The Management of Radioactive Waste at the Oak Ridge National Laboratory: A Technical Review (1985)

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The Management of Radioactive Waste at the Oak Ridge National Laboratory:

A TECHNICAL REVIEW

Panel ~~for~~ to Study ~~of~~ the Management of
Radioactive Waste at the
Oak Ridge National Laboratory

Board on Radioactive Waste Management
Commission on Physical Sciences, Mathematics, and Resources
National Research Council

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Executive Summary

This review was performed for the U.S. Department of Energy by a panel of the Board on Radioactive Waste Management under the National Research Council's Commission on Physical Sciences, Mathematics, and Resources.

In summary, ORNL's waste management practices have kept offsite doses low; some of the practices are temporary and improvised--they may not be as satisfactory in the future; reducing anticipated future releases will be difficult because the limited number of candidate waste disposal locations are characterized by topographic peculiarities; and a major ORNL accomplishment has been the demonstration that hydrofracture can be a successful method of disposal for at least low- and intermediate-level waste.

The panel obtained its information over a 2-year period by examining a large body of technical literature, by making six visits to the Oak Ridge National Laboratory, and through briefings by representatives of government agencies and their subcontractors.

Chapter 2 contains the charge to the panel. Chapters 3, 4, and 5 describe the site, the waste that is present, and the methods used to handle it. Chapters 6 through 10 treat the manner in which the performance of the waste-handling system is monitored, the criteria against which performance is assessed, the panel's assessment of performance, and consideration of alternative methods for future handling of radioactive waste. Chapter 11 contains a brief comparison of ORNL with other sites. The panel's principal conclusions and recommendations are summarized below and treated in detail in subsequent chapters. In general, the conclusions and recommendations considered by the panel to be the most important are provided first.

WASTE MANAGEMENT PLANNING (CHAPTER 10)

By virtue of its relatively long history as a leading research establishment in the nuclear programs of the United States, Oak Ridge National Laboratory has had to overcome two principal handicaps in its handling of radioactive waste. The first of these is that when the laboratory was sited, little thought was given--or realistically could have been given--to geological or hydrological factors later found to be critical to waste handling and disposal. The second is that, as an active facility and center of excellence, ORNL both generated and received from other sites substantial amounts of radioactive waste destined for onsite disposal using the standard, but relatively primitive, methods current during the early stages of their programs. Despite the development of a number of innovative techniques, neither of these handicaps has been overcome. While multiple burial grounds, hydrofracture sites, and special disposal areas have been constructed, used to capacity, and closed, the requirements for new disposal capacity continue to grow, problems with previous sites continue to be recognized, and areas suitable for use under current or reasonably anticipated standards and regulations remain increasingly difficult to find in the Oak Ridge area.

In Chapter 10, current ORNL plans for the development of two large new disposal facilities--the Central Waste Disposal Facility (CWDF) on Chestnut Ridge and burial ground 7 between Haw and Copper ridges--are analyzed. CWDF plans are found to be seriously flawed hydrogeologically; burial ground 7 planning remains to be fully developed. The panel, placing itself in the position of an organization facing disposal limitations, discusses briefly some possible alternative approaches. Finally, the panel comments on plans for corrective measures at existing ORNL disposal sites and on plans for decontaminating and decommissioning selected existing facilities.

Principal Conclusions

1. The site that has been chosen for the Central Waste Disposal Facility is a poor one from hydrogeological considerations for burial of radioactive waste; however, prior treatment of already low-activity waste might reduce releases to satisfactorily low levels.

2. Current plans for shallow land burial ground 7 represent a continuation of recent practices at burial ground 6. The panel believes that water will intrude and that radionuclides will be released. It cannot rule out the possibility that current emissions could increase.

3. There has been no comprehensive analysis of solid waste management alternatives.

4. The need to incur substantial costs to stabilize and/or clean up White Oak Creek sediments or to stabilize and/or clean up sediments in holding basins and ponds has not been established by the analyses provided.

5. The Molten Salt Reactor Experiment (MSRE) facility, as it now stands, contains an inventory of highly radioactive fluoride salts that are safely contained only through the annual recombination of the radiolytically decomposed salts. The extremely toxic and corrosive nature of this inventory, and its transportability in water, represent a potential for significant radioactive contamination in the event of accidental release.

6. Insufficient attention has been given by DOE and ORNL to policies that would limit the amounts of radioactive waste (particularly wastes containing ^{90}Sr) that must be disposed by shallow land burial at ORNL.

Principal Recommendations

1. Alternative CWDF sites should be sought that are not on karst topography--or it should be demonstrated that the potential releases would be insignificant.
2. In view of the inadequacy (to meet projected regulatory requirements) of present burial practices and those now planned, disposal alternatives that promise better confinement of radionuclides should be considered.
3. Solid waste management strategies should be analyzed comprehensively; a systems approach must be used to avoid creating undesirable impacts at one location while solving a problem elsewhere.
4. Before substantial funds are expended for the cleanup and stabilization of White Oak Lake sediments, or sediments in the holding ponds and basins, an integrated assessment should be made of the costs and benefits that will be obtained.
5. DOE should decide what is to be done with the inventory at the MSRE so that firm plans and schedules can be developed promptly for the removal, chemical separation, and disposal of the actinides, fission products, and corrosive salts that remain in the MSRE.
6. DOE and ORNL should consider adopting policies that limit the radioactive waste that must be disposed at ORNL--by placing elsewhere projects that generate large amounts of radioactive waste, by providing incentives to reduce the amounts of radioactive waste generated, and by refusing waste from other sites.

DISPOSAL OF RADIOACTIVE WASTE IN HYDRAULICALLY FRACTURED SHALE (CHAPTER 9)

Low- and intermediate-level waste has been successfully immobilized in hydraulically fractured shale at ORNL for the past 15 years. Despite some indications of localized water migration in exceptional circumstances, the panel believes that the approach is worthy of consideration for application elsewhere and for disposal of additional types of waste--although additional research is a prerequisite to broad acceptance.

Principal Conclusions

1. Placement of low- and intermediate-level radioactive waste by hydrofracture at ORNL has been satisfactory to date.
2. Further application of this process at ORNL requires better understanding of the effects of the emplacement on the host rocks and on the groundwater system.
3. Application of the methodology to other waste forms and other sites has potential, but must be supported by appropriate research.

Recommendations

A series of recommendations is set forth in Chapter 9 to support hydrofracture emplacement of low-level radioactive waste at ORNL and elsewhere, and to support extension of the method to other waste and waste forms.

EFFECTIVENESS OF ORNL WASTE MANAGEMENT PRACTICES (CHAPTER 8)

It is clear that neither routine operations nor the several special cases identified by the panel will expose ORNL personnel or the general public to health hazards. However, if regulatory authorities further tighten allowable effluent release levels, in conjunction with the fixed size and the geological and hydrological limitations of the ORNL site, this would significantly reduce the margin for error in waste management operations.

Principal Conclusions

1. The routine offsite effluents from ORNL radioactive waste operations do not present a health hazard.
2. During the past 20 years, ORNL has achieved large reductions in the amount of radioactive material released as process waste. These reductions cause the contribution from burial grounds and the pits and trenches area to take on greater significance. Further efforts to reduce the small amount of radioactive material released from the process waste systems do not appear to be necessary.
3. Attempted mitigating actions such as shortening trench length, placing impervious covers over trench caps, or diverting surface water around burial trenches, may provide temporary reduction in ^{90}Sr outflow, over a few years; however, the effectiveness of these measures over much longer periods of time remains to be proven.
4. Strontium-90 appears to be the primary radionuclide that may cause effluents to exceed current or future standards for release at White Oak Dam. Any new source of ^{90}Sr buried in the near-surface shale can be expected to add to the total discharge at White Oak Dam, unless adequate measures are taken to control its release.
5. Tritium, as the next most important contributor to offsite dose from liquid effluents, must also be disposed with more consideration given to reducing its discharge to White Oak Creek.
6. Catastrophic washout of White Oak Creek sediments would produce 3 and 5 mrem, respectively, to people consuming drinking water and eating fish from the Clinch River.

Recommendations

1. Prior to establishing new burial grounds in the White Oak drainage basin, future releases of ^{90}Sr and ^{3}H from burial grounds

3, 4, 5, and 6 and the seepage pits and trenches must be predicted quantitatively--and shown not to exceed regulatory standards.

2. Corrective actions should be taken on burial grounds either where release of ^{90}Sr and ^{3}H is expected to increase in the future or where a substantial decrease of current ^{90}Sr and ^{3}H release can be attained at reasonable cost.

3. Research should be conducted with the aim of obtaining a better understanding of the implications of both the groundwater and the streambed sediment data, so that they can be coupled and put to effective use in predicting long-term trends of releases.

4. Groundwater migration at burial ground 3 should be studied in detail to obtain a better understanding of the influence of solution cavities on radionuclide transport from burial trenches.

5. More extensive use should be made of groundwater monitoring at burial ground 6 to compensate for the limitations of the surface water monitoring system at that site.

6. ORNL should determine the extent to which radionuclide migration has occurred from the pits and trenches area. This should be done through the installation of a properly located and constructed monitoring system. There should be more frequent sampling of existing and new wells, as well as gathering of data from seeps, surface water, and lysimeters.

7. ORNL should take action to ensure that process waste pipes do not leak into the sanitary sewer system.

REGULATION OF RADIATION EXPOSURE IN THE UNITED STATES (CHAPTER 7)

Operations have been conducted at ORNL for over 40 years, and throughout that time the regulatory climate has become increasingly more challenging because (1) the release limits have been continually tightened, and (2) there are more regulatory agencies with jurisdictions that appear to overlap and with requirements not always clearly defined.

Principal Conclusion

The regulatory criteria that now apply and those likely to apply in the future are diverse. An example of change is the recent application of the Resource Conservation and Recovery Act (RCRA) to ORNL.

MONITORING (CHAPTER 6)

An extensive system is in place for the monitoring of gaseous, liquid, and solid waste at ORNL. Monitoring system data have been collected and published for many years, and system improvements have been undertaken from time to time. There remain, however, several areas in which additional monitoring should be undertaken.

Principal Conclusions

1. The present method of estimating how much radioactive material is being discharged to the Clinch River either by seepage under White Oak Dam or by burial ground 3 leakage to Raccoon Creek is inadequate.

2. The present monitoring network fails to monitor onsite and offsite concentrations of ^3H in air.

Recommendations

1. ORNL should develop modeling programs that will use geologic, hydrologic, and geochemical test results as well as other pertinent monitoring data to predict the migration of leachate from radioactive waste.

2. A better estimate of the migration of radionuclides to the Clinch River by seepage under White Oak Dam and by leakage from burial ground 3 to Raccoon Creek should be developed.

3. The air monitoring system should be upgraded to include onsite and offsite measurements of ^3H in air.

2

Panel Charge and Approach

A proposal for a 2-year study of the management of radioactive wastes at the Oak Ridge National Laboratory (ORNL) was prepared by the Board on Radioactive Waste Management (BRWM) of the Commission on Physical Sciences, Mathematics, and Resources (CPSMR) of the National Research Council (NRC) and submitted to the U.S. Department of Energy (DOE) on June 7, 1982. The proposal was accepted by DOE for funding, and the contract was signed by both parties on December 22, 1982. The original contract term was from January 1, 1983, to December 31, 1984.

