would seem that provision has not been made for the disposal of actively contaminated-broken glassware or materials not sufficiently clean to be used in other work. I am suggesting that a metal trash can with cover, with red lettering on the can, be provided for the disposal of such material as can be placed in the trash can. Mr. Schwertfeger [of the DuPont Company, then the operator of the Laboratory] has suggested that a suitable location for the burying of this material could be provided over on the burning ground. A suitable pit with enclosed fence could be made." The committee accepted the suggestion and the first burial ground was born. In retrospect, it appears that the site was selected on the basis of its proximity to the early Laboratory and generally similar use of adjoining land. The possibility that the contaminants in the waste could be leached by water does not appear to have been a consideration when burials began.

The earliest record of burials is reflected in a memorandum of April 28, 1944. On that date, cans with red tops were placed in the 706-A Building for the collection of waste materials that could not be disposed of through the drains, such as "Lusteroid bottoms and cloths used to wipe up minor spills" (Greager, 1944). According to one oral account, the first cans were dumped in a long, curving ravine at the foot of Haw Ridge. An inspection of the topographic maps made in 1942 by the Stone and Webster Engineering Corporation suggests that this is the shallow depression that lies immediately east and outside of the area now designated as Burial Ground 1. According to another account, the cans were first placed in auger holes at the east end of the designated site, and later trenches were excavated to receive the waste. However, only a small number of trenches were dug, and it is reported that the site was abandoned when water was found in a trench excavated north of the present road that crosses the burial ground (J. E. Brandon, oral commun., 1974). The date of closure commonly given is 1944. A schematic diagram showing the orientation and approximate location of the trenches is given in figure 6.

7/ The date of this memorandum appears to have been a "turn-of-the year" typographical error. Because the Laboratory did not become operational until the late fall of 1943, it seems probable that the correct date of the document is January 5, 1944.

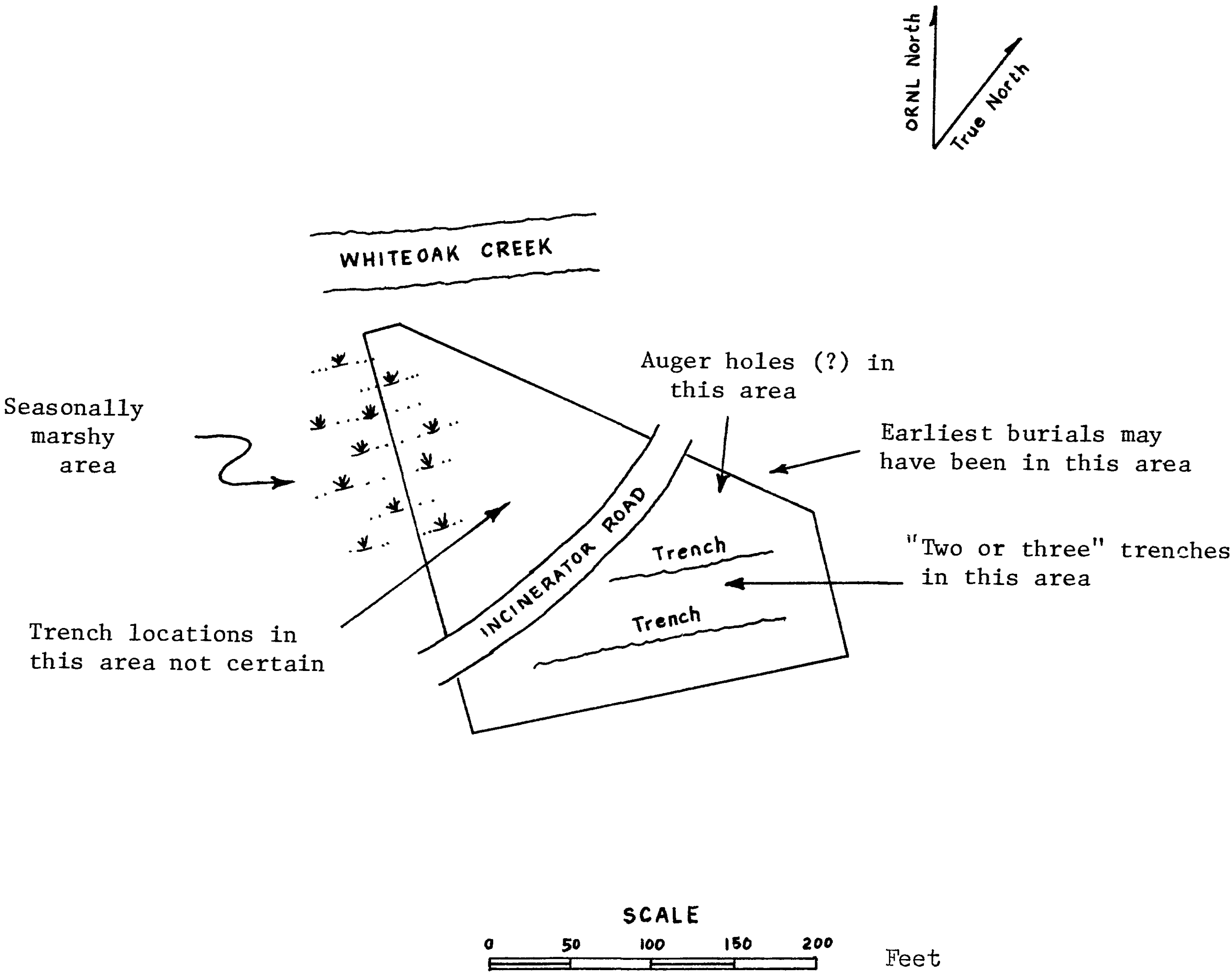


Fig. 6. Schematic diagram showing the orientation and approximate location of trenches in Burial Ground 1. Diagram is based on oral communications from J. E. Brandon and H. Dalton, 1974.

The one-acre site is now fenced and grassed and devoid of evidence indicating unusual erosion. Surface runoff from points as much as 150 feet higher on Haw Ridge crosses the burial ground enroute to Whiteoak Creek and, following periods of rain, tends to collect and foster the development of marshy conditions in the lowest part of the site. It is possible that the water that accumulates in this area may be augmented by the discharge of shallow ground water.

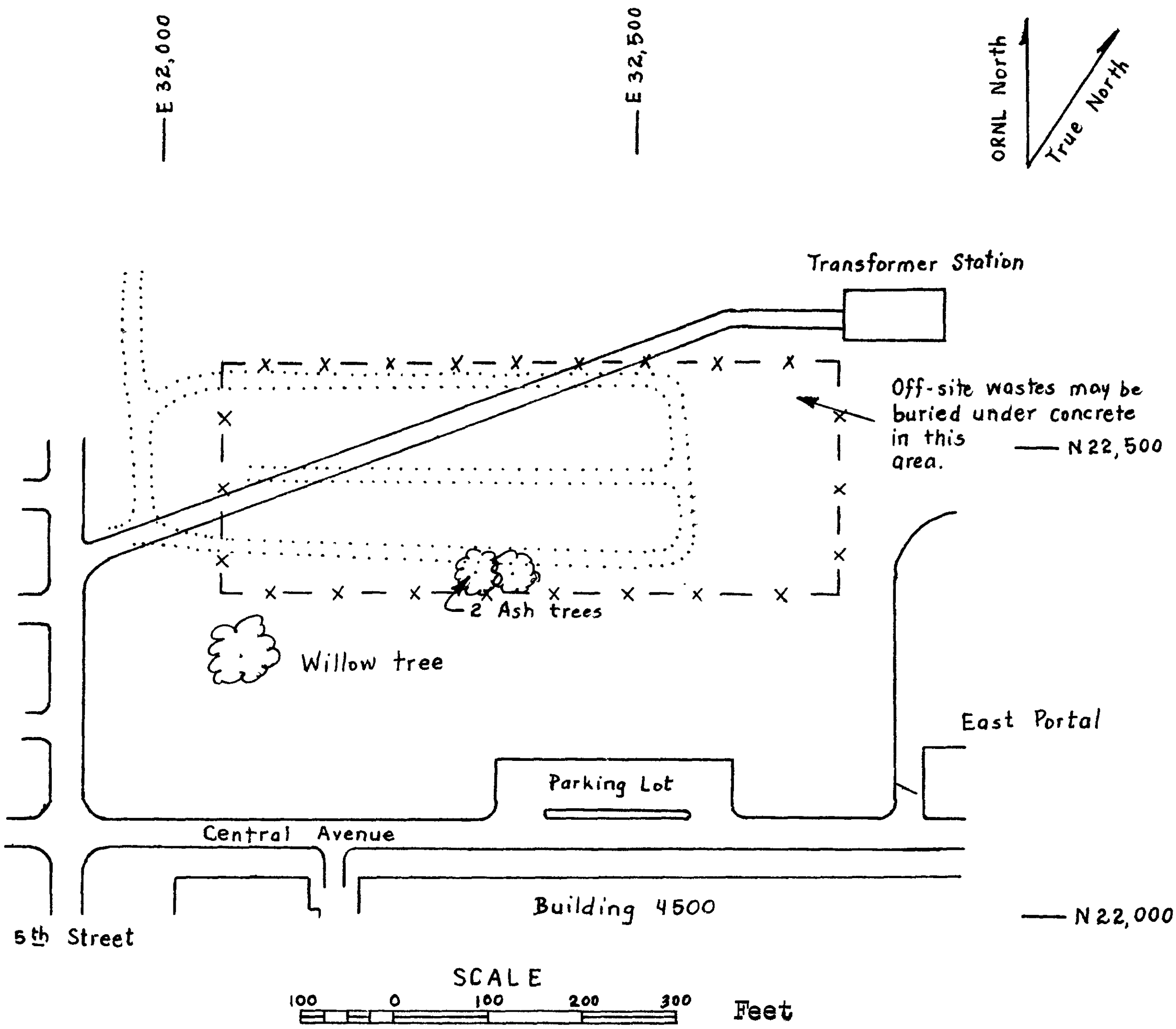
Ground water occurs below the site at a comparatively shallow depth. On June 20, 1950, water was found in a well in the upper part of the burial ground at 14.3 feet below the top of the casing, and in a well in the lower part of the burial ground at 7.9 feet below the top of the casing (De Buchananne, *in* Stockdale, 1951). The water-table contour map of that date indicates that the water table slopes northward towards Whiteoak Creek. It is inferred, therefore, that ground water moves in that general direction and discharges to the creek.

In 1946, in the first record of burial-ground monitoring, the site was surveyed for ground contamination and seven soil samples were analyzed for alpha activity. The survey showed only two spots that read above background level of activity (Ray and Davis, 1946). The correspondence describing the survey did not report the analytical results. The next recorded monitoring activity at this site occurred in 1973 when water samples were taken from a seep and two wells (subsequently destroyed) near, but outside of the lower end of the burial ground. Analyses indicated that water from one of the wells contains a minor concentration of ^{90}Sr (Duguid, in press).

Burial Ground 2

The second disposal site, about 3 to 4 acres in size, was developed on the lower half of a hill near the east entrance to the Laboratory. Available records do not indicate the reason for the site's selection, although memoranda of that time expressed concern about the length of time personnel were exposed to radiation while transporting the waste to Burial Ground 1 and the delays imposed at the gates while obtaining passes to transport materials outside. An area close to the graphite reactor and chemical separations plant and within the Laboratory compound thus appears to have been one criterion for selection of this site. Other criteria suggested by persons knowledgeable of events of that time include the desire for an area with all-weather access, little potential as a building site, and the absence of swampy conditions.

The burial ground is now unfenced or otherwise marked to readily show its location on the hillside. The site's boundary, based on an old map, however, is indicated on figure 7 by a fence line. According to persons familiar with disposals at this area, the burial ground initially had one trench cut in an east-west direction, and later a second, shorter trench cut to the north of the first. The most probable location of the two trenches is between the roads shown in figure 7.



EXPLANATION

X—X—X—X— Former fence around burial ground.

: : : : : : Roads in and near burial ground at time of use.

NOTE: The perimeter of Burial Ground 2 as shown on Plate 1 is based on comments by persons familiar with the former site. Subsequent to the printing of that plate, a topographic map showing roads and buildings at the X-10 site as of 1947 was located. The boundary of the burial ground shown in this diagram is based on that map and is regarded as more accurate than that shown on Plate 1.

Fig. 7. Diagram showing location of Burial Ground 2 relative to present features. Position of trees shown is approximate. Location of former fence and roads at the site is from Oak Ridge National Laboratory Engineering Drawing No. E-559, dated Feb. 1, 1947.

It has been reported, based on an interview two decades later, that solid waste contaminated by beta or gamma activity was placed in black iron drums and buried in the trenches. Liquid waste contaminated by plutonium was put in stainless steel drums and either buried in trenches (Winget, 1966) or stored without burial in a "natural ravine" eroded in the denuded slope (C. Keck, oral cummun., 1974). In addition, waste from an off-site source was buried and covered with concrete (suggestive of alpha contamination) near the present location of a transformer station (P. Kimbrough, oral commun., 1974). The arrival in August 1945 of two shipments of off-site waste, heavily contaminated by "Postum" (believed to have been the code name for polonium) and burial under a concrete slab in the northeast corner of "the new burial ground", are documented by memoranda.

Use of the land for waste burial is said to have been incompatible with long-range land-use planning at the Laboratory, and consequently the burial operation was terminated. The date commonly given for closure is 1946 which corresponds to the date of completion of access to the next site. After closure, all of the waste is reported to have been exhumed and re-buried in Burial Ground 3. The stainless steel drums containing liquid plutonium waste were removed intact, but the black iron drums containing beta-gamma solid waste had deteriorated while interred. Therefore, the dirt around them was also removed and re-buried at the new site. The only material reported to have been left was some unidentified material with a radiation reading greater than 50 rems. The hillside was then bulldozed to smooth out its irregularities and seeded (Winget, 1966). According to other employees recently interviewed, however, large pieces of equipment (such as storage tanks and a vehicle) were also buried at this site, and as far as these persons knew, nothing was removed before the trench area was bulldozed and seeded.

The formerly barren slope is now covered by a dense mat of grass that has stabilized the soil. Erosion is minimized by conveying runoff from points above the burial ground around the hillside in a contour ditch without crossing the trench area; runoff from points within the burial ground is carried by another ditch to the storm sewer system.

There are no well data or records of previous investigations of the site. By comparison with other areas the seasonal minimum depth to ground water at the upper part of the site is probably less than 30 feet, and at the foot of the hillside, less than 5 feet. Although a water-table contour map for this area has not been prepared, projection of contours for the area immediately west (fig. 2) indicates that the water table at this site slopes to the south; hence, the movement of ground water is inferred to be towards Whiteoak Creek or its tributaries.

Recent analyses of ground water from this hillside have not been made nor is there record of past analyses. A few persons' statements regarding removal of a tree found contaminated near the parking lot north of Building 4500 suggest that ground-water contamination did occur at some time in the past.

Burial Ground 3

Burial Ground 3 is about 0.6 miles west of the west entrance to the Laboratory complex. It is in a flat, forested area at the foot of Haw Ridge and is hidden from view of the Laboratory by an intervening rise in the land surface. The site presumably was chosen because of its dual characteristic of proximity to the Laboratory yet out-of-sight location, and because the soils could be readily excavated by power equipment (K. Z. Morgan, oral commun., 1974).