The panel was charged under this contract to review and evaluate waste management plans, practices, and programs at ORNL, to assess their environmental safety, and to compare them briefly with those at such other sites as Hanford and Savannah River. Consistent with the overall charge, consideration was to be given to ORNL plans and practices for managing and monitoring radioactive waste at existing ORNL disposal sites; for facility decontamination and decommissioning; and for alternative methods for long-term management of radioactive waste.

In order to fulfill this charge, the NRC arranged for the formation of an ad hoc multidisciplinary group of experts in such fields as nuclear/chemical engineering, engineering/economics/risk assessment, materials science, geology, hydrology, radiobiology/radioecology/environmental science, and radiation safety and monitoring/environmental engineering.

At the conclusion of its review and evaluation the panel prepared this report on its findings and conclusions. Included in the report are recommendations to DOE regarding the handling of radioactive waste at Oak Ridge. The report was reviewed by members of the BRWM and others in accordance with NRC procedures.

The panel construed its charge to be limited to activities at the ORNL (originally referred to as X-10) site. The activities at the other facilities at Oak Ridge--namely, the Oak Ridge Gaseous Diffusion Plant (ORGDP, originally referred to as K-25), the Y-12 Plant, and Oak Ridge Associated Universities (ORAU)--were addressed only where they relate significantly to those at ORNL. Where ORNL radioactive waste storage and disposal facilities contained radioactive waste received from other sources (Oak Ridge area or elsewhere), evaluation of its management at the ORNL site was considered to be included in the charge. The panel did not construe its charge to extend to the consideration and recommendation of specific future alternative waste disposal areas--either at the ORNL site or elsewhere--in the event that management of existing or currently planned ORNL disposal areas was found to be flawed.

The first of 11 panel meetings was held in February 1983. In addition to the full panel meetings, one of which was held at ORNL, six meetings of panel subgroups were held at the laboratory.

3
Site Description

The Oak Ridge National Laboratory (ORNL) was one of three principal facilities established on the 15,000-ha (37,000 acre) Oak Ridge Reservation under the World War II atomic weapons project in 1942-1943. Activities at the other two facilities were directed to application of the gaseous diffusion process and other techniques for the separation of uranium isotopes. Originally under the jurisdiction of the Manhattan District, U.S. Corps of Engineers (MED), the reservation and ORNL have continued in operation under successor agencies--the Atomic Energy Commission (AEC), the Energy Research and Development Administration (ERDA), and, now, the Department of Energy (DOE). The three principal operations on the reservation have always been under the technical oversight of separate branches of the overseeing federal agency, with ORNL generally being under a research-oriented branch.

The role of ORNL has progressed from process development in support of the MED plutonium programs to development of civilian uses of nuclear materials and technologies and, most recently, to a wide scope of energy applications, many of which are nonnuclear. In addition to the three original facilities, Oak Ridge Associated Universities also occupies a site on the reservation at this time. The city of Oak Ridge is located within the original reservation bounds. An area plan of ORNL, showing principal roads, streams, and geological features, is provided in Figure 3-1.

SETTING

The area ranges from rural to urban in character. The city of Oak Ridge (population 35,000) is on the northeast boundary of the reservation, and Knoxville (population 175,000, with a metropolitan area population of 350,000) is 24 km to the east. The physical environment at Oak Ridge has been described in detail in two recent reports concerning radioactive waste management at Oak Ridge (U.S. ERDA, 1977; Evaluation Research Corporation, 1982).

The Oak Ridge Reservation is typical of the landscape and ecological systems that occur in the Appalachian region of the eastern United States. Within the reservation a series of elongate ridges and valleys

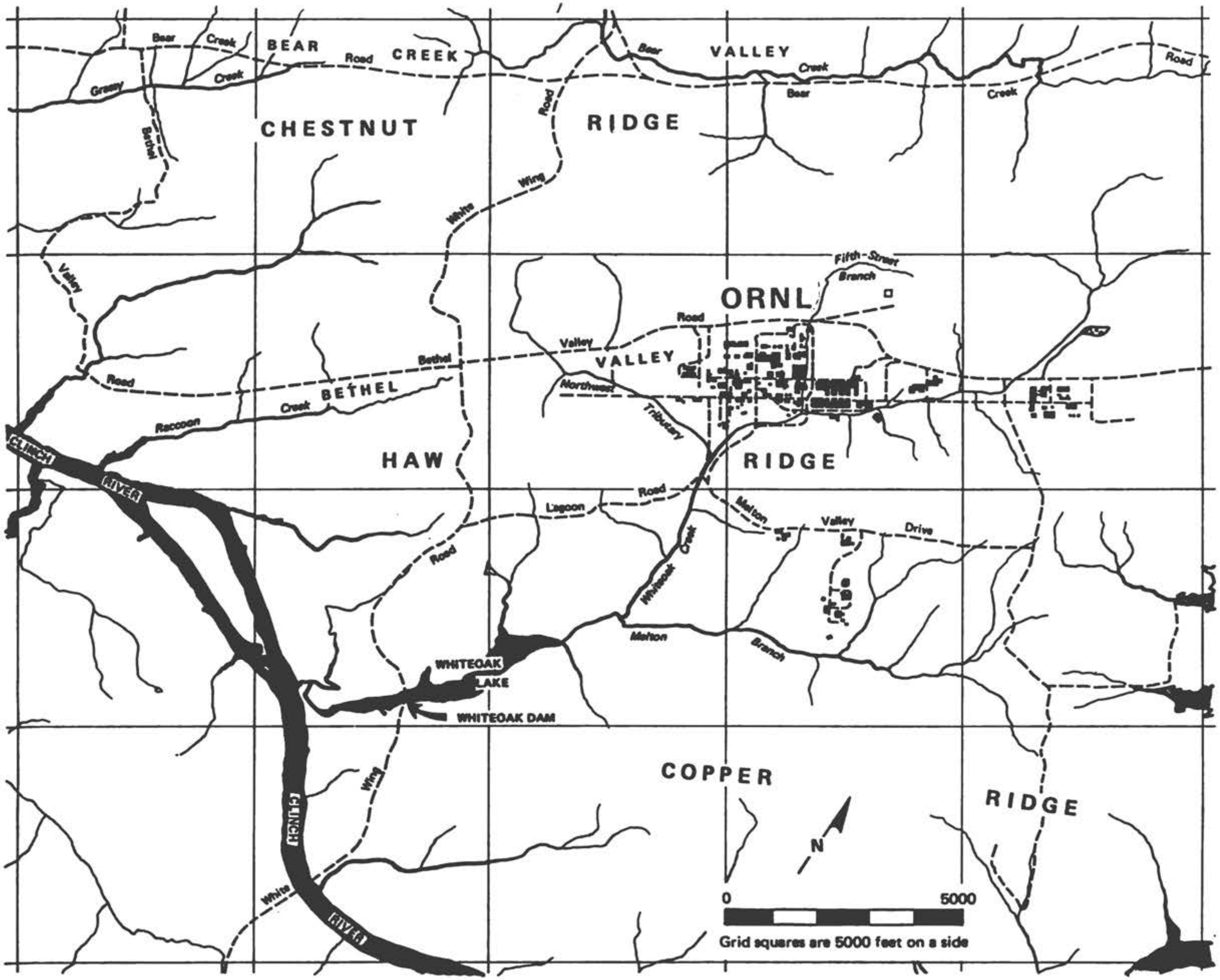

FIGURE 3-1 Plan of ORNL.

trend northeast-southwest, with streams draining the ridges to the Clinch River and thence to the Tennessee River. The area comprises a number of representative terrestrial and aquatic ecosystems, ranging from smaller, established southern coniferous forests to northern hardwood types, and from smaller stream tributaries to man-made reservoir streams.

CLIMATE

The climate of Oak Ridge is moderately humid and temperate. The mean annual precipitation is 136 cm (53.5 in.), and the mean temperature is 14.4°C (57.9°F). The winter months are wettest, averaging more than 13 cm (5 in.) of precipitation per month; July also averages more than 13 cm. The driest months are October, November, September, and June, all averaging less than 10 cm (4 in.) of precipitation. Periods of accumulative winter precipitation cause a high water table in late March. Storms carrying heavy rains in late summer also raise the water table.

Flooding has been a problem, and estimates of flood magnitude and frequency indicate that even small floods are expected to occur often. Several independent studies have shown that most of the sediment transported down the steep slopes of the narrow drainage basins is carried by the larger, less frequent streamflows, which occur only a small percentage of the time.

GEOLOGY

The Oak Ridge Reservation lies in the Tennessee Valley and Ridge portion of the Appalachian Highland physiographic province. The northeast-southwest trending ridges, in general, are underlain by sandstones, limestones, or dolomites that are relatively resistant to erosion; the valleys are underlain by weaker shales and more soluble carbonate rocks. Principal formations are identified in Figure 3-2. Figure 3-3 (in pocket at end of report) is a topographic map of the Bethel Valley quadrangle, which includes ORNL, the city of Oak Ridge, and some neighboring areas.

These geologic formations have been subjected to a series of great overthrusts. Fault blocks have resulted, and each of these blocks, or layers of rocks roughly 3 km (2 mi) thick, have been moved to their present position as much as several tens of miles to the northwest. These blocks have overriden similar layers of rock and, in turn, have been overriden by other layers. Formations on the reservation dip gently to the southeast and become more deeply buried southeastward. As a result of the overthrust faulting, the geology of the area is very complex, and the sequence of formations at Oak Ridge, as shown in Figure 3-2, is not always a normal stratigraphic sequence (youngest to oldest).

Four groups of formations are of immediate interest at Oak Ridge. The oldest is the Rome formation, of Lower Cambrian age. The upper

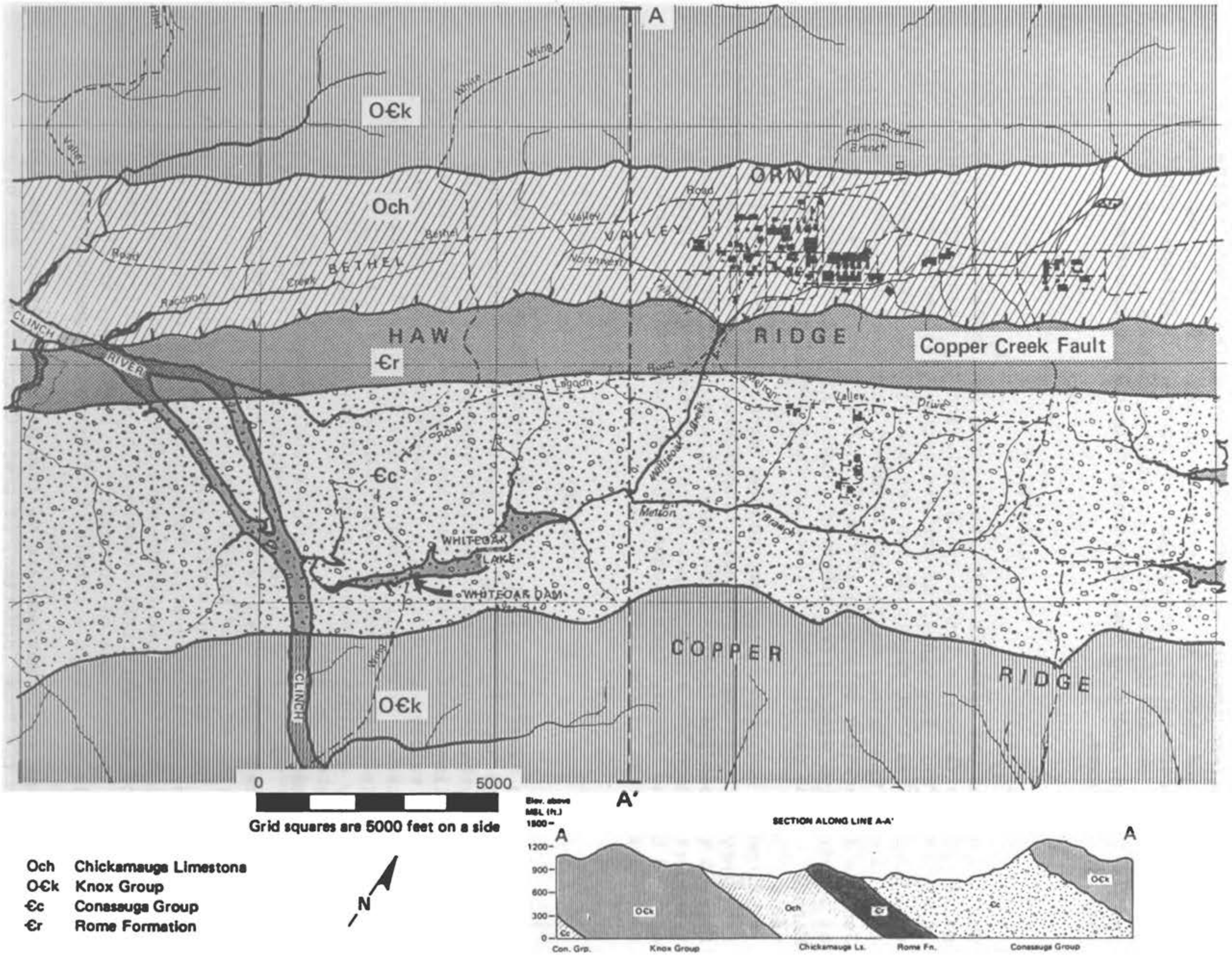

FIGURE 3-2 Basic geological formations.

part of the Rome formation is composed largely of beds of hard brittle quartzite 2 to 30 cm thick. The Rome is normally overlain by rocks of the Conasauga group. The Conasauga group of formations and smaller units include, from top to bottom, the Maynardsville limestone, the Nolichucky shale, the Maryville limestone, the Rogersville shale, the Rutledge limestone, and the Pumpkin Valley shale. In aggregate, the Conasauga group is about 600 m thick. The bottom 100 m of the Conasauga--the Pumpkin Valley member--is a dense argillaceous shale that is thinly bedded and is dominantly red. This is the unit into which radioactive waste is being injected by hydrofracture. Shales and subordinate interbedded limestones of the Conasauga group underlie the solid waste burial grounds and the seepage pits and trenches; the upturned tilted edges of these rocks are commonly concealed and mantled by soil and soft weathered rock to depths ranging from 1 to 12 m. In areas underlain by rocks of the Conasauga group, the depth of weathering ranges with topography, being thicker beneath ridges and thinner in low-lying areas. The thickness of the soil and soft weathered rock varies greatly in low-lying areas.

Dolomites of the Knox group normally overlie the rocks of the Conasauga. The Knox is characterized by broad ridges and incised drainage bordered by steep slopes. In this area there is a deeply weathered blanket of cherty and somewhat clayey silt soil, a deep water table, and some karst features (sinkholes, swallow holes) that indicate solutional enlargement of rock fractures.

The Chickamauga group consists of several hundred feet of shales and limestones. These rocks commonly occupy valley bottoms, such as Bethel Valley. The Chickamauga lies in an area of gentle topography whose soils are variable in thickness but, overall, relatively thin--commonly less than 3 m.

A cross-sectional diagram of the subsurface geology is given in Figure 3-2. A test well has been drilled to a depth of 995 m (3263 ft) on a site near Melton Creek on the cross section. The depths of the various geologic formations in this area were determined from the cores of this well.

Most of the soils are silt, with considerable amounts of clay--the weathered residual products of the underlying rocks. They are highly leached, low in organic matter, and acidic; the pH ranges from 4.5 to 5.7 (Cowser et al., 1961).

The weathering characteristics of these rocks are important because they relate to the sorptive qualities of the residual materials. Kaolinite is the principal clay mineral in the soils of the Knox, and both kaolinite and illite are common in the Chickamauga. The chief minerals in the weathered rocks of the Conasauga group are illite, smectite, and vermiculite. The sorptive properties of the clay minerals range considerably (Means et al., 1978); smectite and vermiculite generally have the greatest sorbent capacity.

SURFACE-WATER HYDROLOGY

Drainage of the Oak Ridge Reservation is to the Clinch River by way of various smaller streams. Among these streams is White Oak Creek, which flows through, and forms the principal drainage system of, the ORNL site. White Oak Creek flows out of Bethel Valley and through Haw Gap at an elevation of 235 m (770 ft). After passing through the gap, it is joined by Melton Branch and then flows south-southwest into White Oak Lake, which is formed by the White Oak Dam; the dam is approximately 3.3 km (2.0 mi) from ORNL. Water from the White Oak Dam flows approximately 1.0 km (0.6 mi) further to the Clinch River.

The periods of maximum and minimum runoff correspond to the variations in rainfall. These data represent averages for the Oak Ridge area, but they presumably apply also to the burial ground sites. White Oak Creek is the natural drainage and, as such, is an integral part of the laboratory's water system, conveying effluents from various parts of the ORNL complex to points beyond the reservation (Webster, 1976). The natural flow of water into the White Oak Creek is augmented by water piped into ORNL from outside the drainage basin and subsequently discharged to White Oak Creek as treated process waste water, laundry water, sanitary sewage, and reactor cooling water effluent. During prolonged periods of dry weather, the discharge from these sources often makes up a major fraction of the creek flow.

GROUNDWATER

The geology and climate at Oak Ridge significantly affect the groundwater conditions; the distinctive groundwater conditions, in turn, significantly affect waste management practices. Emphasis is placed upon groundwater because it is a carrier of contamination, not because of its potential use as drinking water--there are no water wells subject to contamination by groundwater at ORNL.

The sedimentary rocks in the areas used for waste management, chiefly shale and subordinate amounts of limestone, have a low permeability. The flow that does occur is mainly through fractures rather than through the rock matrix--the greatest porosity is in the upper weathered zone. As a result, these beds of the Conasauga group yield very small quantities of groundwater to the test wells (less than 38 L/m, or 10 gal/min, average). There are no productive water wells near the waste storage areas. The residual material over the Conasauga is less compact and the water-bearing openings are larger than in unweathered bedrock. The porosity of the residual material acts as a reservoir feeding water to the fracture system. The rock fractures tend to decrease in size with depth; consequently, the residuum bears most of the groundwater in the Conasauga group outcrop belt, and because the thickness of the residuum in these belts is less than 10 m (30 ft) in most places, the volume of groundwater storage is small and is nearly depleted by September or October (McMaster, 1967).

The distinctive, hilly ridge-and-valley topography with closely spaced streams results in a relatively short flow path of the groundwater from recharge to storage to discharge. The water table is a subdued replica of land surface topography; therefore it is easy to approximate water table contours and to determine the general direction of groundwater flow from ridge tops to the nearest creek. The groundwater flow paths tend to range from as little as 6 m (20 ft) to as much as 300 m (1000 ft), but most range from 60 to 210 m (200 to 700 ft). Some groundwater is not discharged into the nearest creek because it is shunted out to the land surface after periods of heavy precipitation as seeps on lowland slopes. Groundwater travel time may vary from a few months to many hundreds of years.

Figure 3-4 is a groundwater hydrograph showing the typical rainfall effect on the shallow water table system at ORNL. Data are from observation well 277, burial ground 6 (Webster et al., 1980).

The groundwater in the drainage basin is neutral to slightly alkaline (pH 7 to 8.5) and is of the calcium bicarbonate type (high Ca, Mg, HCO_3^-), reflecting the influence of the limestone and dolomite through which the water moves. The limestone constituents are only slightly more dilute in local surface streams. The Ca and Mg in the ground and surface waters interfere with sorption of ^{90}Sr on soils and sediments, thereby increasing the mobility and aggravating the management of this important radioactive waste constituent in the ORNL environment (Webster, 1976; Spalding and Cerling, 1979; Boyle et al., 1982).

SEISMOLOGY

A seismic risk map of the United States, Figure 3-5, was developed for use in establishing design requirements for structures to be located in various portions of the country (McClain and Meyers, 1970); the location of ORNL has been added to this map. Within the southeastern region of the United States, the only zones of highest risk (zone 3) are those around centers of seismic activity in the Mississippi Valley and at Charleston, South Carolina, both of which are about 640 km (400 mi) from ORNL. The area experienced a recent earthquake (November 30, 1973), with an epicenter about 48 km (30 mi) southeast of the ORNL site, and an intensity of approximately IV-V (Modified Mercalli). The intensity at ORNL has been estimated at about IV, and there was no observed damage.

KEY HYDROGEOLOGIC FEATURES OF THE ORNL SITE

1. The land is characterized by steep, elongated northeast trending ridges and valleys.
2. The climate is humid. The average annual rainfall of about 134 cm is fairly evenly distributed throughout the year.
3. Residual soils and underlying decayed rock are relatively thin, and bedrock is commonly about 1 to 20 m below the land surface.
4. The rocks are chiefly shales and interbedded limestones and shales; all are tilted and generally of low permeability. In certain smaller areas, high permeability exists as a result of solutional enlargement of fractures where dolomite is not closely interbedded with shale.