The burial ground became operational in April 1946, although it had received "special hot materials" from off-site waste producers for several months prior to that date (Weiner, 1946). Upon opening, a trench was excavated along its northeast end and lined with concrete. The drums containing alpha-contaminated wastes at Burial Ground 2 were removed from that site, placed in the new trench, and encased in concrete (C. Keck, oral commun., 1974). Subsequently, alpha-contaminated wastes were dumped in unlined trenches and covered with concrete, whereas beta-gamma contaminated wastes were dumped in trenches and covered with native soil. Trenches were cut parallel to each other across the width of the site and as deep as the back-hoe could excavate (Stockdale, 1951, p. 73, described the trenches at this site as being "generally less than 15 feet deep."). During wet weather the trenches often contained water and, on occasion, small dams or dikes were made to hold back runoff while the trenches were open. At other times, the trenches were dry (K. Ladd, oral commun., 1974). In 1949 the site was expanded westerly. Hard rock was encountered which made excavation more difficult, and the site was closed to burials in 1951 after utilizing about seven acres. The ground surface, however, is still used for the storage of large pieces of contaminated equipment that may be used again.

The alignment of trenches and general location of alpha and beta-gamma trenches is shown in figure 8.

The burial ground is now fenced, grassed, and shows no significant evidence of erosion. Although the principal ground cover is grass, it is being supplanted by brush and trees as the vegetation undergoes natural succession.

Runoff from a local area on Haw Ridge crosses the site in two shallow drainages. Runoff is also carried in shallow drainages located immediately outside the fence on both the east and west ends of the site. All of the surface water drains to Whiteoak Creek.

A contour map (fig. 2) showing the water-table elevation in 1950 indicates that a ground-water divide underlies the western part of the site. To the east of this divide ground water moves across the width of the site from southeast to northwest and then towards a tributary of Whiteoak Creek. To the west, movement is westerly towards Raccoon Creek (DeBuchananne, *in* Stockdale, 1951). On June 20, 1950 the depth to the water surface from the top of the well casings ranged from 8.9 feet in well 23 near the northeast edge of the burial ground to 33.9 feet in well 15 near the southwest edge.

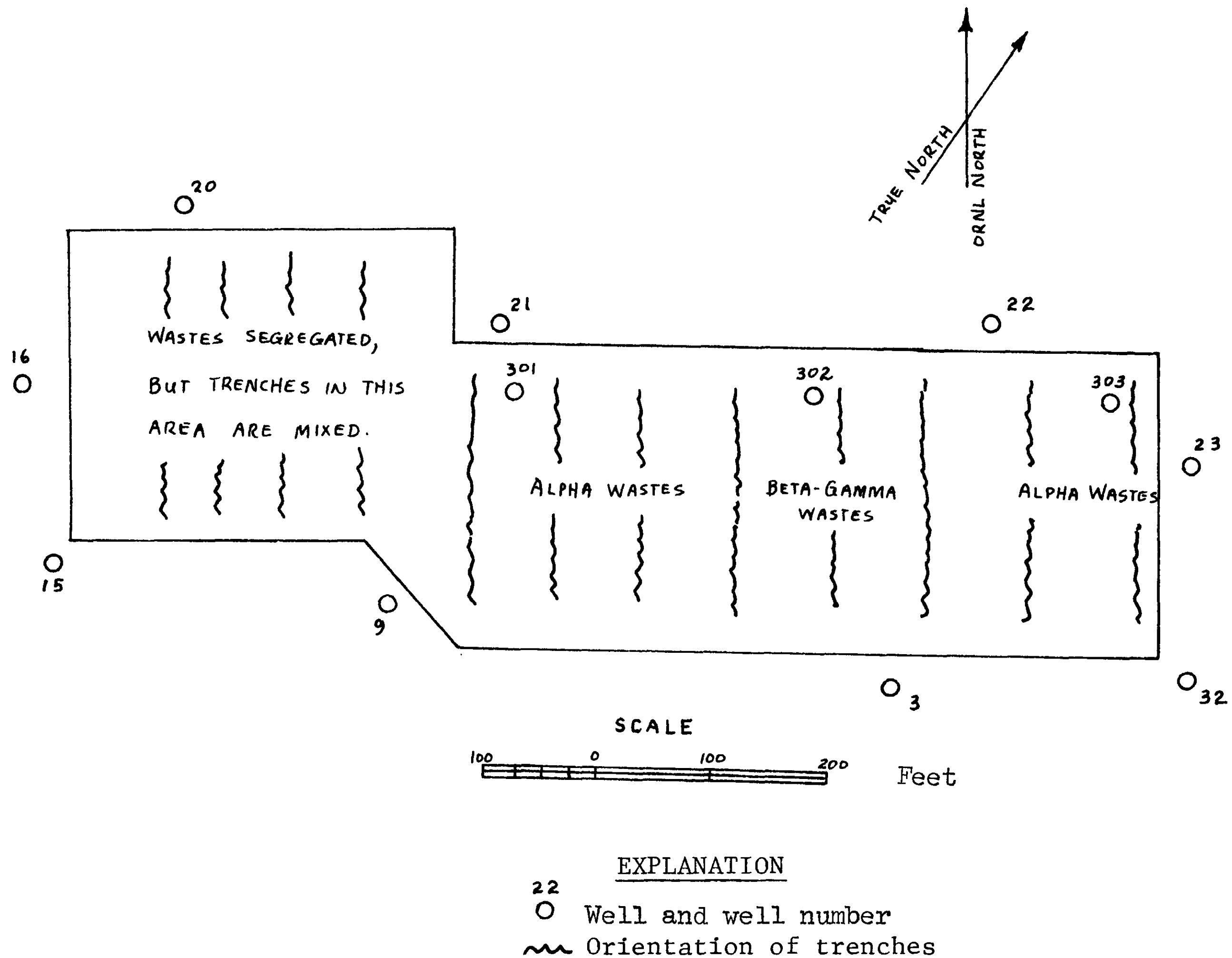


Fig. 8. Schematic diagram showing the orientation and general location of alpha and beta-gamma trenches and location of wells in Burial Ground 3. Trench information is based on oral communication from K. Ladd, 1974.

Samples of well water analyzed in 1964 showed contamination primarily by the trivalent rare earths (TRE), ^{89,90}Sr, and ^{3}H (unpublished manuscript by F. Gera, written about 1964). Recent (1973) sampling of wells indicates that a minor concentration of ^{90}Sr is still present; determinations for ^{3}H and TRE were not made (Duguid, in press). Strontium found in the recent sampling occurred in both the area draining to Whiteoak Creek as well as that suspected of draining to Raccoon Creek. The presence of ^{90}Sr in well 9, located upgradient from the burial ground with respect to ground-water flow, may be due to the leaching of radionuclides from contaminated equipment at the burial ground and transport by surface runoff to the well nearby, to dispersion in ground water, or possibly to the movement of contaminated, perched water under natural hydraulic gradient from a nearby trench.

The Melton Valley Burial Grounds

Burial Grounds 4, 5, and 6 are situated in Melton Valley. The decision to terminate burial activity in Bethel Valley was based on the recommendation of Professor P. B. Stockdale, University of Tennessee, who headed a geologic-hazards investigation of the Laboratory facilities during 1948-50. After studying the geology and hydrology of the X-10 site, he concluded that underground contamination in the limestone seemed inevitable and recommended that all future contaminated solid waste be buried in the Conasauga shale belt of Melton Valley. His reasoning was that "such rock is generally quite impermeable and is not subject to solution..." (Stockdale, 1951, p. 75). In the course of that investigation, a rather complete study of the ground-water regimen in Bethel Valley was made. There is no evidence, however, to indicate that a similar investigation of Melton Valley was made before burials began in that area.

That the hydrologic character of the Conasauga shale belt was misunderstood at that time is reflected in subsequent events. In the belief that the shale was indeed quite impermeable, an experimental pit was excavated to provide badly-needed, additional storage space for liquid wastes having a higher level of activity than could be discharged to the creek. Some persons apparently thought of the pit as essentially tank storage with "very little seepage over geologically long periods of time" (Operations Division Monthly Report, July 31, 1951, p. 9), whereas others conceived of it as safer-than-tank storage because, even if the pit did leak, the waste could not be released to the environment in a massive dose as it could from a leaking storage tank. It was found that the pit not only slowly lost its fluid, but also received an inflow of ground water, thereby demonstrating the low permeability of the shale. It was also found that the activity that appeared in the seepage downslope was essentially all ^{106}Ru; the other contaminants were believed to have been removed by passage through the soil (Witkowski, 1956). This revelation about the soils "cleansing" capability led to the subsequent disposal of intermediate-level liquid wastes in several pits excavated in more suitable locations. The studies of the Conasauga shale that ensued provided a better understanding of the movement of fluids and contaminants through it, and influenced the development of hydrologic criteria for the selection of future burial-ground sites.

Burial Ground 4

The area recommended by Stockdale for a new burial ground was that immediately northwest of the lower end of Whiteoak Lake. A proposal by the Laboratory to develop a new burial site in that area was approved by the AEC (Roberson, 1950), but burials began six months later in an area at the foot of Haw Ridge and near the flood plain of Whiteoak Creek. The reason for the change in location is not disclosed in records now available. According to one oral account, the site near the flood plain was chosen because it was the closest area to the Laboratory underlain by Conasauga shale and its use would save the costs of transporting waste as far as the lake. The criteria for the selection of this site thus appear to have been essentially based on the suitability of the areal geology and proximity to the Laboratory facilities.

The burial ground was opened in February 1951. Its development proceeded generally from the low-lying northeast end to the higher southwest end. Trench orientation was variable and lacked any consistent relationship to original site topography. Trench dimensions ranged from about 50 to 400 feet in length, 8 to 30 feet in width, and 8 to 14 feet in depth. The practice of capping trenches containing alpha wastes with about 18 inches of concrete was continued to discourage future digging in these areas by persons of future generations who are unaware of the hazard; trenches containing beta-gama wastes were simply back-filled with native soil. Significantly, wastes were buried in the low-lying areas during the dry summer months, but in higher areas during the wet winter months, suggesting that there was a seasonal rise of the water table into the low-lying trenches (Lomenick and Cowser, 1961; Abee, 1956).

"Higher-level" waste and some "special high-level" wastes were placed in auger holes 1 to 2 feet in diameter and approximately 15 feet deep. In addition these holes were used for the temporary storage of materials contaminated by fission products of short half-life. About 50 such holes are located along Lagoon Road (Lomenick and Cowser, 1961).

Figure 9 shows the location of auger holes and the orientation and general location of alpha and beta-gamma trenches. It is based on a study of the 23-acre site after its closure in 1959 and is necessarily generalized because of the accidental destruction of the burial records.

Subsequent to closure, much of the site was covered by uncontaminated fill and construction debris. The greatest amount of material was placed on the northeast end of the site, raising the land surface as much as 20 feet in that area. The surface of the burial ground, as modified, now appears as a constructional terrace sloping gently towards the northeast. The terrace is terminated along its south and east sides by a steep cliff dropping to the flood plain of Whiteoak Creek. At one point the creek touches the base of the cliff in a new channel excavated during a flood in 1973 (J. O. Duguid, oral commun., 1974). This channel supplements the main channel a short distance to the east.

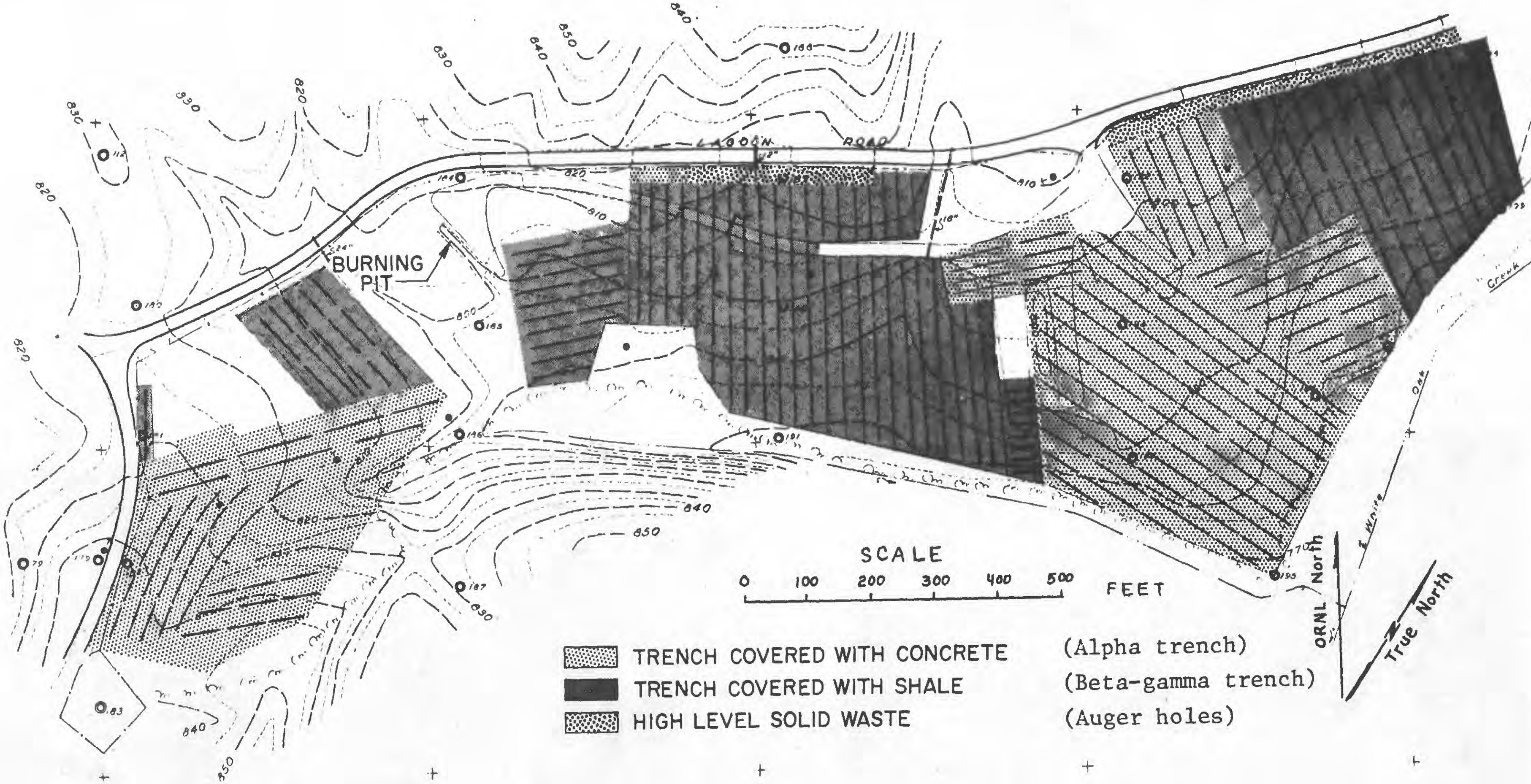


Fig. 9. Map of Burial Ground 4 showing location of auger holes, and orientation and general location of alpha and beta-gamma trenches (From Lomenick and Cowser, 1961).

In several places the grass-covered surface of the burial ground has slumped in response to the partial collapse or compaction of underlying material. The depressions thus formed are of variable size and shape, ranging from a few feet in diameter to an almost complete outline of a trench. Most of the depressions are shallow, but act as small basins for the collection and channelization of runoff, thereby permitting a greater amount of water to percolate through the underlying contaminated waste than otherwise normally would.

A small number of "seeps" have developed near the rim of the terrace in the center third of the burial ground; others are reported to have developed in more central parts of the burial ground, at the base of the steep slope bordering the terrace, and on the flood-plain below the terrace. In winter and spring the discharge from at least two seeps near the rim in the center third of the burial ground amounts to several gallons per minute. One of the seeps in this area and another at the base of the easterly slope of the terrace are reported to be perennial. During dry periods, the discharge decreases considerably.

Along the west half of the burial ground, local runoff from Haw Ridge is carried by three culverts under Lagoon Road to discharge onto the burial-ground surface. The most westerly of the resulting drainages carries sufficient water to run in a small, well-defined channel (pl. 2, C); the paths of the other two drainages can be traced across the grassy terrace by observing the lushness of vegetation during or after periods of precipitation. Drainage from much of the burial-ground surface discharges to a short tributary of Whiteoak Creek immediately south of the burial ground; drainage from the remainder of the site discharges directly to the creek east of the site.

The excavation of trenches in rock or residuum having low permeability and back-filling with materials having greater permeability has enhanced the development of perched-water bodies in the former trenches. The condition is caused by the accumulation of water at a rate faster than the fluid can be dissipated into the surrounding rock. In some trenches the water level rises sufficiently to intersect land surface where additional increments of water are discharged at "seeps" (pl. 2, D).

Measurements of water levels in wells between August 1959 and April 1960 showed that during those eight months the depth to the water table was 2 to 3 feet below land surface in topographically low areas, and 10 to 15 feet in the higher areas (Lomenick and Cowser, 1961). Measurements taken again in February 1974 showed that the water-table depth was less than 2 feet in low areas and less than 5 feet in many places. Only in the topographically high southwest corner was it in excess of 10 feet. The increase in water-table elevation over the 15-year period has been attributed to the dumping of uncontaminated fill on the site, thereby increasing surface elevation and surface permeability (Duguid, in press). The proximity of the water table to land surface indicates that much of the buried waste is bathed in water for at least a part of the year. Even the auger holes drilled on higher ground near Lagoon Road for the disposal of higher level wastes were observed to contain water within an estimated 5 feet of land surface during March-April 1974.

(A)

(B)

(C)

(D)

PLATE 2. BURIAL-GROUND CONDITIONS CONDUCIVE TO RADIONUCLIDE TRANSPORT. (A) Open trench in Burial Ground 6 showing contaminated waste in contact with water, February 1974. It is a moot question whether water resulted from surface runoff or a rise in the water table. (B) Collapsed trench under drainage ditch in Burial Ground 5. Runoff is funneled into trench to accumulate in its low end. Condition at this trench corrected, December 1974. (C) Well-defined channel that carries runoff from Haw Ridge across Burial Ground 4. Part of runoff enters the ground and enhances development of perched-water bodies in closed trenches. (D) Discharge of perched water at a seep in Burial Ground 4, bringing radionuclides in solution to the surface environment.

A water-table contour map for this burial ground in February 1974 is shown in figure 10. The contours indicate that the overall direction of flow in the upper part of the saturated zone is southeasterly to discharge to Whiteoak Creek or its tributary on the south side of the disposal site. In the disturbed zone, the greatest component of flow probably parallels trench orientation, due to the increased permeability caused by trench excavation and back-filling. In fresher rock, the largest component of flow is assumed to be generally parallel to strike, reflecting the movement of water primarily through partings or other slightly permeable zones between the strata.

The direction of ground-water movement through the hillside north of Lagoon Road is important. If it is primarily parallel to strike as suggested by the conclusions of previous studies, then the water could be expected to discharge directly to Whiteoak Creek without recharging the ground-water reservoir beneath Burial Ground 4. If, however, there is significant flow across strike as suggested in earlier discussion, then the ground water north of the road flows towards and beneath the burial ground and is partly responsible for sustaining the water table at shallow depth. The direction of flow would influence the effectiveness of a proposed 20-ft deep trench along the length of Lagoon Road in this area to divert this component of recharge from the disposal site.

Sampling of wells and streams in and near the burial ground during 1959 and 1960 showed that both ground water and surface water were contaminated. Of sixteen wells sampled in the burial ground, water from eight showed beta-gamma contamination and water from one[8/] contained alpha activity. Identifiable radioactive contaminants included ^{90}Sr, ^{106}Ru, and the trivalent rare earths. Relatively high concentrations of sodium, chloride, nitrate, and sulfate in the water indicated that these ions also were being leached from the buried waste.

Both alpha and beta activity were found in water discharged from the seeps and in the intermittent stream that borders the burial ground to the south. Identifiable radioactive contaminants from two seeps included ^{90}Sr, ^{137}Cs, ^{95}Zr-^{95}Nb, ^{60}Co, and TRE; and from the intermittent stream, ^{106}Ru, ^{90}Sr, ^{210}Po, $^{239,240}Pu$, and TRE. Whiteoak Creek was also sampled above and below the burial ground to determine the radionuclide load originating from this site. The creek, however, was found to contain sufficiently large amounts of radiochemicals from the Laboratory's discharge of liquid effluent that the comparatively small contribution from Burial Ground 4 was unmeasurable (Lomenick and Cowser, 1961).

In 1964 samples were taken from six wells and one seep at the disposal site. Radioactive contaminants found at that time were $^{89,90}Sr$, ^{3}H, TRE, and minor amounts of ^{106}Ru (Gera, unpublished manuscript, circa 1964).

8/ The report of this study contained in the Health-Physics Division Annual Progress Report for the period ending July 31, 1960 (p. 28) states that detectable alpha activity was found in two wells.

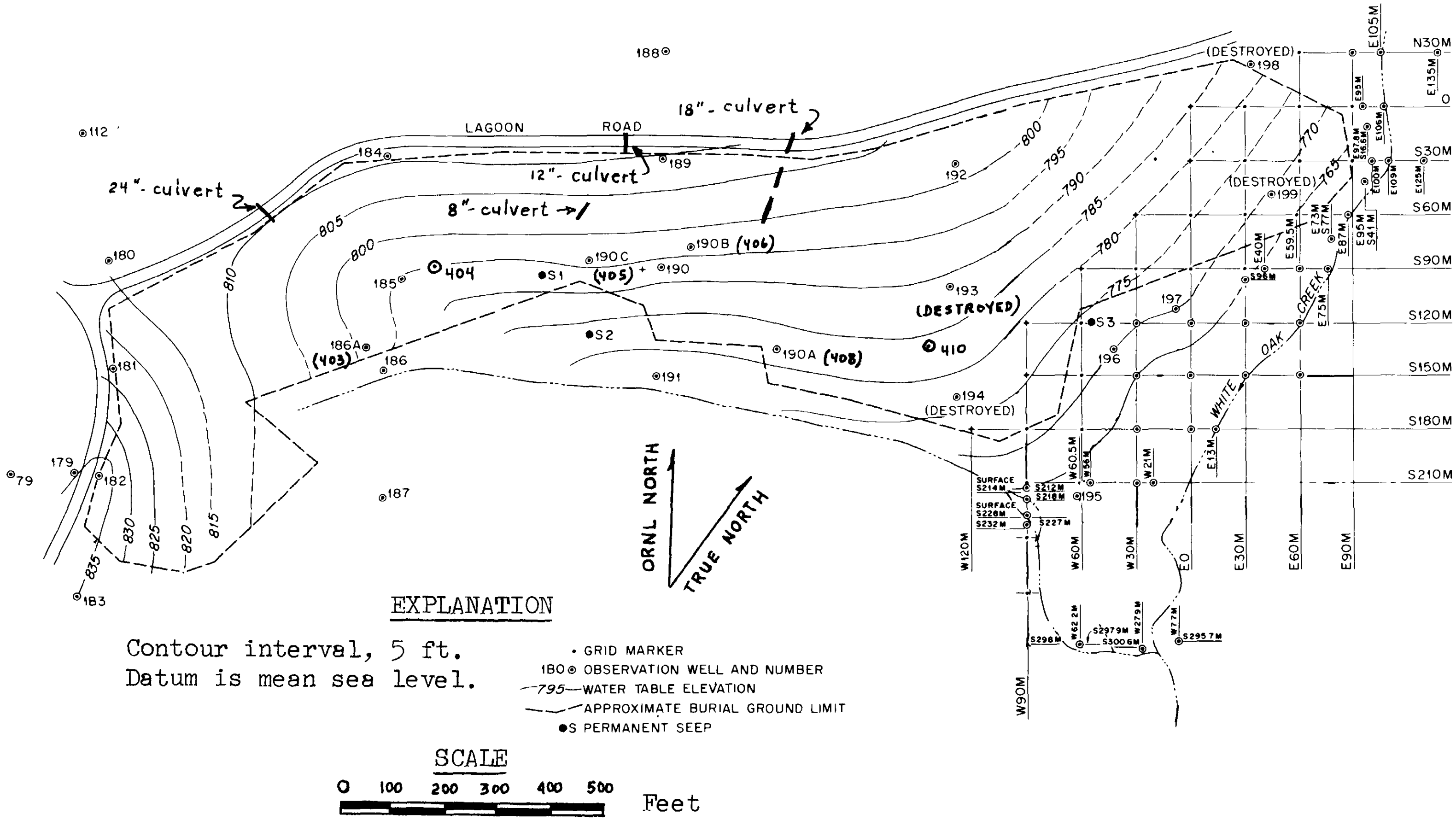


Fig. 10. **Water-table map for Burial Ground 4 during February 1974**, and location of wells and culverts (After Duguid, in press).

In 1973 a number of wells and seeps in or near the burial ground were sampled again. The eight wells sampled on the burial ground surface showed contamination by ^{90}Sr, and two of the wells showed measurable contamination by ^{125}Sb. All ten wells sampled near the ephemeral stream south of the burial ground and on the adjacent flood plain showed contamination by ^{90}Sr, and a small number showed contamination by ^{95}Zr-^{95}Nb, ^{125}Sb, ^{137}Cs, and ^{60}Co. None of the samples contained more than minor amounts of alpha activity (Duguid, in press).

Soil samples were also taken in 1973 from four shallow borings drilled in the flood plain. Significant amounts of ^{137}Cs and ^{90}Sr were found in the four samples; ^{60}Co, in three samples; and ^{95}Zr and ^{125}Sb in one sample each. Additional sampling in 1974 revealed concentrations of ^{239}Pu greater than background in two samples taken on the flood plain within the area of the former Intermediate Pond, and in background concentration in two more soil samples collected from small seeps near the burial ground. This distribution suggests that the plutonium was contained in water released from the graphite reactor during the early days of plutonium production rather than in water that had passed through the trenches in Burial Ground 4 (Duguid, in press). However, additional samples are now (1974) being analyzed for a more positive determination.

The amount of ^{90}Sr discharged from the burial ground to Whiteoak Creek is estimated by Duguid (in press) to have been 1.00 Ci (curie) during 1971, 1.30 Ci during 1972, and 1.78 Ci during 1973. The estimate is based on precipitation, evapotranspiration, and runoff data for the Walker Branch Watershed, located about 3 1/2 miles to the northeast of Burial Ground 4 in a forested area underlain by the dolomite of the Knox Group, and assumes that all precipitation infiltrates the burial-ground surface as it does in the Walker Branch area. The estimate thus is based on dissimilar environmental data, but in the absence of more reliable data or appropriate instrumentation, provides an approximation of the strontium release from this burial ground. For comparison, the annual differences in the ^{90}Sr content of Whiteoak Creek between monitoring station 3 and stations 1 and 2 (plate 1), about 1 mile apart, were 1.19, 1.97, and 2.19 Ci for 1971, 1972, and 1973, respectively. The discharge between these points, however, also incorporates any ^{90}Sr released from Burial Grounds 1, 3, part of 5, and other possible sources.

Burial Ground 5

Burial Ground 5 consists of two sections on the hillside east of Whiteoak Creek and south of Haw Ridge. For the purpose of identification herein, the two sections are referred to as the 5-South area and the 5-North area, but elsewhere the site is known simply as Burial Ground 5 or Solid Waste Storage Area 5. The 5-South area contains most of the buried waste; the 5-North area was appended later to provide retrievable storage of certain fissile-alpha wastes after most of the suitable burial space in the area to the south had been utilized.

Criteria for the fifth site were proposed in 1958 as available space in Burial Ground 4 approached exhaustion. Although there had been no monitoring to determine if contaminants were being leached from that site, study of the pits had shown that ground water could transport dissolved contaminants through the shale. For that reason, one of the criteria for the new burial ground was that the site "should not be subject to flooding by surface water or a high ground-water table" (Cowser, Lomenick, and McMaster, 1961). Other criteria pertained to its size, topography, soil, distance from the Laboratory, and accessibility via private roads. Of the four sites considered, the 5-South area most closely fitted the criteria and was subjected to a detailed geologic and hydrologic investigation. The study included geologic mapping, the drilling of 45 shallow wells (less than 20 ft deep) and 5 deep wells (about 150 ft deep), the measurement of water levels from May 1958 to July 1959, preparation of a minimum depth-to-water contour map, hydraulic-pressure tests of the deep wells to determine the likelihood of water circulation at depth, and chemical analyses of ground water. Recommendations were made that waste should not be buried within one foot of the highest known ground-water level, and that a new trench design should be employed. The features of the suggested design included a sloping bottom with gravel underdrain, an asphalt-lined sump at the trench's low end from which a section of perforated casing extends above land surface, and the placement of an asphalt cap over the compacted fill after the trench has been closed. Two trenches of this design were constructed for experimental purposes (Cowser, Lomenick, and McMaster, 1961).

The topography of the 5-South area is a gently to moderately sloping hillside that rises to two local summits about 100 ft above Melton Branch and Whiteoak Creek. The burial ground includes substantial areas that are topographically or hydrologically unsuitable for the trench disposal of wastes and a small area for the pressure-injection of liquid wastes into the substrata; consequently, the area used for solid-waste burial is considerably less than the 33 acres usually attributed to this site.

Burials commenced in 1958, apparently before completion of the site study. Initially the same burial procedures used in the preceding sites were continued. Alpha-contaminated wastes were interred in the lower part of the area of "undefined trenches" (fig. 11) and capped with concrete, whereas the beta-gamma contaminated wastes were simply covered with weathered shale previously removed from the excavation. The practice of segregating and capping the alpha-contaminated wastes, however, was discontinued sometime during the operational life of this site (J. E. Brandon, oral commun., 1974). Segregation of certain transuranium wastes was resumed in 1970. Auger holes were used for the disposal of higher level wastes and certain less hazardous materials to better utilize all suitable land.

The location and alignment of trenches in the developed site are shown in figure 11. Trench lengths vary considerably, ranging from less than 40 feet to more than 500 feet. The majority of the trenches are oriented more or less parallel to the topographic slope and at substantial angles to the strike of the formation. The length and orientation of trenches in the undefined area (records for this portion of the burial ground were lost by fire) are similar to those in the adjoining area (J. E. Brandon, oral commun., 1974). None of the trenches, except the two excavated for experimental purposes, were constructed according to the suggested design.

The disturbed areas are now covered by a fairly dense growth of grass and weeds and locally, in the vicinity of trenches 42 through 50, by a dense growth of young pine trees. Erosion is a minor problem in some parts of the disposal site. Locally, the fill material covering several trenches has sagged and in a few places has collapsed, and at a couple of trenches the contents have been exposed by the entrenchment of shallow drainage ditches (pl. 2, B). One extreme example of fill collapse occurred recently in the lower part of the burial ground where the fill material slumped and disappeared below water, estimated to have been about 10 feet below land surface.