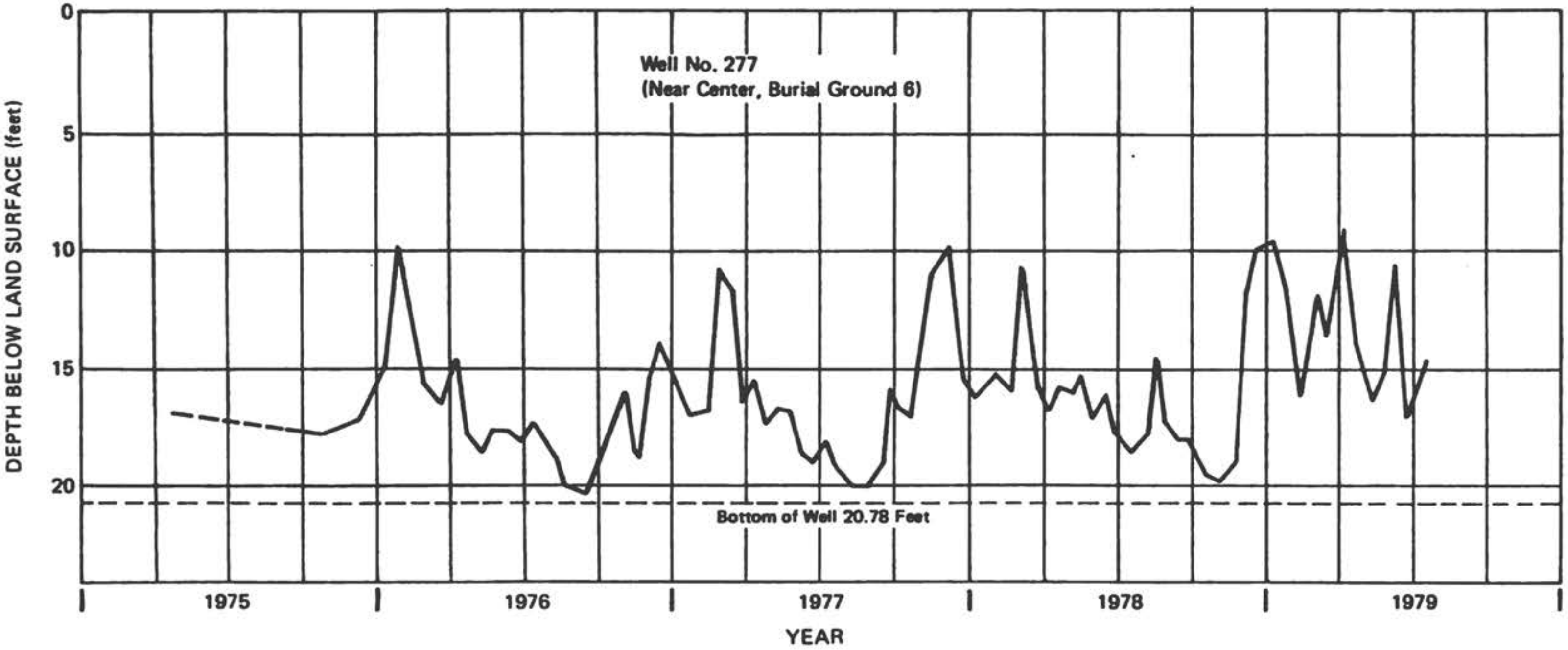

FIGURE 3-4 Typical shallow water well hydrograph.

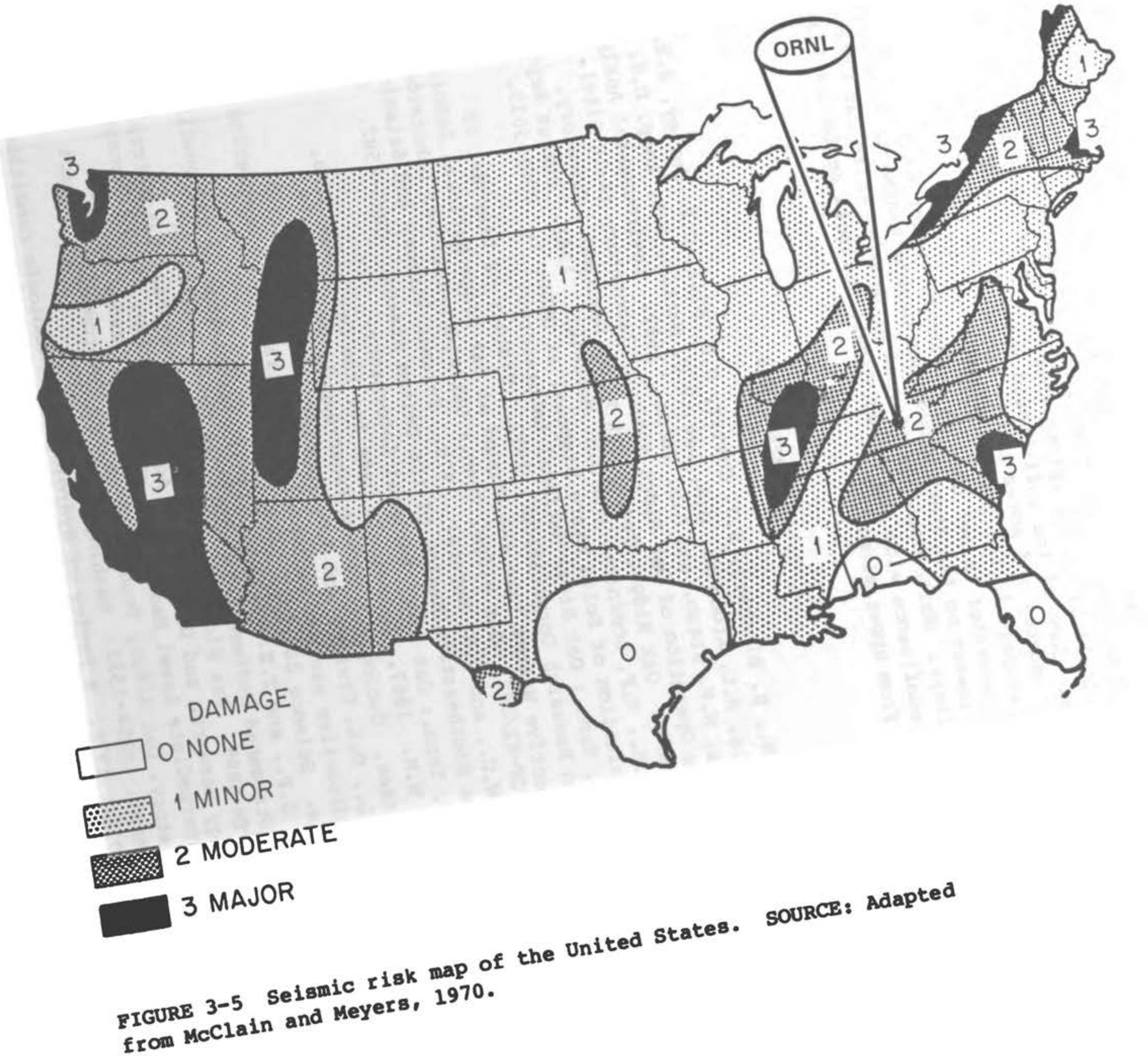

FIGURE 3-5 Seismic risk map of the United States. SOURCE: Adapted from McClain and Meyers, 1970.

5. Perennial streams are close, and ridge tops are less than 500 m from the nearest creek.

6. Groundwater flow is generally in a zone ranging vertically from about 1 m above the top of bedrock to about 15 m below the top of bedrock.

7. Some water that infiltrates the ground tends to be shunted back to the land surface on the steep slopes following periods of heavy rain, particularly in the spring when the water table is normally at a high stage. Some of the infiltrated water stays in the ground near the top of the bedrock and moves slowly underground to discharge as dispersed seepage in the nearest creek.

8. Groundwater is not used as a domestic water supply.

9. Rainwash on the steep slopes has caused sediments to accumulate in the valleys. White Oak Lake, formed by damming White Oak Creek above its confluence with the Clinch River, collects sediments that wash down from upper slopes.

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4
Waste Description

A large variety of radioactive wastes have been generated or received from other sites in the 40-year existence of the Oak Ridge National Laboratory and its World War II precursor organization. Initially, the management methods for these wastes were conditioned by the exigencies of the war effort and, later, by the unpredictability of the federal budget process and the gradually evolving knowledge of the behavior of these radioactive materials in the natural setting in which they were emplaced.

SOURCES OF RADIOACTIVE WASTE

Although most operating facilities at the laboratory have generated radioactive waste, the quantities of waste radionuclides have generally decreased with the changing spectrum of laboratory programs. The major producers of waste radionuclides have been as follows:

- Radioisotope production facilities
- Reactors
- Hot cells and pilot plants
- Research laboratories (physical, chemical, and biological)
- Particle accelerators
- Analytical laboratories

Most of the radionuclides in the waste result directly from process operations, but significant volumes of waste with smaller concentrations of radionuclides will eventually be produced by the decontamination and decommissioning of operation facilities and by remedial actions.

Waste produced at sites other than Oak Ridge constituted a significant fraction of the volume and radionuclide concentrations of solid waste buried at ORNL when, during 1955 to 1963, the ORNL solid waste storage areas were designated by the Atomic Energy Commission as the Southern Regional Burial Ground.

At present, less than 5 percent of the solid waste disposed at ORNL comes from neighboring DOE operations (Y-12 Plant, Oak Ridge Gaseous Diffusion Plant, Oak Ridge Associated Universities), and less than 1

TABLE 4-1 Major Generators of Radioactive Wastes at ORNL--Past Programs

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Defense Related

^{239}Pu production/separations development (bismuth phosphate processing, redox, purex)

Naval Reactors Program

^{140}Ba-^{140}La production

SNAP (Systems for Nuclear Auxiliary Power) source development/production (^{90}Sr, $^{242-244}Cm$)

Mound laboratory waste (1957-1963)

High enrichment fuel reprocessing development

Aircraft Nuclear Propulsion Program

^{3}H target development/fabrication

Special radioisotope sources (^{60}Co, ^{3}H, ^{85}Kr, ^{241}Am)

Low-Intensity Test Reactor operations

Uranium-thorium fuels development (medical, industrial)

Nondefense Related

Radioisotopes application development (medical, industrial)

Reactor development (High-Temperature Gas Reactor, Molten Salt Reactor Experiment, Homogeneous Reactor Experiment)

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percent from other sites. A breakdown of major waste generation operations is given in Table 4-1 for past programs, and in Table 4-2 for current programs (J.D. Sease, ORNL, personal communication, April 20-22, 1983).

Large quantities of radionuclides (fission products, transuranic elements, actinides, and neutron-activated structural materials) are produced during the operation of reactors. When spent reactor fuels are chemically processed, the fission-product nuclides remain in a liquid stream usually defined as high-level liquid waste (HLLW); at ORNL, however, this waste is referred to as intermediate level waste (ILW) (see below). Large quantities of such waste were produced in the Hot Pilot Plant when, beginning in 1944 and for several years thereafter, one of the laboratory's primary missions was the

TABLE 4-2 Major Generators of Radioactive Wastes at ORNL--Current Programs

Radioisotope production and distribution

TRU element production

Reactor operations

^{233}U storage and processing

Fuel cycle technology

Radioisotope applications research and development

Biomedical research and development

development of methods for chemical separation of the plutonium produced in the Oak Ridge Graphite Reactor. Although the amounts of fuel reprocessed at ORNL were small in comparison with those handled at Hanford, Savannah River, or Idaho, the fission product waste from earlier operations continues to have a significant effect on waste management at ORNL.

Fuels irradiated at the operating ORNL reactors are transported to other DOE sites for reprocessing, where the resulting waste is then commingled with the waste stored at those sites. The unique nature of the Homogeneous Reactor Test and the Molten Salt Reactor Experiment fuels, however, has prevented their transfer to an offsite reprocessing plant; they remain stored on the site.

Although the High-Flux Isotope Reactor fuel is shipped offsite for reprocessing, the highly radioactive target rods in which transuranic elements are generated are processed onsite. This effort, in the Transuranium Processing Facility (TRU), results in solid and liquid waste that is highly radioactive.

ORNL has been one of the world's leading producers of radioactive and stable nuclides for research, medical, and industrial applications. Most of the radionuclides have been separated and purified at the Fission Product Development Laboratory (FPDL) and in a few specialized smaller facilities. These operational campaigns generally involve the chemical separations of irradiated targets, small amounts of reactor fuel, or manipulation of previously separated radioactive materials. The FPDL has been a major producer of waste radionuclides and is likely to remain so for the near future (J.H. Coobs, ORNL, personal communication, January 5, 1984).