The 5-North area consists of about 5 acres of gently to steeply sloping hillside that culminate in a summit about 100 feet above Whiteoak Creek. Development of this area commenced in 1970 in response to an "Immediate Action Directive" requiring segregation of certain type wastes. The area contains structures for the retrievable storage of Class B transuranium wastes (transuranium wastes having measurable radiation greater than 10 µCi/kg), concrete and stainless steel lined auger holes for the storage of wastes contaminated by alpha and higher level beta-gamma activity, a small number of trenches for the disposal of wastes contained in concrete casks from hot cell operations, and a controlled area for special burials. The location and orientation of the few trenches excavated in this area are shown in figure 12.

Surface runoff from higher areas to the east of both the 5-North and 5-South sites travels downslope to tributaries of Whiteoak Creek a few hundred feet west of the site. Part of the runoff from the 5-South area also drains to Whiteoak Creek, but a larger amount discharges to Melton Branch, about 150 feet south of the site.

During the pre-development study of the 5-South area, the seasonal minimum depth to ground water was found to range from less than one foot below land surface in areas near drainages to about 59 feet in a deep well near the highest part of the burial ground. Shallow, perched water was found during periods of heavy rainfall, but perched conditions prevailed for only a limited period of time. Seasonal fluctuations in the deep wells ranged from 1.5 to 14 feet; the range in fluctuations in the shallow auger wells was less (Cowser, Lomenick, and McMaster, 1961) and is probably more representative of original conditions in the burial zone.

Waste was buried generally in areas where the minimum depth to water was mapped as greater than six feet. An exception is in the low-lying area east of a deep ravine that divides the site into two lobes. A spot check of records suggests that several trenches throughout the low end of the burial ground were excavated to depths in excess of the minimum water-table depth. It is in this low area east of the ravine that several seeps have developed, indicating that the lower ends of the trenches fill with water seasonally. Seeps also appear at the toes of the long, sloping trenches in the west lobe of the burial ground, although there have not been as many reported in that area as in the east lobe.

The pattern of ground-water movement through the subsurface has likely been altered as a result of the gross changes in permeability caused by trench excavation and backfilling. Within the trenches, water moves most readily downslope and accumulates in the low end. In the uppermost part of the saturated zone, water probably moves in directions having a significant component of flow normal to the present pattern of water-table contour lines. These contours may be somewhat displaced from those of December 1959, shown in figure 3. Again it is assumed that the fraction of the waste solution reaching fresh rock moves in a direction generally parallel to strike.

Relatively little study has been made of the site during or following development. Measurements of water levels were taken at several wells near the periphery of the 5-South area during April 1974 in conjunction with present Laboratory studies. Because of the location of the wells, the data are insufficient in distribution to permit preparation of a post-development water-table contour map.

Radiochemical analyses were made in 1964 of water samples from several wells and of the wet-weather drainage that divides the site into two lobes. The principal contaminants found at that time were $^{89,90}Sr$, ^{106}Ru, ^{3}H, and the trivalent rare earths. Cores from several new wells were also analyzed for ^{106}Ru, ^{137}Cs, and ^{60}Co (Gera, unpublished manuscript, circa 1964); the data suggest that at that time there had been only minor movement of these radionuclides from the trenches. Several wells, seeps, and the drainage are reported to have been sampled again during the latter 1960's in an effort to locate the area from which large amounts of tritium were being discharged to the surface drainage. Sampling showed that Burial Ground 5 was the major source (T. F. Lomenick, oral commun., 1974).

Recent (1974) water sampling from a seep near the lower end of Trench 83, from several seeps immediately south of the burial ground, and from the wet-weather drainage, indicates that ^{90}Sr and ^{3}H currently are the principal contaminants in the seepage discharge. The average concentration of tritium in the samples is 3.9×10^5 dpm/ml, or 0.2 μCi/ml. Alpha activity and ^{125}Sb are present in measurable amounts in a small number of the samples (Duguid, in press). The sample taken from a seep a few feet south of Trench 83 is of interest because of the comparatively high concentration of ^{244}Cm, ^{90}Sr, and ^{125}Sb in the water.

This trench is one of the longest in the burial ground, permitting infiltrating water to come in contact with a considerable volume of waste before overflowing at the seep.

Samples of soil water and atmospheric water taken in or near the lower part of the burial ground during July 1974, at a time when evaporation and transpiration were comparatively high, indicated that tritium was present in concentrations of 30,000 dpm/ml at a depth of 10 cm, 90,000 dpm/ml at land surface, and 30,000 dpm/ml at a height of 10 cm above land surface (M. Witkamp, oral commun., 1974). The reason for this distribution of activity is not known.

Samples of water taken in 1974 from a small number of wells along the west side of Burial Ground 5 did not show evidence of alpha activity or ^{90}Sr (Duguid, in press).

Burial Ground 6

Burial Ground 6, the site currently used for waste disposal, is located immediately northwest of Whiteoak Lake. The site is situated on a wooded hillside that has a gentle to locally steep slope. The burial ground includes about 70 acres, but a third or more of the area is unsuitable for waste disposal because of excessively steep terrain or the presence of shallow ground water. The site presumably was selected because it is underlain by Conasauga shale, has hydrologic characteristics similar to those of Burial Ground 5, and was the only area in Melton Valley that had not been used for waste disposal or used or reserved for experimental reactor sites.

A study of the hydrogeology of the site was made during 1964-65. The study was generally similar in scope to that of Burial Ground 5, except hydraulic-pressure tests of the deep wells were not made because such tests had been made at other wells in the vicinity. Again, the recommendations were made that waste should be buried at least one foot above the highest known ground-water level and that a special trench design be used (Lomenick and Wyrick, 1965).

The first contaminated waste was buried at the site in 1969, although it was not until Burial Ground 5 was closed in 1973 that this area became the principal burial site for the Laboratory. Trenches initially were excavated as long as was topographically convenient; those excavated more recently have been limited to a length of about 50 feet. The trenches cut in the low terrace on the northwest side of Whiteoak Lake are an exception; many in this area are less than 50 feet long. Current practice is to place a section of perforated casing in the low end of the trench before disposal commences to permit the monitoring of fluids in the trench after they have been filled. The trenches generally are oriented at a substantial angle across the strike of the formation. Trench alignment and location are shown in figure 13.

Surface runoff from the site drains directly to Whiteoak Lake or to short drainages that discharge to the lake.

During the nine months in 1964-65 that water levels were measured, the minimum depth to water in wells was reported to be less than six feet throughout much of the low-lying areas. In three topographically high areas, it was greater than 21 feet. Perched water was found locally. A water-table map of the site was not published, but the water-table configuration was described as "essentially a subdued replica of the land surface." It was believed at the time that most subsurface water would move in a direction parallel to the strike of the formation and thus discharge to Whiteoak Lake or to short, ephemeral streams tributary to the lake (Lomenick and Wyrick, 1965, pp. 5-7). According to the interpretation presented herein, there may be significant movement in the weathered zone in other directions, but regardless, the subsurface discharge by either interpretation is to the lake and its tributaries.

There have been no subsequent studies made of the site. Owing to the recency of burials, it seems unlikely that sufficient time has elapsed for any significant movement of contaminants from the trenches to the surface drainages. It must be noted, however, that the potential exists. During the early months of 1974, water was observed in all of the open trenches. Some of the water probably was derived from surface sources, but it is likely that some also resulted from a seasonal rise in the water table. Fig. 13 shows that the trenches on the hillside (trenches generally in the series 30-42) have been excavated where the water table stands during its seasonal high at a depth of about 10 to 15 feet below land surface, and the trenches in the low-lying terrace in an area where it stands at about 5 to 13 feet below land surface. The observed depth to water in the hillside trenches during the early months of 1974 was estimated to be about 12 to 15 feet (pl. 2,A) and in those in the terrace trenches, at about 8 feet. There can be little doubt that water in the latter area, if not also in the hillside area, was the result of a seasonal rise in the water table.

Characterization Of The Waste

The material consigned to the burial grounds is generally described as "low-level solid waste", although its specific physical or chemical nature is poorly documented. A few reports indicate that a large portion of the waste consists of such ordinary items as filter media, oils, powders, laboratory glassware, wiping materials, protective apparel, lumber, scrap metal, concrete, soil, and animal tissue. Occasionally, large pieces of equipment that could not be economically decontaminated, such as metal tanks, buildings, vehicles, and military equipment, have also been interred. While it is commonly stated that the burial grounds contain only solid waste, they have also received liquid wastes contained in drums for an unknown interval of time (Winget, 1966; Operations Division monthly report, April 1948), and sludge from the waste-water treatment plant for a few years during the 1960's (J. R. Gissel, oral commun., 1974).

Relatively little is known about the identity, quantity, and concentration of contaminants associated with the waste. The paucity of information is due in part to the initial lack of records, the later loss of records, and always to the problem of sampling and adequately describing the heterogeneous mixture of materials that become "trash". A limited amount of indirect data regarding the identity of contaminants is available from the radiochemical analyses of wells, seeps, and drainages near the burial grounds, as indicated in preceding paragraphs. Other chemically toxic and radioactive contaminants, mentioned in various reports or by persons who have disposed of waste or worked with waste disposal, include uranium, thorium, plutonium, polonium, radium, tritium, sodium, cobalt, mercury, lead, and "all the chemicals" that were kept in Chemical Stores when that facility moved. It seems likely that if a complete list of buried contaminants could ever be compiled, it would likely include a large part of the radiochemical spectrum.

The level of activity of much of the waste is considered low. However, that wastes with higher levels of activity also have been and are being buried can be inferred from (1) the comparatively high level of radioactivity at a seep in Burial Ground 5, (2) the burial of wastes in auger holes and in concrete casks having a wall thickness of as much as 54 inches, and (3) the need for changing waste handling crews while wastes were en route to the older burial grounds because the men had exceeded their radiation-exposure limit (J. R. Gissel, oral commun., 1974).

Although burial activity records prior to those of Burial Ground 5 are not available, it has been estimated that the accumulation of long-lived activity in the burial grounds is less than 10,000 curies, exclusive of tritium which itself may amount to more than 50,000 curies. It also has been estimated that as of June 1973 there had been about 6.1 million cubic feet of waste buried in the Bethel and Melton Valley sites (U. S. Atomic Energy Comm., 1973). While a sizeable fraction of this has originated from the facilities at Oak Ridge, much also has been shipped from sources external to the Reservation. As early as 1944, Oak Ridge received a shipment of waste from Argonne National Laboratory (Stone, 1944) and during 1945, received two shipments from "Site M" in Dayton (Wirth, 1945; Coveyou, 1945; Simons, 1945). The latter were the prelude to virtually weekly shipments from a source in that city during the late 1940's (Operations Division Monthly reports, 1948-49). Between 1955 and 1960 the volume of waste from off-site producers had increased to such an extent that it comprised about 40 percent of the waste buried (Morgan and others, 1962) and between 1961 and 1964, approximately the time that Oak Ridge was designated a regional burial ground, off-site waste comprised about 55 percent of the material interred. Subsequent to 1964, the volume of off-site wastes declined steadily and now amounts to only a small percentage of that buried annually. During the time that large amounts of waste came from off-site sources, information pertaining to the quantity and chemical character of contaminants often was incomplete. Data provided commonly pertained only to the level of external radiation to protect those who handled the containers (Lomenick and Cowser, 1961).

RADIONUCLIDE MOVEMENT

Sorption and Ion Exchange

The principal vehicle for the transport of radionuclides from the burial grounds to the surface environment is ground water. The principal mechanisms for retarding or preventing their transport to the surface are adsorption, absorption, and ion exchange. In adsorption, radionuclides, occurring as electrolytes in solution, are attracted to soil particles by opposite electrical changes and held to the particle surface. In absorption the radionuclide penetrates the crystal lattice of the particle. The two processes are commonly termed sorption. When an ion attached to a soil particle is released to the solution in exchange for a radionuclide from the solution, the process is one of ion exchange. The effect of these processes is to decrease the linear velocities of the individual radionuclides fronts[9/] to less than that of the liquid front, and to provide storage of radionuclides in the geologic environment in space greater than that available from porosity alone.

As noted previously, the clay minerals can be particularly effective in this process. Considerable study has been made of the sorptive and ion exchange properties of the local clays because of the former practice of discharging radioactive liquid waste into pits and trenches. With some limitation, the results of these studies can be applied to the expected chemical behavior of ground water contaminated by passage through burial-ground waste.

The sorptive capacity of the clays for some of the more hazardous radionuclides has been determined by laboratory experimentation. The sorptive capcity is commonly expressed as K_d, the distribution coefficient, representing the ratio of activity sorbed per unit weight of soil to activity per unit volume of solution. Table 3 shows the average K_d and average percentages of cesium, cobalt, strontium, and zirconium-niobium in a distilled water solution at pH 6 sorbed by various standard clays and Clinch River sediment after a contact time of seven days (eight days for vermiculite). Later research showed that the presence of calcium and magnesium in natural water interferes with sorption, especially of strontium. When tap water, which roughly approximates the composition of local ground water, was substituted for distilled water, the sorption of strontium by Clinch River sediment[10/] was reduced to 5.07± 0.27 percent of that in the distilled water system.

9/ The radionuclide front is the peak concentration of contaminant in a distance versus concentration curve.

10/ Clinch River sediment is a mixture of approximately 60 percent illite, 15 percent kaolinite, 10 to 15 percent vermiculite, and 10 to 15 percent quartz (Morton, 1961).

Table 3. Average percent and average K_d of radionuclides sorbed by clays in distilled water at pH 6 over a period of 7 days (vermiculite, 8 days). (From Morton, 1961; tap water data from Carrigan and others, 1967.)

Material		Percent Activity Sorbed				Average K_d			
		Cs	Co	^{85}Sr	$^{95}Zr-Nb$	Cs	Co	^{85}Sr	$^{95}Zr-Nb$
Illite		98.39±0.23	86.43±0.37	26.88±0.54	94.05±0.22	180,000	6,400	370	47,500
Kaolinite		68.47±0.25	60.92±0.25	66.44±0.24	94.93±0.22	2,200	3,100	4,000	56,000
Montmorillonite		49.95±0.45	62.36±0.46	67.21±0.21	35.24±0.46	1,000	1,700	2,100	540
Vermiculite		99.60±0.24	98.96±0.16	97.33±0.19		12,000	4,700	1,800	
*Clinch River sediment	distilled water	97.78±0.24	97.28±0.17	41.83±0.39	86.56±0.24	88,000	72,000	1,400	12,900
	tap water	93.1±0.25		2.12					

*A mixture of approximately 60% illite, 15% kaolinite, 10-15% vermiculite, 10-15% quartz.

It is believed that the calcium and magnesium, which have similar chemical properties as strontium, compete with strontium for available exchange positions on the clay and thus diminish sorptive capacity for this ion. However, the presence of calcium or magnesium has little effect on cesium sorption. A re-determination with tap water decreased the cesium sorption by Clinch River sediment only a minor amount (Carrigan and others, 1967, p. 46-47). Other laboratory tests have shown that the Conasauga shale[11] has comparatively little sorptive capacity for ruthenium in waste solution (Lacy, 1957; Blanchard, Kahn and Robeck, 1958). The latter study found that only about 20 percent of the ^{106}Ru in a sample of waste solution containing several radionuclides was sorbed by shale upon passage through an ion-exchange column, and that this contaminant was the first to appear in the effluent. These laboratory determinations suggest that the clays (illite and vermiculite) developed from the Conasauga are highly efficient in removing cesium, cobalt, and zirconium-niobium from solution, less efficient in removing strontium, and comparatively inefficient in removing ruthenium. Collectively, a somewhat smaller efficiency may be associated with the clay (kaolinite, illite, and some montmorillonite) in the Bethel Valley area. Decreasing efficiency can be translated generally into a requirement for additional soil contact (that is, a greater distance of contaminant transport) to remove a given concentration of radionuclide from solution.