The generation of radioactive waste in recent years has decreased significantly at ORNL, compared to its first three decades of existence. Consequently, much of the long-range planning is now devoted to management of the legacies of the past, replacement of aging facilities, and improvement of environmental monitoring. Decontamination of both operating and surplus facilities will continue to generate a significant volume of radioactive waste with a wide range of radionuclide concentrations.

TYPES OF RADIOACTIVE WASTE

Airborne Waste

Radioactive gases can be considered almost entirely as an effluent, since only negligible amounts are recovered and stored. The gaseous radionuclides discharged from ORNL consist mainly of ^{85}Kr, ^{133}Xe, and ^{3}H. The major stack discharge points are as follows:

- The central stack (building 3039) discharges 40 percent of the total volume and 80 percent of the radionuclides.
- The HFIR-TRU stack (building 7911) discharges an additional 40 percent of the total volume.
- The CPPP (building 3020) stack accounts for most of the remaining discharges. Other smaller discharge points are identified in Chapter 5.

Airborne radioactive particulates are largely retained by HEPA filters. Radioiodine and ruthenium and other volatile elements are removed by chemical scrubbing at the source of generation--but releases have occurred during operations upsets.

Liquid Waste

Liquid radioactive waste, which has been generated at ORNL from the first days of operation, is classified by ORNL as follows (Evaluation Research Corporation, 1982):

- Low level, concentration of less than 1.1 mCi/L (published as 4 mCi/gal)
- Intermediate level, concentration greater than 1.1 mCi/L (published as 4 mCi/gal) but less than 1.3 Ci/L (published as 5 Ci/gal)
- High level, concentration greater than 1.3 Ci/L (published as 5 Ci/gal)
- TRU waste (fissionable isotopes of U and all actinides): liquid, concentration greater than 2.6 nCi of alpha emitters per liter (published as 10 nCi/gal).

Only liquids meeting the following specifications can be discharged to the watershed without further treatment:

- alpha-emitting radionuclides of less than 1 cpm/ml (counter efficiency of 20 percent)

- beta-emitting radionuclides of less than 1 cpm/ml (same efficiency)
- pH of 6.5 to 9.5

Annual average liquid waste generation rates in recent years were as follows (L. Lasher, ORNL, personal communication, 1984):

- Low-level liquid waste monitored, not requiring treatment and discharged to the watershed--6.4 x 10^5 L/day (1.7 x 10^5 gal/day)
- Low-level liquid waste treated by ion exchange prior to discharge--7.9 x 10^5 L/day (2.1 x 10^5 gal/day) (Ad Hoc Committee, 1983)
- Intermediate-level waste treated by evaporation--13 x 10^3 L/day (3.5 x 10^3 gal/day)
- Evaporator bottoms disposed by hydrofracture--380 L/day (100 gal/day)

Solid Waste

Solid waste containing radionuclides is produced by most operating facilities at ORNL. This waste consists mainly of contaminated paper, clothing, glassware, equipment, scrap metal, filters, animal carcasses, and so on. On average, about 1.7 x 10^3 m^3/yr (6 x 10^4 ft^3/yr) of beta-gamma solid radwaste have been buried, and about 85 m^3/yr (3 x 10^3 ft^3/yr) of solid TRU waste (concentration greater than 100 nCi/g) have been placed in retrievable storage. ORNL expects that larger quantities of solid waste will be generated in the future--approximately 3 x 10^3 m^3 (11 x 10^4 ft^3) containing about 22 x 10^3 Ci per year by the late 1980s (J.H. Coobs, ORNL, personal communication, August 7, 1984).

The radionuclides contained in waste from decontamination operations were produced by previous operations (e.g., reactors, fuel and target processing). The presence of various cleaning agents (surfactants and complexing agents) will increase the mobility of most radionuclides buried with these agents.

LOCATION OF RADIOACTIVE WASTE

Storage Tanks

Intermediate- and high-level liquid waste has been stored in tanks at Oak Ridge from the start of operations. Six underground concrete tanks (referred to as "Gunite" tanks because of the method used in their construction and designated as W-5 through W-10), each with a capacity of 640,000 L (170,000 gal), were built in 1943 for the purpose of storing all but low-level process waste. Although an operational period of only 1 year was originally planned by ORNL, the Gunite tanks were continued in use and were an important component of liquid waste management for nearly four decades--until their removal from service in 1978. In 1983, it was estimated that the tanks contained over 2 x 10^6 Ci of intermediate-lived radionuclides, primarily ^{90}Sr and ^{137}Cs, with some actinides also present (Coobs and Myrick, 1983). About 95 percent of this material is expected to be removed from the tanks as the sludge is disposed by hydrofracture; under these circumstances about 10^5 Ci would be left as an unremovable residue.

Many other tanks have been built at ORNL for such specific purposes as hold-up for monitoring of radionuclide concentrations, surge capacity for various processes, feed preparation, and so on. Although not by original intent, some of these tanks have become, for extended periods, de facto storage facilities for substantial quantities of radioactive liquids. For example, a 19,000-L (5000 gal) stainless-steel tank, originally constructed for a different purpose, was filled in 1969 with a highly fissile uranyl nitrate solution containing 1050 kg of uranium isotopes (mostly ^{235}U and ^{233}U). With time, the buildup of decay products has vastly increased the gamma ray emission rate of this solution and has made additional shielding necessary. Planning for a project to solidify this solution and to place the dry uranium-bearing product in shielded storage was initiated in 1976 (ORNL, 1983). Construction was completed in FY 1984, and the project is scheduled for completion in FY 1987.

Tanks removed from service are decontaminated to varying degrees, but they continue to require source surveillance over extended periods, as well as occasional remedial maintenance.

Many tanks that were removed from service, either because of leakage or because they became redundant, are among the listed surplus facilities at ORNL (tanks WC-1, WC-15, WC-17, W-1 through W-4, W-11, W-13 through W-15, TH-1 through TH-4, T-1 through T-4, T-9, shielded transfer tanks). Most of these tanks were emptied before retirement and their residual radioactive contents are described as being "in the curie range." However, several tanks are identified as containing larger amounts: TH-4, a Gunite-sprayed 15,000-L (4000 gal) underground tank filled with a sludge containing irradiated uranium and thorium and an unknown amount of other radionuclides, and five shielded transfer tanks (STT) used for the shipment of ^{137}Cs from Hanford to ORNL and stored above ground at burial ground 4. Each of the STTs is estimated to contain about 1000 Ci of residual ^{137}Cs (Coobs and Myrick, 1983).

Underground Emplacements

By far the largest quantity of radionuclides and contaminated materials at ORNL has been placed in underground locations, nearly all in a nonretrievable mode. With the exception of the waste/grout composites injected by hydrofracture, at depths on the order of 300 m (1000 ft), underground emplacements are close to the surface. Their depth was dictated by shielding requirements and, in some cases, by hydrological considerations. Placement details are described in Chapter 5; summary data are provided in Table 5-1. Many of these facilities are no longer in use, and some have become sources of radionuclide release to groundwater and surface water. They must be monitored, and, occasionally, remedial actions have to be taken.

During the operation of the old hydrofracture facility (1966-1979), 5.7×10^6 L (1.5×10^6 gal) of waste containing 1.3×10^6 Ci were injected. Almost this same volume, 4.2×10^6 L (1.1×10^6 gal) containing 0.4×10^6 Ci, was disposed of at the new hydrofracture facility in 1982 and the first four months of 1983.

Above-Ground Storage

From the laboratory's earliest days of operation, means were devised at ORNL to impound large quantities of water, either containing or suspected of containing radionuclides. The purposes of these open liquid storage facilities were to collect, treat (usually by adding caustic), settle, monitor, and regulate the discharge rates to White Oak Creek. To accomplish this, a number of retention ponds, equalization basins, dams forming lakes, and PVC-lined basins were constructed.

Surplus Facilities

Many facilities at ORNL contain substantial amounts of radionuclides or are themselves radioactive at the end of their useful lives. The decontamination and decommissioning of these facilities are often delayed by budgetary constraints and uncertainties regarding future programs, but safety considerations require continued surveillance and periodic maintenance. Such activities are now conducted at ORNL as part of a national Surplus Facilities Management Program (SFMP). The facilities included in the 1983 SFMP are discussed in Chapter 10; details on their radionuclide content appear in Table 10-5. These facilities contain varying amounts of radionuclides, some in forms suitable for removal and disposal, some intimately associated with structures and equipment. For example, the contents of the Gunite tanks are being transferred to the New Hydrofracture Facility for permanent disposal, using well-developed procedures; the operation was completed in FY 1984. By contrast, the highly radioactive fuel salt (4650 kg of a fluoride mixture) used in the Molten Salt Reactor Experiment (MSRE) and currently stored in tanks within the containment cells of the MSRE building will have to be converted to a suitable form before permanent disposal. Such a conversion process has not yet been devised or demonstrated.

In terms of actual source strength, the Gunite tanks (even after sludge removal) and the MSRE are by far the most contaminated facilities. The dispersed nature of the contamination in most of the other facilities and structures discussed in the SFMP, however, mandates active monitoring and maintenance programs. The eventual decommissioning of these facilities will generate significant volumes of liquid and solid waste, which could be handled by current procedures.

Sites of Dispersed Radionuclides

Several floodplain areas on the site have been reported to be contaminated (Stueber et al., 1978; Oakes and Shank, 1979). The old lake bed that was created by the construction of a dam in 1943 appears to have the highest radionuclide content, mainly ^{137}Cs.

Large volumes of subsoil have become contaminated when underground tanks or transfer lines developed leaks and released radioactive liquids to the surroundings. There have also been releases of radionuclides that had accumulated in underground ventilation ducts or other structures. In some cases, the contamination was sufficiently high to require the excavation of the affected soil and its transfer to a controlled burial ground.

The release of contaminated water to the Clinch River tributary creeks on the ORNL site, especially during the early years of operation, led to both the dispersal of radionuclides in these water bodies and the accumulation of radioactive sediments in the creek and river bottoms.

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5

Radioactive Waste Management Practices at ORNL

BACKGROUND

From 1943 to about 1960, untreated gases containing radionuclides were released to the atmosphere; some waters containing radionuclides were released to surface streams; and solid radioactive waste was buried at convenient locations.

Beginning in the mid-1950s, however, increased effort has been directed toward a reduction in total radionuclide releases. Gaseous effluents have been reduced so much that new, more sensitive, equipment is required to monitor them. Releases of radionuclides in liquids from ORNL operations have been reduced by a factor of about 1000. Since the 1970s, most of the radionuclides sorbed onto the Clinch River sediments originated from past disposal operations. Since the early 1970s, when it became apparent that the burial grounds were significant sources of radionuclides in the surface streams, considerably more attention has been given to burial practices.

GASEOUS WASTE

Early Practices

Releases of gases and particulates have been monitored since 1962. The primary radioactive constituents released are ^{3}H, ^{133}Xe, and ^{85}Kr, along with small amounts of ^{131}I, and radioactive particulates.

Current Practices

There are two separate waste gas streams: building and hot-cell ventilation air, and process off-gas. The building and hot-cell ventilation air contributed the major volume of gaseous release, but only a minor fraction of the radionuclides (Eisenhower et al., 1982). It is passed through HEPA filters, then exhausted through a stack. The smaller volume, the process off-gas, contains most of the gaseous radionuclides. Treatment of process off-gas includes caustic scrubbing at the source of the off-gas, followed by additional scrubbing at a central facility, if necessary, and then HEPA filtration and stack discharge (J.H. Coobs, ORNL, personal communication, 1984). Spent HEPA filters are disposed of by shallow land burial.

Currently, six actively operating stacks are the principal release points for effluents from ventilation systems. Four are in Bethel Valley--at the High-Radiation-Level Analytical Laboratory (Building 2026), the Chemical Processing Pilot Plant (3020), the Isotope Area (3039), and the Linear Accelerator (6010). Two stacks are in Melton Valley--at the High-Flux Isotope Reactor (7911) and the Molten Salt Reactor Experiment (7503).

LIQUID WASTE

Early Practices

In the early operations at ORNL, the low-level process water was not chemically treated; it was released to White Oak Creek or Melton Branch through either equalization basins or holding ponds. This practice contributed significantly to the residue of contaminated downstream sediments. Contaminated sediments are located in the intermediate pond east of burial ground 4, in flood plains of White Oak Creek and Melton Branch, in White Oak Lake, and in the Clinch and Tennessee rivers, as well as the sediments of the equalization basin, and the holding ponds themselves.

A soda-lime treatment plant for low-level waste was placed in operation in 1957. Other treatment facilities more efficient than the initial one were brought on line in 1976 and again in 1981. Sludges generated from these facilities were disposed of in the liquid waste pits (1957-1976) and in a PVC-lined basin (1976-1981) (Ad Hoc Committee, 1983).

Intermediate-level waste (ILW) was initially collected in large underground concrete tanks (Gunite tanks), where, with the principal exceptions of cesium and ruthenium, radionuclides were precipitated with caustic. Until 1949, when the tanks were full, the supernatant liquid from the Gunite tanks was diluted with low-level process waste water and released to White Oak Creek. In 1949, more stringent liquid waste disposal requirements were instituted. The tank supernatant was evaporated, the condensate was discharged to White Oak Creek, and the concentrate was returned to the tanks. From 1952 until 1966, the liquid waste from the tanks (intermediate-level waste) was disposed of in seepage pits and trenches. It is estimated that more than 159 million L (42 million gal), containing over 1 MCi of fission products, were disposed in this manner (Evaluation Research Corporation, 1982). From 1965 to date, the supernatant from the tanks, after concentration through evaporation, has been disposed of by hydrofracture (see Chapter 9).

Ponds and Basins

A number of retention ponds, equalization basins, dams leading to the creation of lakes, and PVC-lined basins were constructed to impound large quantities of water containing radionuclides. Although many of these facilities are no longer in use, they are sources of radionuclide contamination that must be monitored, and, occasionally, remedial actions have had to be instituted.

Open ponds, usually containing only small amounts of radionuclides, are still part of the liquid waste treatment system (e.g., holding pond for 4500 complex, process waste equalization basin, and HFIR and TRU process waste basins). Under normal operating conditions the quantity of radionuclides entering these ponds or basins is small, but upsets have occurred and the quantity of radionuclides in the ponds and basins will increase with time.

Underground Emplacement

The form of waste at the time of emplacement has varied: uncompacted and compacted solid waste that was contained or uncontained was disposed in burial grounds; liquids and some sludges were disposed in seepage pits and trenches; and liquid-grout mixtures were disposed by hydrofracture. Table 5-1 shows the total quantity of radionuclides (in curies) estimated to have been disposed in each of those facilities.

Waste Pits and Trenches

The chemical waste pits and trenches, excavated in weathered Conasauga shale in Melton Valley (Figure 5-1), were used for disposal of radioactive solutions (mainly the alkaline supernate from processed ILW, 1951 to 1966) and sludges (mainly from the soda-lime and later the Scavenging Precipitation-Ion Exchange treatment of LLLW, 1957-1976). The bulk of the radioactive cations (^{137}Cs, ^{90}Sr, rare earths, actinides) was retained close to the original emplacement sites but, after variable delay, significant amounts of the more mobile species, ^{3}H (as water) and ^{106}Ru, ^{125}Sb and ^{60}Co (as anions or anionic complexes in alkaline solution), migrated to surface streams. The mobility of individual radionuclides in the ground is determined by many factors--local hydrology, composition and pH of groundwater, oxidation state, compound formation and sorptive behavior of the radionuclides, and sorptive properties of the soil. Because the ground disposal units were close to the land surface and mobile radionuclides were being released to the watershed, and because the mobility of individual radionuclides could not always be predicted or controlled, that method of waste disposal was eventually abandoned.

The numeric designations of the pits and trenches, the total volumes of liquids and slurried sludge wastes and quantities of radionclides they received, and their periods of use are shown in Tables 5-1 and 5-2. The data in those tables and the historical

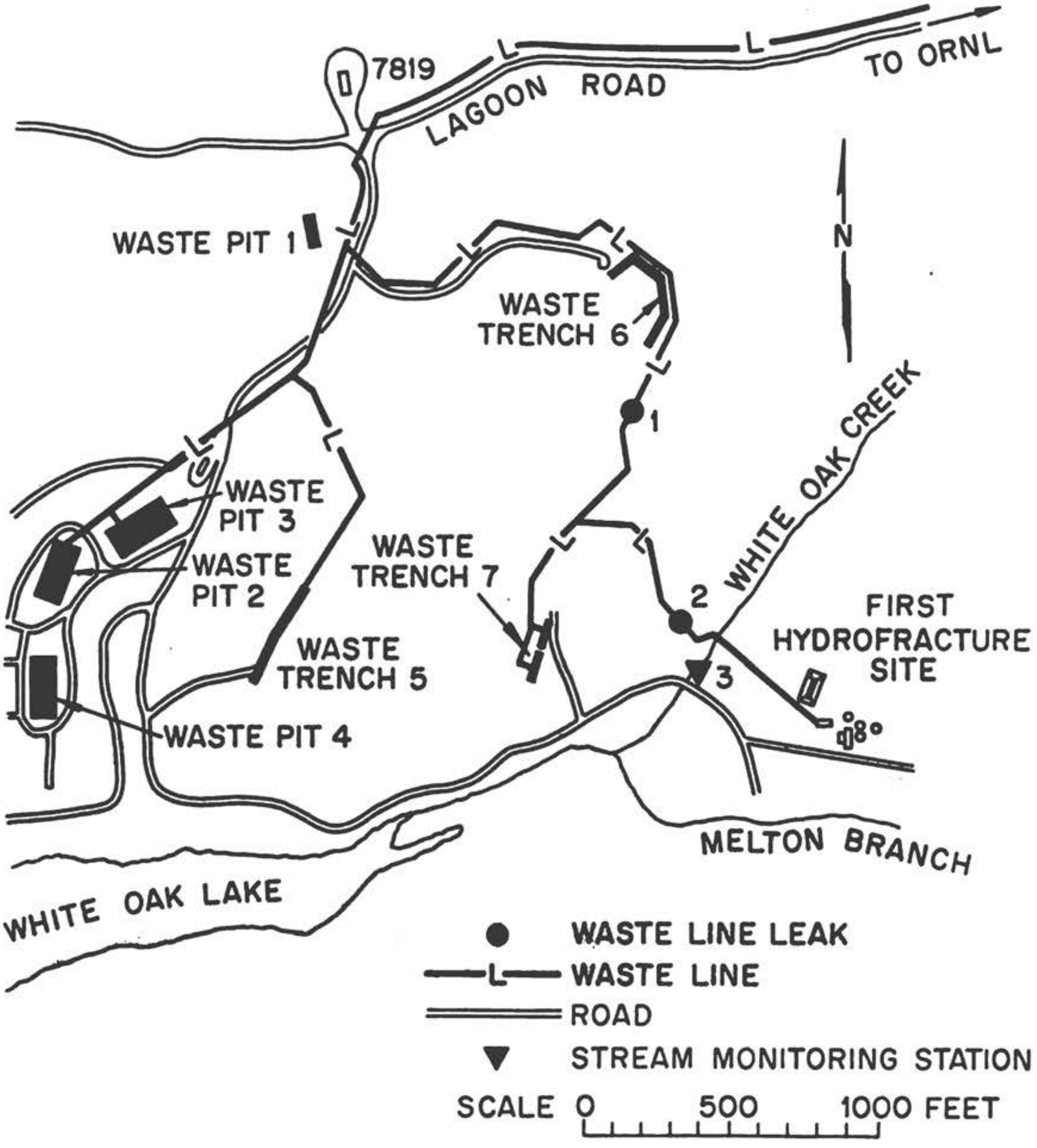

FIGURE 5-1 Location of waste pits, waste trenches, and transfer lines at ORNL. SOURCE: Duguid and Sealand, 1975.

TABLE 5-1 Major Waste Emplacements in the Ground at ORNL

Designation	Service Period	Waste Form at Emplacement	Waste Volume Emplaced, m^3	Radioactivity (When Emplaced), Ci	Status
Waste pit 1	1951	Liquid or sludge	4.70×10^1	4×10^2	Inactive
Waste pits 2, 3, 4	1952-1976	Liquid or sludge	1.17×10^5	5×10^5	Inactive, covered asphalt
Waste trench 5	1960-1966	Liquid or sludge	3.14×10^4	3×10^5	Inactive, covered PVC, soil, and asphalt
Waste trench 6	1961	Liquid or sludge	4.75×10^2	1×10^5	Inactive, covered PVC, soil, and asphalt
Waste trench 7A	1962-1966	Liquid or sludge	1.76×10^4	1.4×10^5	Inactive, covered PVC, soil, and asphalt
Waste trench 7B	1962-1966	Liquid or sludge	1.46×10^4	1.2×10^5	Inactive, covered PVC, soil, and asphalt
First hydrofracture facility	1966-1979	Grouted sludge	5.70×10^3	1.3×10^6	Inactive
New hydrofracture facility	1982-present	Grouted sludge	4.18×10^3 [a]	4.0×10^5 [a]	Active
Burial ground 1	1943-1944	Solid	1.4×10^3	4.0×10^3	Closed
Burial ground 2	1944-1946	Solid	1.4×10^3	4.0×10^3	Closed, excavated, reburied in burial ground 3
Burial ground 3	1946-1951	Solid	2.0×10^4	5.0×10^4	Closed
Burial ground 4	1951-1959	Solid	5.7×10^4	1.1×10^5	Closed
Burial ground 5	1959	Solid	9.1×10^4	2.1×10^5	Operating for storage of TRU waste
Burial ground 6	1969	Solid	2.2×10^4	2.5×10^5	Operating for low-level waste

[a] Through April 1983.

SOURCE: J. Coobs, ORNL, personal communication, November 14, 1983.

TABLE 5-2 Amounts of Liquid Waste Discharged to Waste Pits and Trenches

		Quantity of Radionuclides, Ci			
Chemical Waste Pit	Volume, L (gal)	^{90}Sr	^{137}Cs	^{106}Ru	Period of Operation
1[a]	0.045 (0.012) x10^{6}	--	--	--	1951, one month
2, 3, 4	91 (24.0) x10^{6}	43,500	201,000	236,000	1952, 1953, 1955, respectively, to 1960
5	36 (9.5) x10^{6}	96,500	207,000	5,000	1960-1962
6	0.49 (0.13) x10^{6}	125	660	50	1961-1965
7a[b]	17 (4.5) x10^{6}	24,000	117,000	1,750	1961-1965
7b[b]	15 (4.0) x10^{6}	23,500	102,000	1,480	1961-1965
TOTAL	159 (42.1) x10^{6}	188,000	628,000	244,000	
Average concentration at time of discharge, µCi/ml		1.2	3.9	1.5	
Residual quantity as of Dec. 1981, Ci		125,000	418,000	less than 0.1	

[a] Information taken from Oak Ridge National Laboratory Waste Disposal Operations Monthly Reports. An estimated 400 Ci of radioactivity had been released to pit 1.