The experimental results for illite and vermiculite have been confirmed to a large degree by the discharge of intermediate-level liquid waste to pits and trenches located between Burial Grounds 4, 5, and 6 (pl. 1). Between 1952 and 1965, about 35 million gallons of highly alkaline waste containing over 1 million curies of mixed fission products were released to the pit system (Lomenick, Jacobs, and Struxness, 1967). The principal contributors to radioactivity during the first several years of operation were ^{137}Cs, ^{106}Ru, and the trivalent rare earths; lesser amounts of ^{89,90}Sr, ^{60}Co, and ^{125}Sb were present. After about two years of operation, the waste fluid appeared at a seep on the hillside below Pit 2, but the only active radionuclide found in the discharge was ^{106}Ru (De Laguna, 1956, p.448). Until 1959, this was the only contaminant positively identified in important amounts in any of the observation wells, seeps, or streams in the area, although small amounts of ^{60}Co and ^{125}Sb were found in some samples. The establishment of a low-level analytical laboratory at that time enabled the identification of other activity masked by the large amount of ruthenium activity. Sampling showed that ^{137}Cs had traveled to one well 50 feet from Pit 2, and that ^{90}Sr in concentrations of as much as 2×10^{-5} µCi/ml had traveled to several wells as far as 50 feet from Pits 2 and 3, and in concentrations of less than 10^{-6} µCi/ml to wells more distant (Cowser, De Laguna, Parker, and Struxness, unpublished manuscript, 1961).

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[11] The average composition of Conasauga shale is about 40 percent illite, 25 percent vermiculite, and 35 percent quartz (Tamura and Jacobs, 1960).

It could be expected that radionuclides from burial grounds developed in the same geologic environment would be sorbed at similar rates as those from the liquid waste. However, there may be some difference in the sorptive characteristics of the shale for at least three elements, ruthenium, zirconium, and strontium, originating from buried solid waste, and for any radionuclide affixed to a complexing agent. The ruthenium in the alkaline waste solution occurs largely as a negatively-charged nitrosyl complex that is repulsed by the negative charge of the soil particle, whereas ruthenium associated with buried waste may occur in leachate as a cation that would be readily attracted to the particle. The charge of the zirconium ion is uncertain and hence its sorptive characteristics are not definitely known (T. Tamura, oral commun., 1974). And for an equivalent concentration of strontium, a greater distance of strontium transport is implied because of the more neutral pH conditions that probably prevail at the burial grounds. Tamura (1962) has shown that strontium sorption by vermiculite, the clay mineral with greatest affinity for this ion (Table 3) is dependent on the pH of the solution, with sorption increasing as the pH is raised from a value of 4 to 9 and desorption occurring as it is lowered from 9 to 4. Moreover, Tamura (1963) has shown that the hydrous iron and aluminum oxides commonly found in soils have extremely high selectivities (that is, partiality for a particular ion in the presence of others) for strontium under alkaline conditions and has suggested that these sesquioxides may have been responsible for removing a sizeable portion of the strontium discharged to the pits. Where more neutral pH conditions exist, such as at the burial grounds, the amphoteric sesquioxides may have little or no selectivity for strontium. Consequently, the removal of this ion from water contaminated by passage through the burial grounds may be dependent solely upon clay mineral exchange.

The transport of radionuclides affixed to complexes provides additional complications. Complexing (including organic complexes) may serve either to assist sorptive processes or to increase transport, depending on the properties of the complex formed. For example, the small amount of ^{60}Co and ^{125}Sb found in well water and surface streams near the pits is thought to have been transported in complexes that have little affinity for the shale, whereas the same radionuclides if transported as dissociated ions would have been readily sorbed by the shale.

From this discussion it can be seen that sorption and ion exchange are processes of major significance to radioactive waste disposal, regardless of whether the waste is in solid or liquid state. These processes must not be viewed as fool-proof mechanisms by which all leached contaminants become a part of the geologic medium, however, nor can the near-surface earth materials be conceived of as a "sink" of unlimited capacity. Certain limitations must be recognized. The sorptive capacity of the shale is finite, and if this value is exceeded further sorption does not occur until shale with unsaturated capacity is reached. Where saturated, a steady-state condition exists and movement of nuclides equals movement of water. Moreover, the theoretical capacity of the shale as determined by laboratory experiments may never be achievable in the field because actual field conditions do not replicate the idealized laboratory test conditions. In the field the total body of rock or residuum is more heterogeneous and more solid than the pulverized material used in the laboratory, probably has less total area exposed to contact by fluids per unit volume of material, may have fractures or zones through which solutions move more rapidly, and might have fluids of changing chemical composition moving through it as leachates of different character are assimilated -- each of these factors could contribute to a reduction in the rock's theoretical sorptive capacity. There is also reason to believe that the K_d decreases over a period of time. Comparatively high values initially may be associated with the shale as the more accessible sites are readily occupied, followed by decreasing values as the progressively less accessible sites become occupied. And in addition, sorption may or may not permanently affix the radionuclides to the soil particles. Subsequent movement could occur either by desorption or erosion of the terrain. The permanence of radionuclide retention in the geologic environment after sorption, therefore, becomes an important question.

Considering first the rate of natural erosion, Sun (1975) has estimated, based on a denudation formula developed by Schumm (1963), that the average rate of denudation of the Melton Branch drainage basin is 0.13 foot per 1000 years and that 3 feet per 1000 years would be very high. The actual rate of denudation within a burial ground probably would be faster than this because of the gross disturbances to the land surface, but even if Sun's rate were to be used, it follows then that the contents of a 15-feet deep trench would be exhumed and the surrounding rock would be eroded to the level of the bottom of the trench in 115,000 years if man did not intervene in some way. If the trench had filled or partially filled with water during that time, it is possible that radionuclides may have been leached from the waste, sorbed by the earth materials along the walls of the trench or by the surrounding residuum at levels above trench bottom, and become subjected to erosion at an even earlier period of time. Thus, contaminants that have very long "hazard lives" (the "hazard life" of an isotope commonly is estimated as 10 times its half-life) may be exposed and undergo movement while still hazardous just by mass wasting of the surrounding terrain.

Movement of radionuclides that have been sorbed also can result from desorption. Research regarding desorption has been directed primarily at two radionuclides, ^{137}Cs and ^{90}Sr, because of their long half-lives and biological hazard. Tamura and Jacobs (1960) found that cesium is sorbed and tightly held by the illitic clays in the Conasauga, and that the high affinity results from the spacing between the illite lattices and collapse of the lattice structure. Jacobs (1960) believed that the cesium occupies "fixation sites" from which it would be extremely difficult for ground water to leach. Moreover, even though rain water percolating through the soil could remove interstitial cesium and a small amount of exchangeable cesium, the contaminant would be resorbed upon reaching fresh shale. In laboratory studies of clay from the bed of Whiteoak Lake, Lomenick and Tamura (1965) have shown that cesium can be desorbed from the lattice structure only by destruction of the clay lattice. Fixation to illite is so great that the predicted average velocity of ^{137}Cs movement through the Conasauga in the waste pit area is less than 0.05 inches per year (Lomenick, Jacobs, and Struxness, 1967, p. 904). The data thus suggest that cesium will move through desorption only a minor distance before decaying to an innocuous level of activity.

Strontium, attracted to the vermiculite clay and possibly to the sesquioxides, is more mobile than cesium because it is not tightly bonded to fixation sites. In a study of the pit area, Lomenick, Jacobs, and Struxness (1967) found that at least half of the ^{90}Sr is held in a rather easily exchangeable form on the shale and thus may be leached and transported by percolating fluids. Under the less alkaline conditions that would prevail following pit abandonment, they estimated that ^{90}Sr would move at an average velocity of 0.8 feet per year.

It is cautioned that the rates given for strontium and cesium movement are average velocities of the front. Because of the rather heterogeneous character of the shale, radioactive contaminants in some zones may move at rates faster or slower than these averages. In areas where interconnecting fractures are present, there may be little contact between waste solution and residuum, and the movement of radionuclides may be comparatively rapid. It is along such pathways that Lomenick, Jacobs, and Struxness (1967) believed that known small quantities of cesium and strontium had migrated from the pits to the wells and surface streams of the area.

Synthesis

With an understanding of the transport mechanism, it is possible to synthesize the general characteristics of radionuclide migration from the burial grounds and to examine the adequacy of monitoring coverage. Radionuclide migration is summarized in the following paragraphs and the monitoring system is discussed in the next section.

Transport begins by dissolution of the radionuclides in water that enters the trench as infiltration or as percolating ground water. At Burial Grounds 1, 2, and 3 movement is towards Whiteoak Creek and its tributaries, except in the western part of Burial Ground 3 where there may be some migration to the Raccoon Creek drainage. In addition to movement in the residuum in Bethel Valley, transport may occur along bedding planes and joints or fractures in the limestone. There may be some deep movement of contaminants in Bethel Valley, but if so, it remains unproven. In Burial Grounds 4, 5, and 6 most radionuclide transport initially is towards the low end of the trenches. After leaving the trenches, the bulk of movement in this area probably occurs at the base of the weathered zone, below which there is considerably less transport. The direction of movement is towards Whiteoak Creek, Melton Branch, or Whiteoak Lake.

Migration from a burial ground generally occurs at a relatively slow rate of speed. The movement of water (note: not waste) at a measured velocity of 0.5 feet per day in Melton Valley is indicative of its slow speed at one location, and may not be greatly different from the average velocity of water through the larger body of that rock. With surface drainages in Melton Valley occurring at intervals seldom greater than 2,500 feet, it can be surmised that water contaminated by passage through a trench could reach a drainage within a period of several months to a few years, depending on the location of the trench and the actual rate of water movement. The velocity of most radionuclide fronts is far less than the velocity of water due to the retardive effects of sorption and ion exchange. Some contaminants thus may decay to harmless levels of activity while still confined to the geologic environment. Those radionuclides that have little affinity for the local earth materials, and those of longer half-life that undergo slow transport by sorption and desorption, could appear in the surface streams while still radioactive.

Upward movement of contaminants occurs by the accumulation of water in trenches, plant uptake, and evaporation. Water and contaminants discharged at seeps may infiltrate into the ground at points downslope or move directly to a surface drainage. Most of the discharge from the major seeps moves as surface runoff because of the low natural infiltration rate and saturated condition of the soil following a period of rain. Upward movement by evaporative stress and uptake in plants can occur wherever the contaminated water migrates and remains within the evaporative reach of the atmosphere and the root zones of plants. Contaminants brought to the surface environment by trees or other vegetation may be leached and recycled to the ground after seasonal defoliation or death of the plant tissues. Contaminants leached from this source may be transported by runoff, and there is the possibility that some nuclides may be sorbed by particulate matter on the ground surface and later transported as airborne dust.

A few seasonal relations can be postulated. The greatest amount of radionuclide leaching occurs during the winter and early spring months when trenches become filled with water that remains in prolonged contact with the waste. Maximum rate of movement through the soil and weathered rock occurs during late winter because differences in hydraulic head are greatest then. The maximum amount of upward movement occurs during the spring and summer seasons when vegetation is undergoing vigorous growth, transpiration is high and evaporation is greatest.

The general avenues of water and radionuclide movement from the burial grounds to the surface environment are summarized in figure 14.

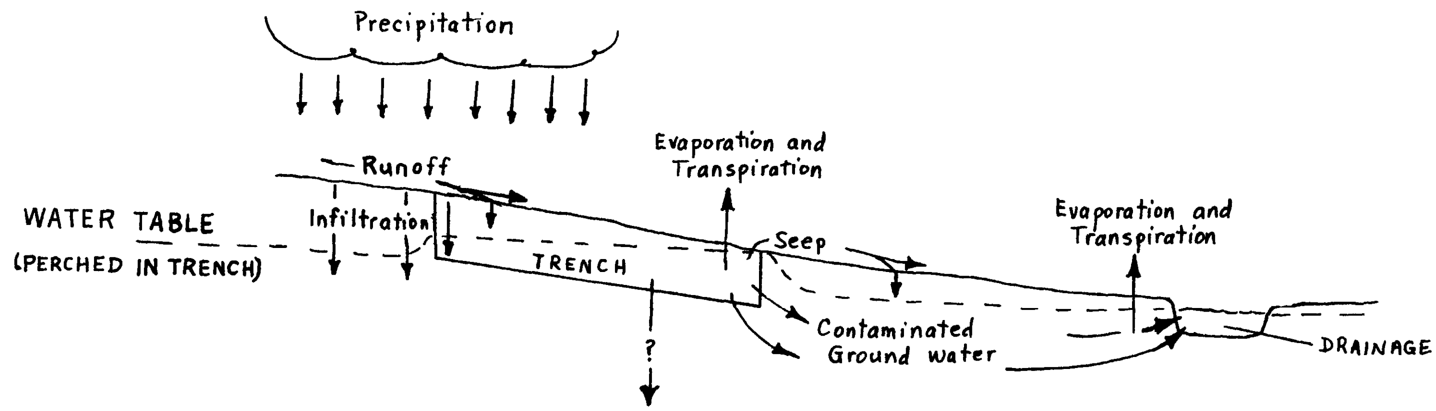


Fig. 14. Diagram showing general avenues of water and radionuclide movement from a hypothetical trench to the surface environment.

MONITORING

Historical Surveillance[12]

Throughout their 30-year history, the Oak Ridge burial grounds have received only infrequent monitoring attention. The earliest reference to site surveillance appears to be a memorandum in 1946 by W. H. Ray and D. M. Davis describing a ground survey of Burial Ground 1 with various radiation detection instruments, and a determination of the level of alpha activity in seven soil samples taken from that burial ground. There appears to have been no further monitoring activity until 1950 when 51 exploratory wells were drilled in Bethel Valley in conjunction with a study of the local geology by Stockdale (1951). At that time samples of water and sludge were taken from the wells, including those in Burial Grounds 1 and 3, to determine the extent of ground-water contamination resulting from radioactive liquid and solid waste stored or buried at the X-10 site. In 1959 a number of shallow wells were augered at Burial Ground 4 to obtain radiochemical analyses of ground water and to determine hydrologic conditions at that site following its closure. In 1960-61, in a continuation of that study, temporary sampling stations were installed in Whiteoak Creek and the tributary to the northwest to identify and quantify the inflow of contaminants being leached from Burial Grounds 3 and 4 and contributed from certain other areas at the plant. As noted previously, the activity in the plant effluent discharged to the creek was sufficiently great that the comparatively small amount believed to originate from Burial Ground 4 could not be identified (Lomenick and Cowser, 1961). In 1964 analyses were made of water samples taken from numerous wells in Burial Grounds 3, 4, and 5 to investigate contaminant movement, and activity analyses were made of soil borings from several new wells augered at that time (Gera, unpublished manuscript, circa 1964). During the latter 1960's (about 1968), wells, seeps, and a surface drainage in Burial Ground 5 were sampled in an attempt to determine the source of tritium appearing in large quantity in Whiteoak Creek (T. F. Lomenick, oral commun., 1974). Wells were not sampled again until 1973 and 1974 when those in or near Burial Grounds 1, 3, 4, and 5 were sampled in connection with present burial-ground studies by Duguid (in press). The results of these monitoring efforts have been discussed previously.

The reason for the infrequency of burial-ground monitoring has been the rather widespread belief that these areas are not a serious threat to the environment. Consequently, funds simply have not been allocated to initiate and maintain a program of routine burial-ground surveillance.