[b] Waste pit 7 actually consists of two pits, 7a and 7b, with a central divider separating them.

summary that follows were drawn from Evaluation Research Corporation (1982). The original aim of the waste pits was to contain liquid wastes in the "tight" shale formation in large, deep evaporation ponds, but waste pit 1 was closed after only 1 month because seeping fluid containing mobile radionuclides was observed. However, the observation that the more hazardous, longer-lived radionuclides had been retained by the shale led to the construction of six more "seepage" pits and trenches. Pit 1 was not reopened because of its poor location, but it continued to receive fluids (presumably containing both radionuclides and complexing agents) from decontamination and decommissioning activities until about 1980.

Waste pits 2, 3, and 4, located on the crest of a low ridge, were operated as a single unit. They had a combined capacity of about 1.1×10^4 m^3 and received roughly one-half of all liquid wastes disposed of in this manner. Caustic was added to the already alkaline liquids in the pits and trenches to raise the pH to about 12 and increase the chemical reaction with the fill and to coprecipitate ^{90}Sr with $CaCo_3$ and Ca_3 $(PO_4)_2$.

Four covered trenches (numbered 5, 6, 7a, and 7b) were used for the same purpose and in the same manner after 1960. The trenches were long (62 to 150 m), narrow with sloping sides (about 12 m at the top, 3 m at the bottom), and about 4.5 m deep. They were oriented with their long axes east-west at right angles to the bedding planes of the formation to provide maximum liquid contact with the more permeable zones between the shale beds. The trenches were backfilled with coarsely crushed limestone to aid in maintaining ^{90}Sr in an insoluble form and covered with a dirt mound to provide a radiation shield. Trench 6 was used for only about 1 month, when ^{90}Sr and ^{137}Cs were detected in a surface seep below the trench, indicating the existence of a preferred water pathway (fracture) to the land surface.

Disposal of radioactive liquids in the near-surface facilities was stopped in 1965, when a hydrofracture system was put into operation, although pit 4 continued to receive sludge from the LLLW treatment plant until 1976. During the years of operation of these waste disposal units, under 2×10^8 L (4×10^7 gal) of alkaline fluids and slurries, containing over 10^6 Ci of mixed fission products in solution or suspension, was deposited in or percolated through the ground. Large amounts of ^{106}Ru and lesser amounts of ^{125}Sb and ^{60}Co seeped out into surface streams, but much greater amounts were retained or delayed until decay.

Transfer Lines

Liquid and slurried waste was initially transported to the pits by tank truck. In 1954 a 5-cm (2 in.) diameter, underground, cast iron pipeline along Lagoon Road (Figure 5-1) was installed to transfer waste to pits 2, 3, and 4 (Duguid and Sealand, 1975). Later, in 1958, leaking sections of this line were replaced with carbon steel (Evaluation Research Corporation, 1982). By 1960, a 5-cm (2 in.) diameter black steel pipe extension had been added to transfer waste to trench 5. In

1961, the 5-cm (2 in.) diameter cast iron pipe was extended to trench 6. In 1962, the cast iron pipeline was extended to the first hydrofracture site (Duguid and Sealand, 1975). This transfer system was used until a new stainless-steel line to the hydrofracture site was put in service in 1978. The new line provides double containment, leak detection, and cathodic protection.

Current Practices

Flow sheets for the operating ORNL radioactive liquid waste treatment systems are shown in Figure 5-2.

The radionuclides contained in the liquid waste are concentrated by ion exchange (LLLW) and evaporation (ILW) and are eventually incorporated into a grout, which is injected under pressure into fractured shale formations for permanent disposal. The current LLLW treatment facility does not generate sludge, and the solutions used to regenerate the ion exchange columns are added to the ILW waste system for disposal by hydrofracture (Evaluation Research Corporation, 1982).

SOLID WASTE

Solid radioactive waste is produced by most operating facilities at ORNL; the current management scheme is shown in Figure 5-3. Some solid waste is pretreated prior to burial (e.g., compaction, heat sterilization of animal remains). The occasional waste packages having surface dose rates of more than 200 mR/h are placed in auger holes, but most of the solid waste is buried in trenches. TRU waste was formerly buried in separate trenches and covered with concrete, but since 1970 it has been placed in metal or concrete containers in a retrievable manner. Although the six principal burial sites have been called, interchangeably, burial grounds, solid waste storage areas (SWSAs), and solid waste disposal areas (SWDAs), the designation burial ground is used in this report (Table 5-1).

Since the opening of burial ground 1 in 1944, five burial grounds have been filled, and burial ground 6 is now nearly full. As the size of ORNL and the scope of its operations increased, so did the amount of solid radioactive waste and the size of the area needed for its disposal. The location of burial grounds 1 through 6, the proposed burial ground 7, the Central Waste Disposal Facility at Chestnut Ridge, the two hydrofracture sites, the 0800 Experimental Gamma-Ray Field, and the location of the pits and trenches are shown in Figure 5-4.

General Descriptions of Burial Grounds

The sites for the first three burial grounds were selected primarily for convenience of access from ORNL. They are in Bethel Valley and are underlain by the Chickamauga limestone. Cessation of burial in Bethel Valley stemmed from concern that the underlying limestone, where

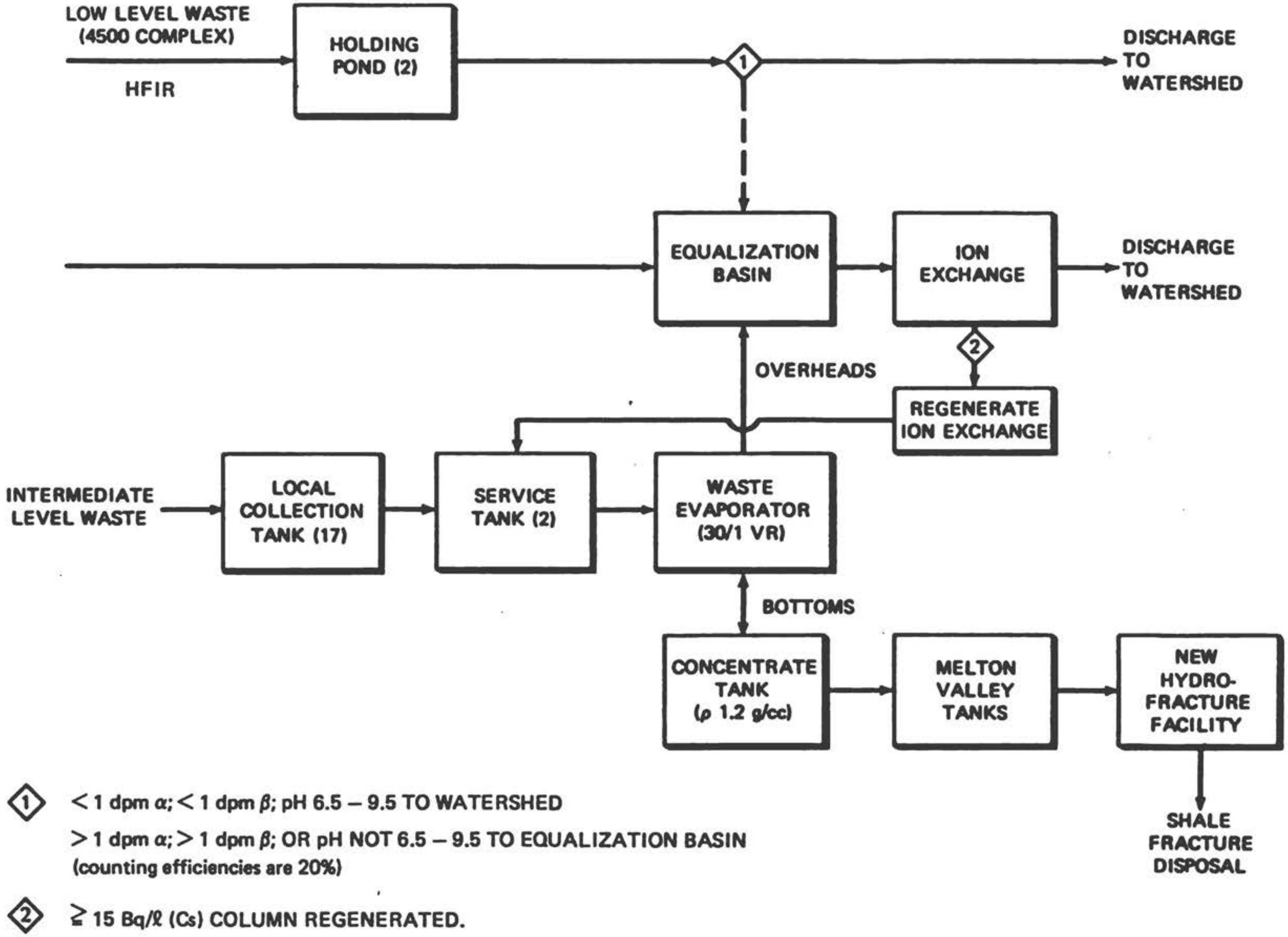

FIGURE 5-2 ORNL radioactive liquid waste treatment systems.