12/ Historically there have been four general areas where water may become contaminated at the Laboratory. These are at facilities within the plant, at the pits and trenches, at the burial grounds and in the vicinity of spills and broken pipelines. The discussion of monitoring herein pertains only to those monitoring activities and the monitoring system that relates to the transport of radionuclides in water from the burial grounds. Other monitoring activities are beyond the scope of this report.

Indeed, the few efforts that were made after P. B. Stockdale's study (1951) and prior to current studies are said to have been accomplished with funds assigned to other activities.

The surface drainage, on the other hand, has received more or less continuous surveillance. The frequent attention given to Whiteoak Creek stems from the potential health hazard resulting from the continual discharge of liquid waste from the plant and, in past times, indirectly from the seepage pits. These wastes historically have been of variable chemical character and concentration and released sometimes on an emergency basis and occasionally by accident. Water near the mouth of the creek, therefore, has been sampled frequently to maintain contaminant concentrations discharged to the Clinch within permissible levels, giving consideration to the dilution afforded by that river. While the monitoring of Whiteoak Creek was not started with the intent of monitoring the burial grounds, it has provided a degree of indirect surveillance inasmuch as contaminants from most burial areas could leave the Reservation only by this watercourse.

Water samples from Whiteoak Creek were first collected in 1943 to determine the level of activity and concentration of dissolved substances under natural conditions, and daily sampling was commenced on or shortly after the date of the first discharge of effluent (K. Z. Morgan, oral commun., 1974; this date is given as March 6, 1944 by Overstreet and Jacobson, 1944). In the ensuing years there were occasional periods when the sampling frequency decreased to weekly or monthly intervals; there were also times when, because significant changes in the level of activity were anticipated, the creek was sampled at intervals more frequently than once a day. For many years the sampling technique consisted of lowering a bottle into the creek at Whiteoak Dam, a practice commonly termed "grab sampling". This continued until 1958 when a continuous sampling device with scintillation probe and remote recorder was installed. This device pumped water continuously from the creek into a collection drum at a constant rate. It was replaced in 1960 (although not made operational until about 1961) by a continuous and proportional flow monitor that takes samples in proportion to discharge. This method of sampling is considered more accurate than either grab sampling or continuous pumping because the constant volume techniques are not related to variations in discharge. Consequently, determinations of concentrations were weighted against periods of higher flow. It has been during such times that comparatively large amounts of activity have been discharged to the creek to take advantage of the creek's dilutive capability.

During the latter 1950's an unaccountable increase in activity, particularly of radiostrontium, was noted in Whiteoak Creek between the plant and Whiteoak Dam. Concern about the origin of the strontium led to the installation of continuous and proportional samplers at Melton Branch and Whiteoak Creek above Melton Branch (stations 4 and 3, respectively, pl. 1) in 1961. These stations were not installed to monitor all contaminants, however, but to determine which valley was the source area for the strontium.

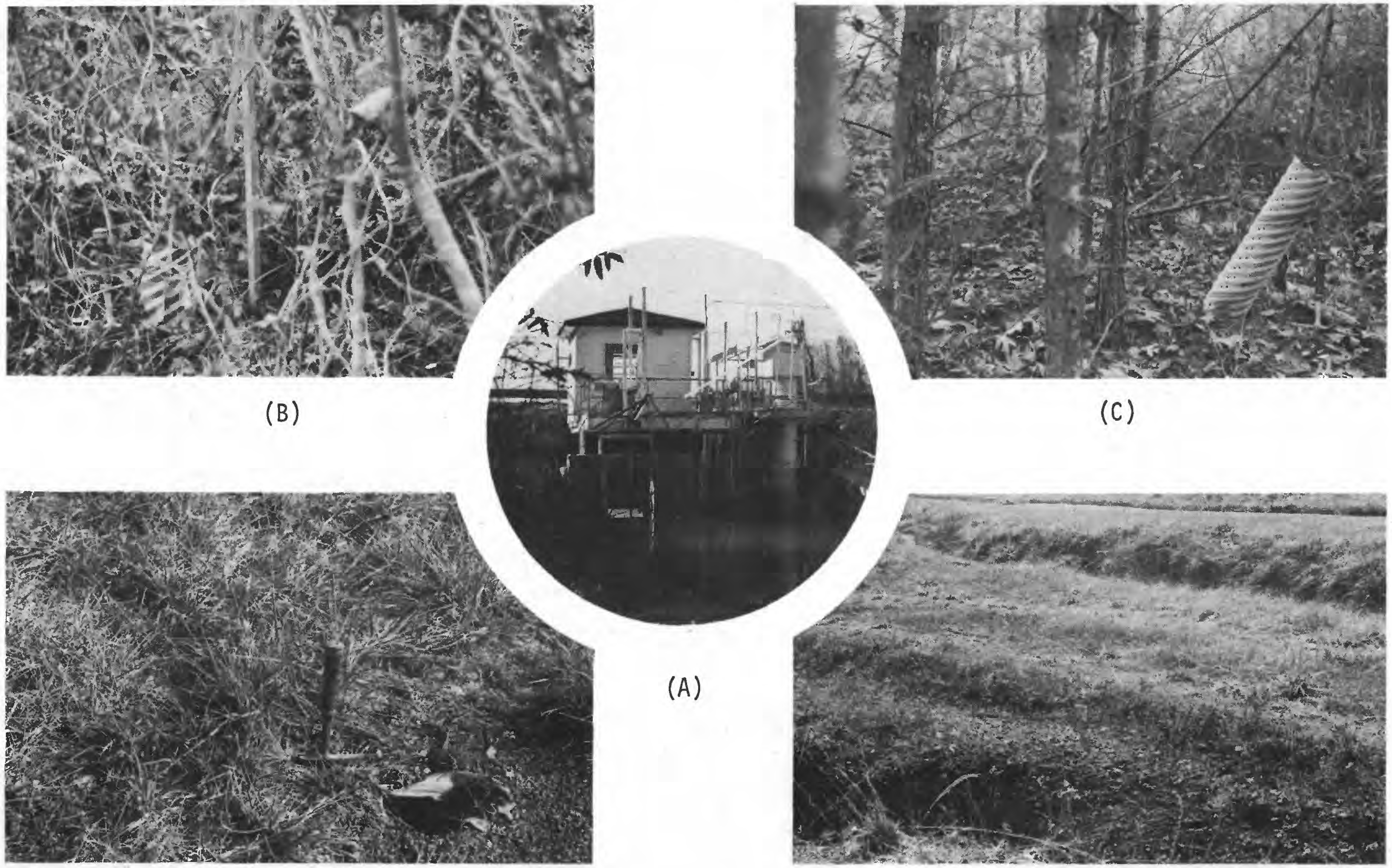
Samples taken at Whiteoak Dam between 1944 and 1948 were analyzed only for gross beta activity. A relatively few samples were analyzed for strontium and later for cesium, but this was not the usual practice (K. Z. Morgan, oral commun., 1974). Subsequent routine samples were composited into monthly samples and analyzed for gross beta activity, cesium, ruthenium, strontium, the trivalent rare earths, cerium, zirconium, and niobium. Iodine-131 analyses also were begun in 1948 or 1949, but presumably on a weekly basis because of that isotope's short half-life. Analyses of monthly composites for cobalt were commenced by 1955, and for tritium by 1964. Current analyses are made of weekly composites for gross beta activity, iodine, strontium, tritium, plutonium and transplutonium isotopes; and of monthly composites, for all of the preceding constituents except iodine. The amount of radionuclides released annually from the Laboratory between 1959 and 1973, as measured at Whiteoak Dam, is shown in Table 2.

Present Monitoring System

The current monitoring system may be viewed as having two components: (1) a series of seldom-visited wells in some of the burial grounds, and (2) five proportional samplers in the Whiteoak Creek drainage.

Wells reportedly have been drilled in each of the burial grounds, although many wells were subsequently destroyed or otherwise rendered unusable for monitoring. Wells that now appear capable of yielding samples are located in or near Burial Grounds 3, 4, 5, and 6; their distribution is shown in figures 8, 10, 11, and 13, respectively. The wells drilled or augered in Burial Grounds 1 and 2 are no longer visible and probably have been destroyed by grass-mowing. In Burial Ground 5 and to a lesser extent in 6, a number of the wells installed for the predevelopment investigations have been destroyed by road building, trench excavation, and grass-mowing. Most of the wells in Burial Grounds 4, 5, and 6 have been constructed with corrugated casing having perforations from top to bottom, and have been left uncapped. The condition of the well field in Burial Ground 5 is shown in plate 3 (B, C, D, and E).

Proportional samplers are located in the Whiteoak Creek drainage at points shown on plate 1. Station 1 monitors the effluent discharged from the settling basin and waste-water treatment plant. Station 2 provides information about radionuclides entering the creek upstream from the effluent outfall, and stations 3 and 4 provide general information about the contaminant load from each valley. Station 5 (pl. 3, A) is the point for determining the amount of radionuclides in aqueous transport released from the Laboratory to the Clinch River. Discussion is limited here to stations 3 and 4, because they are the first stations intercepting ground-water and surface-water discharge from most of the burial grounds, and station 5, because of its significance.



(B) (C) (A) (D) (E)

PLATE 3. VIEWS OF THE MONITORING SYSTEM AT WHITEOAK DAM AND BURIAL GROUND 5. (A) The focal point of the monitoring system is Station 5 at Whiteoak Dam, although data obtained at this point are not indicative of contaminant origin. Only in a broad sense does this station monitor radionuclide migration from the burial grounds. (B) Of the initial wells installed in Burial Ground 5, those located away from burial areas have been least disturbed. Several of these wells have become engulfed by a dense growth of brush, attesting to infrequent visitation. The conditions at well 161 are an example. (C) Many wells located closer to or within the burial areas were destroyed by burial operations. The bent casing of well 167, near the edge of a burial zone,is shown. (D) Even wells installed subsequent to burial, such as well 504, have been destroyed by grass mowing. (E) There presently is no physical evidence to indicate the existence or location of many destroyed wells, such as well 171. The area in the vicinity of this well is shown. This photo may be considered as most typical of the former well field in this burial ground, as nearly half the wells of record have been destroyed.

Whiteoak Creek at station 3 receives the drainage from Burial Grounds 1, 2, 3, 4, 5-North, and part of 5-South; the discharge from the process waste-water treatment plant, laundry, and sewage-treatment facility; and numerous areas in the Laboratory complex contaminated by leakage from broken pipelines, defective tanks, spillages, and other possible sources of contaminants. Melton Branch at station 4 receives drainage from the remainder of Burial Ground 5-South, several reactor sites and areas contaminated by leakage from broken pipelines. The two stations are generally similar and may be described together.

The creeks are impounded at each station by a Cipolletti weir, creating a shallow pool of water on the upstream side. The amount of water passing through the weir is a function of head (water level above the crest of the weir) and is determined by the pressure that water in the pool exerts upon a tube containing compressed gas. Through electromechanical devices, head is converted to a flow measurement that is recorded on a rotating chart as a percentage of maximum flow and to a non-recorded digital value from which flow may be computed for any desired period of time. Water is pumped continuously through the system from an intake resting on creek bottom on the downstream side of the weir. By a system of relays and cams, a sample pump is actuated once every 15 seconds, for a period not to exceed 12 seconds, to remove a part of the water moving through the system; the fractional part of the 12 seconds that the pump is actuated is proportional to the head of water across the weir.

Additional devices at these stations sense pH, dissolved oxygen, and temperature in the pool on the upstream side of the weir, and beta-gamma activity in water moving through the system. These data are telemetered to the Operations Division monitoring facility in Bethel Valley and recorded on strip charts.

Samples taken at stations 3 and 4 are composited and concentrated into monthly samples. Since July 1969 they have been examined for total alpha, gross beta, and strontium concentrations (L. Lasher, oral commun., 1974).

The station at Whiteoak Dam receives the drainage from all of the sources of contamination listed for stations 3 and 4, plus drainage from the now abandoned pit area and Burial Ground 6. The sampling device at this station must be responsive to an even greater range in flow than the samplers at stations 3 and 4 as well as to changes in the vertical dimension of the weir caused by raising or lowering the sluice gate in the dam. The design has been described by Abee and Hart (1961) and is illustrated in figure 15. At this station water from the lake is pumped continuously through a pressure-relief valve and discharged to the spillway. At one hour intervals a solenoid valve opens for a two-minute period, permitting the water to bypass the relief valve and discharge to a specially designed collecting vessel. Water rises in this vessel to the level of an overflow pipe, and the excess is discharged to the stream. Upon completion of the fill cycle, the solenoid valve closes and the

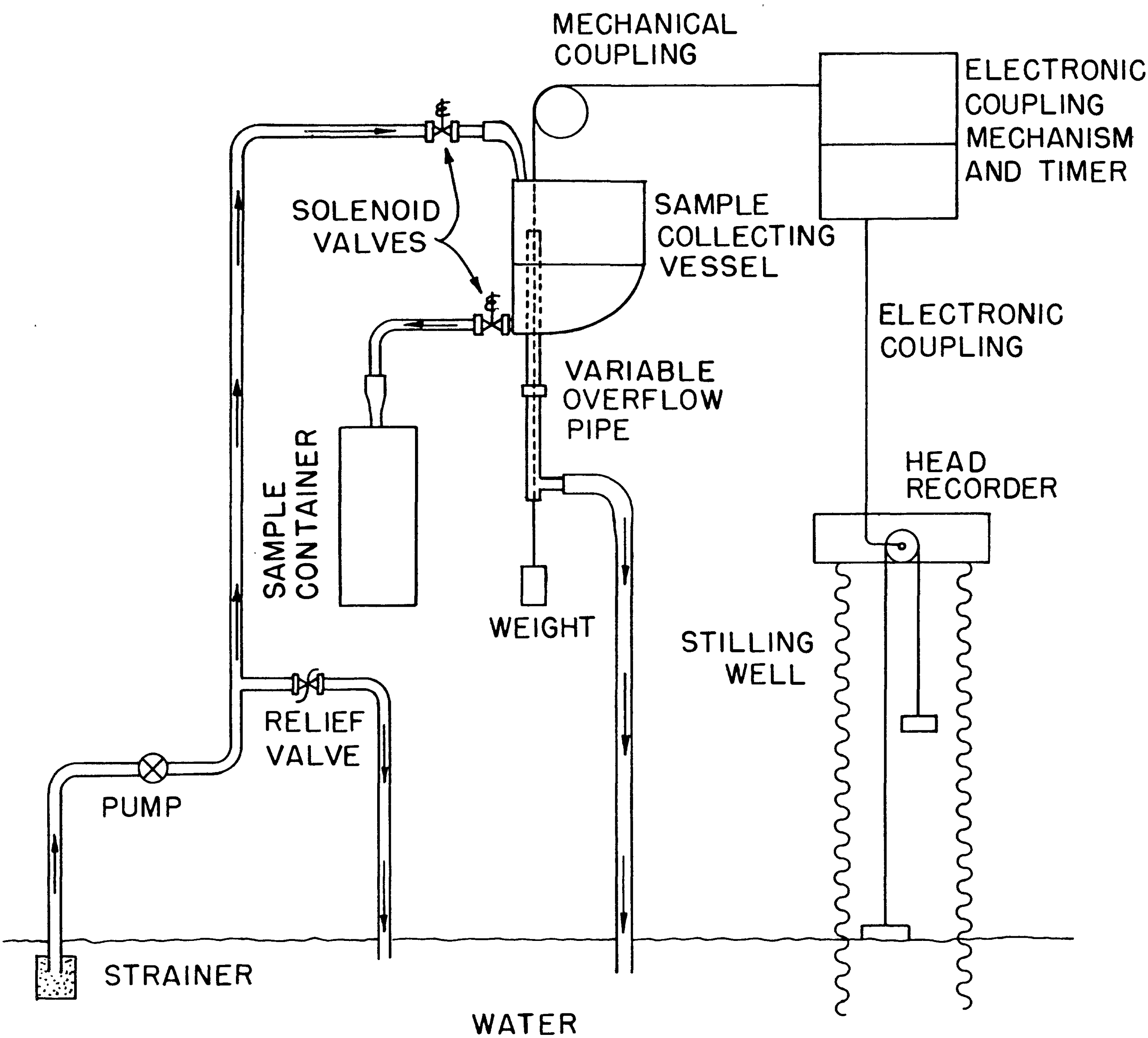


Fig. 15 Schematic diagram showing operational design of monitoring station at Whiteoak Dam (From Abee and Hart, 1961)

drain valve opens, releasing the sample to two 40-gallon drums. The collecting vessel is so shaped that its volume is approximately proportional to the flow across the weir. Volume is controlled by the variable position of the overflow pipe, which moves in a vertical plane in response to fluctuations in lake level as measured by a Stevens[13/] water-level recorder. To compensate for changes in gate position, the instrument is so designed that the position of the collecting vessel can be moved vertically in proportion to the effective change in the weir's dimension.

As at stations 3 and 4, additional devices measure pH, dissolved oxygen, temperature in the lake, and beta-gamma activity in the water moving through the system. These data are telemetered to the Health Physics Division monitoring facility and recorded on charts. Should radiation exceed a pre-set limit or should the system fail to circulate water, an alarm is designed to sound at that facility.

Recent computations have shown that the side of the specially-shaped collecting vessel should be more irregular than it is to obtain true proportionality to flow (E. Gupton, oral commun., 1973). Rather than fabricate a complex form, the station will be modified in October 1974 to operate by digital computer. Whereas the existing sampler takes a sample of variable volume at constant time intervals, the modified sampler will collect a sample of constant volume at variable time intervals.

For flows of less than 30 cfs, the sampler will be activated by passage of 10,000 cubic feet of water: for greater flow, it will be activated by passage of 100,000 cubic feet of water. The U.S. Geological Survey rating for the weir, relating head to flow, will be used to program the instrument.[14/]

Adequacy

Adequacy has been defined in the dictionary as "the quality of being good enough for what is required or needed." The stipulation, "what is required or needed", infers a purpose or function that, in monitoring, is related to the monitor location. The purpose of the observation or monitor well fields in and near the burial grounds is here considered to be to test the concept that buried contaminants are retained in the subsurface geologic environment and, if the concept is found deficient, to aid in the identification and quantification of the contaminant and the determination of its source. The purpose of stations 3 and 4 is to provide general data on the type

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13/ The use of the brand name in this report is for identification purposes only and does not imply endorsement by the U. S. Geological Survey.

14/ The older sampling technique described in the preceding paragraphs is still operational in July 1976. Computer-based equipment has been installed, but as of this date is still undergoing calibration.

of radioactivity and amount of strontium transported past those points. The purpose of station 5 is to provide specific information about concentrations and quantities of radionuclides discharged from the Laboratory and to ascertain that the annual concentration of mixed fission products released to the Clinch River is maintained below the recommended limits established by appropriate national or international authority, or as low as is realistically possible.

Placed in this context, the well-field system must be viewed as inadequate for at least three reasons. First, the existing wells are insufficient in number and distribution to determine, identify and quantify the characteristics of contaminant transport from the burial grounds to the surface environment. There are no permanent wells in Burial Grounds 1, 2, and 5-North, and some of the wells in Burial Grounds 4, 5-South, and 6 have been destroyed. Ideally there should be monitor wells at those points where ground water from the burial grounds discharges to the drainage system, and this series of wells should be augmented by additional wells closer to and in the burial grounds. Second, the construction of many existing wells is inadequate to test the concept of radionuclide retention in the subsurface geologic environment. The open top, perforations at ground level, and annular space around the casings are areas where contaminants in the surface environment may enter the well. A finding of radionuclides in well water thus does not offer incontrovertible evidence that the contaminants were transported in ground water; there is the possibility that contaminants in a well may have been transported in seepage water or runoff, as wind-blown matter, by leaves, or by other means. And, third, even if a battery of properly-constructed wells were in existence today, the system would still have to be regarded as inadequate on the basis of past monitoring frequency. In an area where the operating hypothesis is unproven or doubtful, or where so little is known about the identity and concentrations of contaminants buried, a group of wells visited only about once in a decade would be more properly considered as only an observation well field rather than a part of a viable monitoring system.

Stations 3, 4, and 5 are viewed as adequate for their purpose, but as unsuitable for monitoring the burial grounds per se. Unsuitability stems from the inability to define the origin of contaminants intercepted at those points. This should not be construed as discounting the importance of these stations. Station 5 is necessary for ensuring that the amount and concentration of contaminants released to the Clinch River is maintained within acceptable limits. Stations 3 and 4 are highly desirable for determining from which valley contaminants emanate, to provide surveillance on the level of activity passing their respective locations, and to give warning of unexplained measurable increases in activity between any two stations. The stream monitors are a necessary part of an integrated monitoring system, but at best afford only broad, indirect surveillance of the burial grounds.

While the stream samplers are adequate for monitoring contaminant transport past their respective locations, errors could be introduced into their measurements in three possible ways: (1) sample volumes would no longer be proportional to discharge when flows are sufficiently great to go over the top of the weirs; (2) sediment could be included in the sample that is unrepresentative of the type and quantity of that in the discharge; and (3) subtle changes in the characteristics of the weirs and backwater areas could occur that may cause weir ratings to lose their validity.

The amount of time per year that discharge exceeds the capacity of the weir at station 5 is less than 1 percent (E. Gupton, oral commun., 1974). At stations 3 and 4 it is greater than at station 5 because of the smaller dimensions of the weirs. The amount of error introduced from high flows depends on the discharge in excess of weir capacity, the period of time involved, and the concentration of activity during that interval.

In any kind of sampling scheme, there is always the question of how representative the sample is to the whole. In creek sampling, the question arises because of the sediment content. Suspended sediment has been shown to carry a significant portion of the radionuclide load in Whiteoak Creek (Lomenick and others, 1963b). At stations 3 and 4 the sample water is pumped from an intake resting on the creek bed in the turbulent zone on the downstream side of the weir; at station 5, the sample is pumped from an intake about 2.4 feet above the muddy lake bottom and 2.4 feet below the crest of the weir (fig. 16). Deposition of sediment in the lines is known to have caused problems in the proper functioning of valves. Conceivably, aberrations in representative sampling due to sediment content could be brought about as a result of the intake position, pumping, deposition of sediment in the plumbing, movement of deposited sediment, and in compositing daily or weekly samples to monthly samples.

The proportionality of the sample to discharge is obtained through a weir rating relating head to flow across the weir. The weir rating is valid as long as the approach conditions remain constant and the crest of the weir is clean. However, sediment deposition in the pool on the upstream side of the weir can cause an increase in velocity across the weir without a corresponding change in head, thereby causing a change in discharge and accuracy of the rating. Scour also can change the accuracy of the rating, as can moss or leaves or branches caught on the weir crest. Moreover, an accumulation of leaves behind the weir, which may be a typical condition during fall, can cause a small, local increase in water-surface elevation, thereby causing the instrument to take a proportionally larger sample.

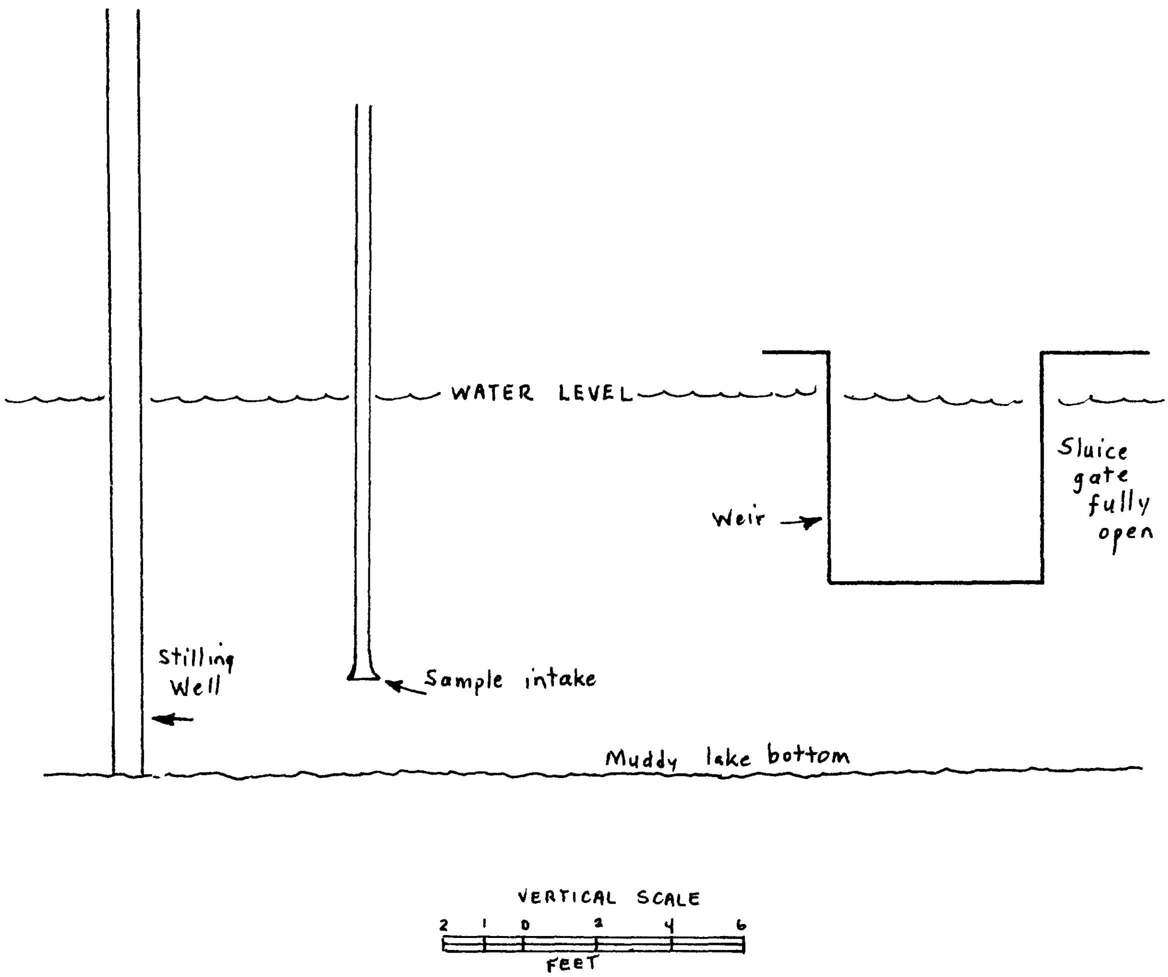

Fig. 16. Cross-sectional diagram showing intake position of sampler at Whiteoak Dam relative to lake bottom, water surface, and weir.

CONCLUSIONS AND RECOMMENDATIONS

The practice of burying radioactive waste serves to remove the contaminated material from the surface environment, to initially sequester the radionuclides in a controlled location, and to greatly reduce the immediate threat of radionuclide movement into the biosphere. In some geographic areas, simple burial in trenches may afford permanent disposal, but with the hydrogeologic conditions that prevail at Oak Ridge, neither the trenches nor the surrounding earth retain all radionuclides permanently. Evidence indicates that at this location some contaminants return to the surface environment by transport in ground water and eventual discharge into surface streams, by overflow from trenches, by uptake in plants and, in the case of tritium, by evaporation to the atmosphere. Thus, neither the early concept of safe and permanent retention of all radionuclides in trenches at Oak Ridge nor the later concept of retention in the geologic environment is valid. However, in view of the relatively high sorptive capacity of local soils for most of the radionuclides buried, the slow movement of ground water, and the abundance of surface water, it seems unlikely that, to date, large concentrations of contaminants, with the exception of tritium, could have been released from these areas at any one time.

The suitability, or lack of suitability, of the six burial grounds for the long-term disposal of contaminated waste varies with the nature of the waste interred and the hydrogeologic conditions that exist during and after burial. The three small sites in Bethel Valley have been free from known problems, which suggests that they might be suitable for this purpose, but actually their potential for long-term contaminant retention is unknown in view of the limited scope of past and present burial-ground monitoring, the lack of information about the contaminants buried, and the uncertainties regarding deep ground-water circulation. Burial Grounds 4 and 5 in Melton Valley have clearly demonstrated that they will not retain all radioactive contaminants, for either short or long periods of time, under existing conditions. Among the factors that have contributed to the mobilization of contaminants at these sites are the large amount of annual rainfall, the shallow depth to ground water, the residuum's very low permeability (which retards the underground dissipation of water that infiltrates into the trenches), and such practices as the dumping of a thick deposit of fill on the surface of Burial Ground 4, diverting runoff from Haw Ridge to that site, cutting excessively long trenches along slope in Burial Ground 5 and possibly in Burial Ground 4, and excavating trenches below the water table at both sites. In this environmental setting these actions collectively have caused waste to become saturated for prolonged periods of time each year, thereby establishing a condition conducive to the leaching of contaminants from the waste, the movement of radionuclides, and the development of seeps. Burial Ground 6, which recently has been opened for waste burial, has the same natural setting as its predecessors in Melton Valley and, therefore, can be assumed to have the same inherent natural potential for radionuclide transport as those sites have. Yet, it can be more suitable for the disposal of waste than Burial Grounds 4 or 5 if the role of water in the transport process is heeded and more effort is given to minimizing the contact of the buried waste with water.

While remedial measures could be applied to Burial Grounds 4 and 5 to abate contaminate transport and improved practices could be implemented at Burial Ground 6, the underlying fact that must not be overlooked is that the pathways for ground-water movement, and hence radionuclide transport, at each burial ground, including those in Bethel Valley, are not known other than in a general way. Consequently, assurance can not be given that radionuclides already leached from the waste will be contained below ground within the Reservation, or that radionuclides that may be leached at some future time will be similarly restrained. It would be imprudent, therefore, to view these disposal sites as suitable for the long-term storage of waste presently buried until such time as the avenues of ground-water movement from the sites are known in considerably more detail than at present and the movement of water-borne radionuclides through the subsurface is known, predictable, and, if necessary, capable of containment within the controlled area of the Laboratory by appropriate engineering methods.

The "types of waste" appropriate for long-term storage are rather nebulous inasmuch as the word "types" may refer to the physical nature (solid or liquid) of the waste, the level of radioactivity (high, intermediate, low) associated with it, the kind of radiation emitted (alpha, beta, gamma), the specific isotopes involved, or other factors. With reference only to the chemical composition of the contaminants, the evidence discussed in this review shows that the weathered Conasauga has the inherent capacity to sorb a substantial variety of radionuclides, provided that exchange sites are available on the residuum or rock particle. Not every kind of radioactive ion is readily sorbed by this geologic unit, however. As might be expected from geochemical relationships and as confirmed by stream monitoring, tritium appears to be little attracted to it, and strontium is rather imperfectly sorbed. In addition, it is possible that radionuclides attached to complexes may have little sorptive potential by the geologic medium and probably have been and are released to the drainage in minor concentrations but have not been identified as of burial-ground origin. In the absence of more extensive surveillance of the burial grounds, it thus appears that tritium, strontium, and nuclides transported in some of the complexes are contaminants that could be identified as problematical for trench burial in relatively short periods of time at this location. It stands to reason that over a longer period of time, a second group of contaminants that could be problematical are those of very long half-life. The problem with this group stems from the abundant rainfall in the Oak Ridge area which provides potential for the relatively rapid erosion of soft, "fill"-type terrain and the slower, but steady erosion of the native residuum. Even though many long-lived nuclides may be sorbed quite readily by these earth materials, the soil or residuum at shallow depths, where most of the nuclides become affixed, may be eroded after an extended period of time, thereby exposing and releasing these very long-lived contaminants to the environment while they are still radioactive.

One additional aspect of radionuclide transport must be recognized when considering types of waste appropriate fcr "long-term" storage. This is the reversibility of sorption. Desorption of some radionuclides can occur, and these nuclides may undergo slow movement by sorption and desorption and eventually be discharged to a surface drainage before having decayed to a stable element. Thus, radionuclides having extreme longevity, and perhaps others of somewhat shorter longevity, may not be appropriate at all for shallow burial, although specific nuclides that would be inappropriate cannot be identified within the scope of this review.

That ground water has the potential to mobilize the contaminants buried with the waste does not seem to have been recognized when the first burial grounds were developed; consequently, criteria for the selection of the first few sites were factors of convenience addressed to an immediate need. As ground water's potential for transport became recognized, there gradually evolved a few geologic and hydrologic criteria for evaluating the suitability of a prospective site, although in retrospect these criteria may have been subordinate to economic considerations, and in the subsequent development of the site due respect to groundwater's potential as a mobilizing agent went unheeded. The experience at Oak Ridge shows that a longer list of hydrogeologic considerations can now be compiled for evaluating site suitability. These include surface drainage, slope, depth to the regional water table and any perched water tables, distance from streams, permeability of the geologic medium, sorptive capacity of the medium for isotopes of other than short half-life, absence of active faults or other unusual hydrogeologic features that could lead to exhumation of the waste, and ability to describe the hydrogeologic system in the vicinity of the site in three dimensions. In essence, these criteria describe sites where stability of the regional land mass is assured, the potential for contact of waste with water is minimal and the three-dimensional movement of radionuclides away from the burial grounds is predictable.

In view of the long-held belief that the burial grounds do not present a significant hazard to the biosphere, it is not surprising to find that, realistically, a monitoring system designed to maintain surveillance of radionuclide migration from these areas simply does not exist. The present monitoring system is intended to measure the release of radionuclides from the X-10 area in order to fulfill regulations imposed by the AEC Manual upon contractor sites. The amount of radioactivity released to the drainage from the burial grounds can be determined only by ascertaining the difference between two successive stream monitoring stations, and this difference cannot be measured accurately because of the possibility that activity from other sources has been introduced. Moreover, complete analyses are made of samples taken only at Whiteoak Dam; samples from upstream stations are analyzed only for strontium and type of radioactivity in the water. This approach thus does not provide more than an indirect and uncertain measure of the amount of radioactivity transported to the drainage network from the burial grounds. Very significantly, it does not reveal how much of the contaminant load from these areas is transported in seepage water or other surface flow as opposed to transport below the land surface in ground water. It does not test the concept of retention by sorption or ion exchange in the geologic environment, and it does not offer predictive capability for the future. In summary, the present monitoring system must be evaluated as adequate for meeting legal requirements, but as inadequate for maintaining surveillance of radionuclide movement from the burial grounds or for providing information necessary to manage these areas for the long-term retention of their contaminants.

The appearance of formerly-buried radioactive contaminants on the ground surface of the disposal areas and in the streams draining these areas raises questions about whether burial grounds developed in this kind of a hydrogeologic setting can be managed for long-term radionuclide retention. Without doubt, the implementation of various remedial measures at the "old" burial grounds and improvement of operational practices at the current site could help reduce contaminant migration. But ultimately, the real, long-term management of contaminants cannot be achieved until the flow system in which they move can be managed. This would require a much clearer definition of the flow dynamics than presently exists. Recommendations resulting from this review, therefore, must be of three broad categories:

(a) an intensification of hydrogeologic studies of the area to better define the movement of water and factors controlling its movement in the vicinity of the burial grounds;

(b) development of an integrated ground water - surface water monitoring program; and

(c) implementation of remedial measures that would appear to have potential for reducing radionuclide transport.

These recommendations are discussed forthwith.

I. Hydrogeologic studies

Despite the several studies that have been made of the hydrogeology of the waste-disposal areas in Bethel and Melton Valleys, present knowledge of ground-water movement and, hence radionuclide movement, is inadequate to make long-term predictions about the movement of radionuclides from the burial grounds, to implement long-range management solutions to the burial-ground problem, or to develop an effective network of monitoring wells. The major obstacle is in defining the ground-water flow system in a complex geologic medium characterized by variable lithology and the irregular and unpredictable occurrence of fractures and solution zones through which contaminants in water may be transported. Yet, until such time as that flow system can be described in three dimensions, the direction and speed of water and of contaminant movement can be known only in a general way. Studies, therefore, that would lead to defining fluid movement in this medium are essential to determining past or present transport of radionuclides, predicting future transport, and implementing effective actions intended to keep radionuclides within designated areas.

Major objectives of the studies are:

(1) the development of a mathematical model that will simulate ground-water movement and radionuclide transport through the geologic medium; and

(2) the development of a network of monitoring wells that can be properly located and drilled to sufficient depth so as to intercept water that has passed through or below the buried waste.

In recent years the simulation of ground-water flow by computer-based mathematical models has been found to be a very valuable predictive tool for managing the ground-water resources of many areas. Basically a model is a set of equations that describe flow under present conditions and the changes in flow that would result if the flow dynamics were manipulated by making changes in some controlling factor. Applied to the burial-ground problem, the development of such a model would permit the making of predictions of radionuclide movement under existing conditions and of changes in movement that would result if one or more stresses in the flow system were changed (as used here, a stress is an act or event that would alter some component of the hydrologic regimen, for example, decreasing infiltration by placing an impermeable material over much of the disposal area, lowering water levels by continual pumping, or changing the direction of ground-water flow by inducing a recharge mound, etc.). Developing and calibrating a model for radionuclide transport through fractured and cavernous rock is far more difficult than that for a homogeneous geologic medium and challenges the present state of modelling art. Complete development of a model, therefore, may not be possible for years, if ever. Nevertheless, in view of the long-term hazard stemming from the burial of waste, it is strongly recommended that research efforts be pursued in this direction.

Mathematical models describing solute transport require substantial amounts of data. For example, a theoretical model for the waste-burial site at Maxey Flats, Kentucky which, like Oak Ridge, is underlain by geologic materials of very low permeability, would require data for 17 parameters in order to define radionuclide movement through both the unsaturated and saturated zones (Papadopulos and Winograd, 1974). Data for some of the parameters must be collected over a continuous two-year period or longer. It is advisable, therefore, that programs of data collection be initiated as soon as the data requirements can be determined for an Oak Ridge model.

A network of monitoring wells is necessary to provide timely detection of contaminant movement, to identify areas where radionuclide migration is occurring, to identify and quantify contaminants in transport, to evaluate the effectiveness of remedial measures taken to abate contaminant transport, to provide input data to a simulation model, and to predict future contaminant discharge. In order to monitor radionuclide movement in ground water from the burial grounds, the ground-water flow system must be described adequately enough so that observation points can be located not only areally but also in the third dimension. Ideally, if a simulation model existed, the model could be used for selecting monitoring well locations, for the data would show the three-dimensional path of ground-water flow, the extent of solute dispersion, and the places of discharge. In the absence of a model, it would seem that an incipient network of monitoring wells -- a precursor to a more thorough monitoring system -- could be established on the basis of present, generalized information of the flow system and after studies that result in (a) a remapping of the water table during its seasonal high and seasonal low, (b) a determination of the direction of ground-water flow near the base of the weathered zone, and (c) an evaluation of the extent of flow through fractures or solution zones below the residuum. Ultimately, a more extensive network of wells, incorporating this basic scheme, will be needed after more data about the subsurface are obtained and a simulation model has been developed. Indeed, if the geologic medium is too complex to model, this may have to be the approach taken to develop a ground-water monitoring net. To obtain data for this early network of wells will require the drilling of many shallow "water-table" wells, the drilling and coring of some deeper wells, initiation of ground-water tracer studies, and examination of the subsurface by various geophysical logging techniques or aquifer tests.

Definition of the flow system, the development of a model (if possible), and the establishment of a monitoring network are viewed as key elements for a long-term management program. Without them, it is not possible to determine what is in transport below the ground, what will later be discharged where, or how the flow system will respond to changes in stress.

Other study should be directed at determining the adequacy of a one-foot minimum separation between trench and water table (as measured before the burial-ground is developed). This interval is suspiciously thin in view of the natural fluctuations in the water table resulting from changes in precipitation, and the increased infiltration resulting from widespread excavation of a material of inherently low permeability. This small a distance may place the deeper part of the buried waste within the zone of saturation after the burial ground has been phased out of operation, thereby leaving the waste bathed in water seasonally, if not longer.[15/] To determine the effect of extensive trench excavation upon water-table elevation, fluctuations of the present water table in the Burial Ground 5 area should be monitored for a year or longer.

II. Development of a monitoring program

Assuming that a network of monitoring wells is developed, a program of routine surveillance should be established to monitor radionuclide movement in ground water, or conversely, lack of movement. The program should continue essentially into perpetuity, for in each burial ground there have been interred radioactive materials having extremely long half-lives. Monitoring can and should be done by at least three approaches: (1) routine analyses of water samples from wells to identify nuclides being transported in ground water and the concentration of radioactivity; (2) spectral logging of wells to identify gamma-emitting radionuclides in or near a well, to ascertain whether these radionuclides are in solution or have become sorbed to the aquifer skeleton, to determine permeable zones as indicated by concentrations of nuclides, and to provide historic data that may be used for purpose of comparison in later years; and (3) occasional radiochemical analyses of soil borings or well cores to identify contaminants that have been in solution but have been stopped at least temporarily by geochemical processes. In addition, routine periodic measurements should be made of water levels in burial ground wells to ascertain the extent of trench saturation.

It should be noted that a ground-water monitoring program may be the only effective way of detecting contaminant transport in Burial Ground 6. Unlike the other burial grounds, leachates from this source will enter Whiteoak Lake without first passing monitoring stations 3 or 4. Dilution in lake water may be sufficiently great that small additions to radiochemicals found at those stations are not measurable at station 5. Even if measurable, the data would not indicate whether the additional radionuclides emanate from this burial ground, the waste pits and trenches, or other sources, or are due to errors inherent to the stream-monitoring process.

15/ For purpose of comparison only, it may be worthwhile noting that licencees of the State of Tennessee are not permitted to bury radioactive waste within 10 feet of the water table (Tennessee Department of Public Health, 1972, p. 26), although it should be recognized that the inhibition of nuclide transport also depends on factors other than distance above that surface.

The frequency for taking water samples from monitoring wells cannot be readily defined. However, in order to maintain surveillance of known troublespots and to detect emerging problems in or near other burial grounds, a frequency of once a year would seem to be minimal.

Contaminants in the stream environment are monitored by use of proportional samplers in the drainage. Despite the samplers having been in operation for more than a decade, inquiry did not reveal efforts having been made to calibrate flow measured by these instruments with actual flow, other than development of a theoretical rating curve for the weir at Whiteoak Dam. Some routine check on the accuracy of flow as measured by this monitoring system thus appears warranted, although it must be recognized that this is only one of several potential sources of error. To evaluate the accuracy, the actual discharge at each monitoring station should first be measured under various conditions of flow with a current meter and those values compared with (1) calculated values using the appropriate equation for the weir and with (2) determined values indicated by the monitoring equipment. The closer the correlation, the greater the amount of faith that can be placed in the accuracy of the instrument-measured flow.

The samplers also should be checked to determine if differences exist between the sediment content of the sample collected at each monitoring station and that contained in the actual discharge. This is desirable because some of the radioactivity in water is transported by suspended sediment, and inclusion of the sediment in the measurement is essential to a valid determination of radionuclide transport. If a significant difference is found at station 5 (Whiteoak Dam), it may be desirable to design an intake for this station at some fixed position below the water surface rather than at a fixed position above the lake bottom.

After the initial calibration of the proportional samplers, occasional comparisons should be made of the discharge indicated by them and flow as calculated from the weir equation. This could quickly indicate a malfunction in this part of the equipment. At less frequent intervals, perhaps on a 3 to 5 year basis, discharge should be measured with a current meter to detect the possibility of subtle changes having occurred in approach conditions which would affect the validity of the weir equation.

The data obtained from monitoring, whether of the ground-water system or the surface-water system, will be a necessity for verifying input and output data for a simulation model.

III. Implementation of remedial measures

The adoption of several remedial measures and improved burial practices are recommended to reduce radionuclide transport from the previous and present burial areas. Most of the recommendations are based on the thesis that water is necessary for radionuclide migration. Corrective measures, therefore, generally revolve around minimizing contact between waste and water. In considering these recommendations, it should be recognized that the burial-ground problem has taken three decades to evolve to its present degree; that another considerable period of time will be required to bring about effective results; that these recommendations are "band-aids" rather than cures; and that real control of the situation cannot be achieved until the hydrogeological system and relevant geochemical processes are completely understood.

1. Detailed water-table maps should be constructed for all existing and future burial grounds. These maps will indicate the depth of water and range of fluctuations that can be expected at each site during different climatic seasons.

2. New burial trenches should be constructed so that the elevation of the bottom of the trench is well above the highest expected ground-water elevation after the burial ground has been developed.

3. To avert the development of seeps, trenches that are excavated down slope should be of restricted length, as is the current practice. It should be noted, though, that where trenches are entirely above the water-table, the movement of water from them is essentially downward to the saturated zone, rather than parallel to the strike or hydraulic gradient. Thus, there is no hydrologic advantage to be gained by orientation perpendicular to the strike of the formation (or downslope) as was done in Burial Ground 5. Therefore, trenches in the higher part of the burial ground, where the water table is not likely to be penetrated, could be excavated for longer distances parallel to topographic contours without developing seeps.

4. In view of the demonstrated problem of confining ^{3}H and ^{90}Sr to the subsurface, consideration should be given to segregating wastes contaminated by either of these radionuclides and burying that waste in special trenches in the higher part of the burial ground away from surface water or ground water. Trenches containing these more mobile contaminants should be capped by relatively impermeable materials to reduce infiltration. Such covers should extend beyond the walls of the trenches in all directions.

5. A considerable volume of surface runoff from Haw Ridge is discharged to the surface of Burial Ground 4 by culverts under Lagoon Road. This runoff should be diverted.

6. Repairs should be made to the land surface in Burial Grounds 4 and 5 where backfill covering the waste has sagged or settled, thereby causing surficial depressions which collect runoff. Repairs will help minimize the channelization of water to these spots and the infiltration of water to the underlying trenches.

7. Fill should not be dumped in a burial ground in areas previously used for burials or where the increase in infiltration through the fill will decrease the depth to the water-table sufficiently to increase the potential for waste-leaching.

8. Trees and other deep-rooted vegetation should be removed from all burial areas because they have the potential to translocate radionuclides from the subsurface to land surface and above.

9. Trenches that overflow should be covered by an impermeable material to reduce the volume of water reaching the low end of the trench.

10. In the vicinity of Burial Ground 4, Whiteoak Creek could be re-routed into an older, deeper, abandoned channel to the east of its present two shallow channels, one of which touches the lower slope of the burial ground in a meander bend. Re-routing would ameliorate the long-range threat of the creek undercutting the deposit of fill and hence accelerating erosion of the burial ground.

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