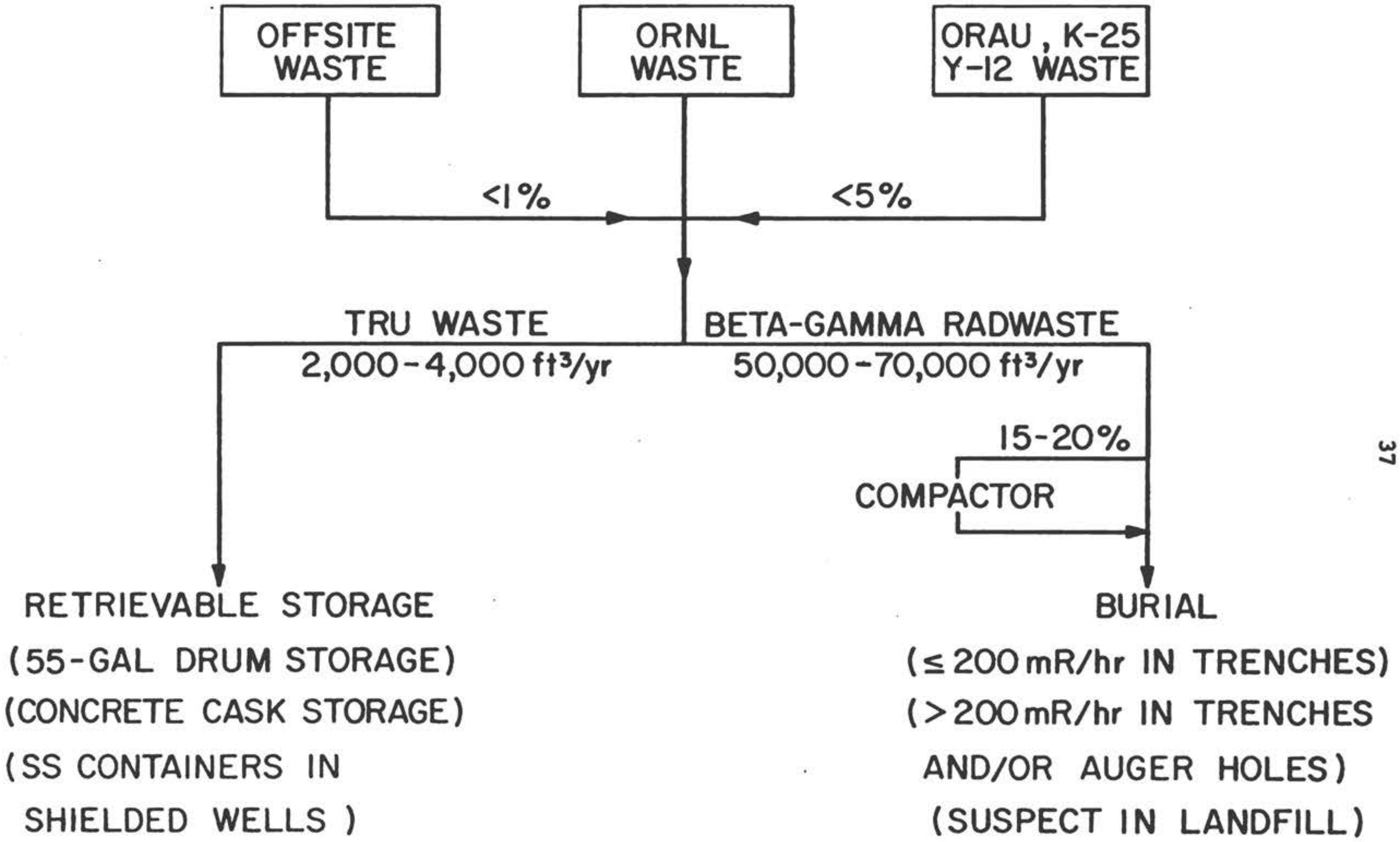

FIGURE 5-3 ORNL solid radioactive waste disposal operations.

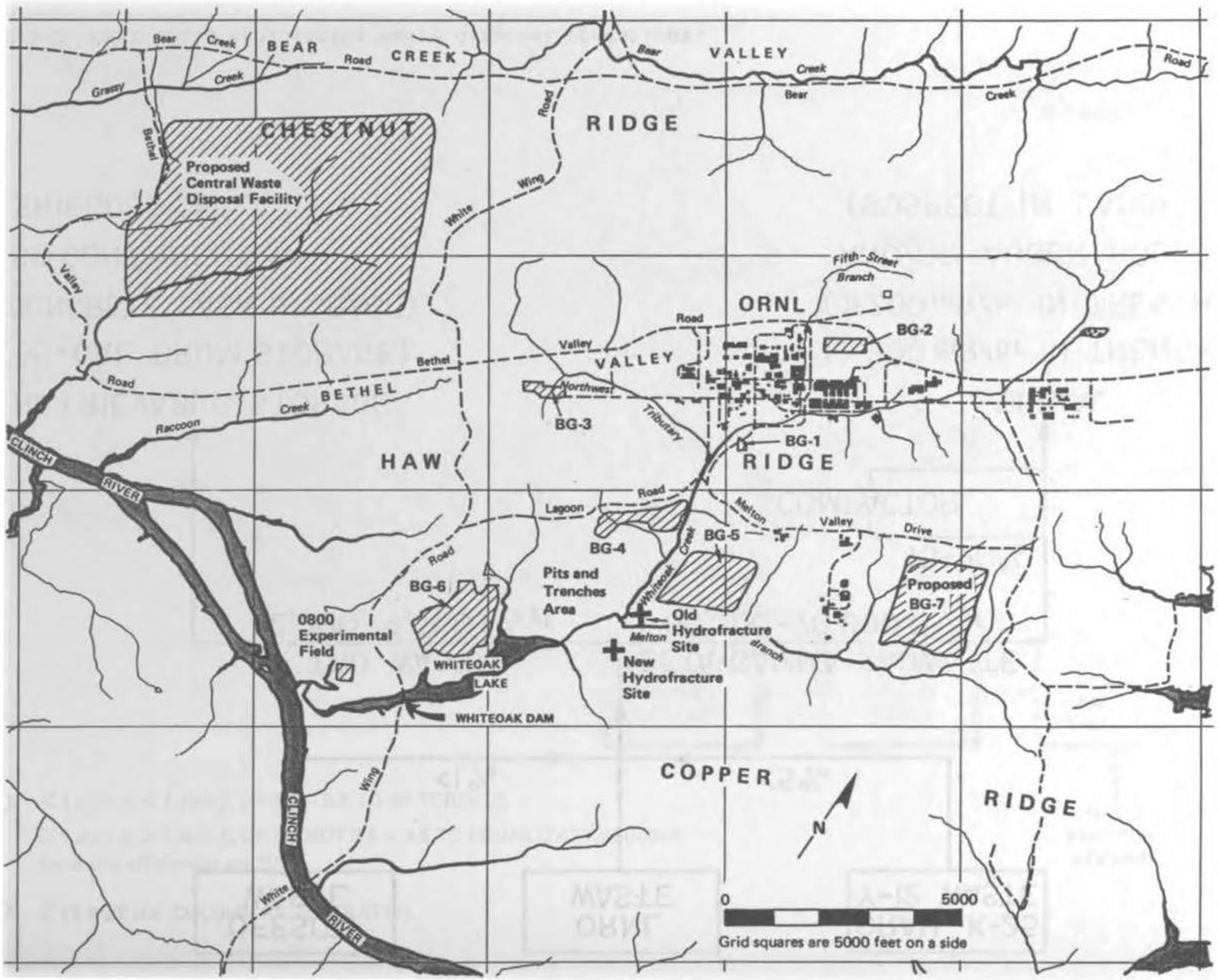

FIGURE 5-4 ORNL burial locations.

radionuclides might migrate relatively rapidly, can become contaminated (Webster, 1976).

The more recently developed burial grounds (numbers 4 through 6) are in Melton Valley on weathered shales of the Conasauga group, which was selected because the shales were thought to be impermeable and not subject to the formation of underground solution cavities (Webster, 1976). The site for burial ground 4 was chosen because it was the area closest to ORNL, although geology and hydrology were given some consideration prior to its choice (Webster, 1976). The development of burial grounds 5 and 6 (in the early and middle 1960s, respectively) was preceded by detailed siting studies; for example, more than half of the area designated as burial ground 6 was found to be unsuitable for disposal of waste because of steep slopes and/or the presence of a shallow groundwater table.

The sequence of establishment of burial grounds and information on burial methods and corrective actions taken are presented in Table 5-3.

Specific Details on Burial Grounds

Details on each burial ground are summarized in the following sections. The graphic and detail maps of burial grounds 1, 2, 4, 5, and 6 are shown by Webster (1976) and of burial ground 3 by Stueber et al. (1981).

Burial Ground 1. Burial ground 1 is in a low-lying area near White Oak Creek that was used for incineration of combustible waste prior to 1944 (Webster, 1976). Only a small amount of waste was buried in this site. It was abandoned after water was found in an open trench.

Burial Ground 2. Burial ground 2 began operation in 1944. It consisted of two trenches; there are no records of the quantity or type of waste buried. Beta- and gamma-contaminated solid waste was buried in iron drums. Plutonium-contaminated liquid waste in stainless-steel drums was either buried or stored on the surface. After closure of burial ground 2, all known waste (both surface stored and buried) was removed and buried in burial ground 3 (Webster, 1976).

Burial Ground 3. As is the case for burial grounds 1 and 2, little information is available on the volume, character, and specific location of the waste in burial ground 3. During early operations at burial ground 3, alpha waste in drums was deposited in concrete-lined trenches, but it was later placed directly into unlined trenches and covered with concrete. Beta-gamma waste was buried in separate, unlined trenches and backfilled with soil (Evaluation Research Corporation, 1982). As the site expanded westward, near-surface rock was encountered, and the burial ground was closed. Shallow ditches, at the east and west ends and two that cross the site, carry runoff from the site and from a local area on Haw Ridge to the Northwest Tributary of White Oak Creek (Webster, 1976).

Large items of equipment that were slightly contaminated and either salvageable or too awkward to bury were stored above ground at this

TABLE 5-3 Low-Level Shallow Land Burial Grounds at ORNL

Burial Ground	Area, hectares (acres)	Method of Burial	Corrective Actions[a]	Date of Operation
1	0.6 (1.5)	Alpha and beta wastes in soil-covered trenches	Periodic mowing	1944
2	1.2 (3.0)	Alpha and beta wastes in soil-covered trenches	N.A. (burial ground exhumed)	1944-1946
3	2.8 (7.0)	Beta wastes in soil-covered trenches. Alpha wastes in concrete-covered and -lined trenches Auger holes	Removal of surface-stored equipment; periodic surface maintenance and mowing	1946-1951
4	9.3 (23)	Beta wastes in soil-covered trenches Alpha wastes in concrete-covered trenches Auger holes	Surface water diversion 1975, replaced by groundwater and surface water diversion 1983; periodic surface maintenance and mowing	1951-1959
5	13.4 (33)	Beta wastes in soil-covered trenches Alpha wastes in concrete-covered trenches Auger holes	Surface water drainage system; sealing of trenches locally with PVC or clay membranes, periodic surface maintenance and mowing	1958 to date (TRU waste storage)
6	28 (68)	Beta wastes in soil-covered trenches Auger holes	Sealing of some trenches with clay membranes; installation of shallow groundwater drains; periodic surface maintenance and mowing	1969 to date

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[a] Mowing prevents the growth of deep-rooted plants. Surface maintenance consists of filling in of surface depressions or openings caused by trench subsidence due to natural waste compaction.

site. These surface-stored items were removed in 1979. Salvageable items were moved to a storage area between burial ground 4 and the seepage pits. The remaining items were buried in burial grounds 5 and 6 (Evaluation Research Corporation, 1982).

Burial Ground 4. Burial ground 4 lies at the foot of Haw Ridge in the lower end of a small watershed. It is a catchment and receives both surface runoff and subsurface discharges from the watershed (Duguid, 1976). Soil cover ranges in thickness from 1 to 5 m (Cowser et al., 1961).

Burial procedures consisted of emplacement of beta-gamma-emitting waste in backfilled trenches 15 to 120 m (50 to 400 ft) long, alpha-emitting waste in concrete capped trenches, and high-activity gamma-emitting waste in auger holes. The orientation of the long trenches lacked any consistent relationship to site topography; many were excavated with their long axes parallel to the slope to avoid caving of the walls along the bedding planes of the shale. Wastes were buried in low-lying areas in the dry months and in the higher areas during wet months, which suggests there was a seasonal rise of the water table into the low-lying trenches.

For a number of years after closure, much of the site received uncontaminated fill and construction debris. In some places this fill has raised the land surface as much as 6 m (Webster, 1976), contributing to a general rise in the water table (Duguid, 1975). Records of the types and volumes of waste disposed prior to 1957 were destroyed by fire (Webster, 1976). However, between 1955 and 1964 the volume of waste increased sharply when Oak Ridge was designated the Southern Regional Burial Ground. During this time, poorly characterized wastes from offsite accounted for approximately 50 percent of the buried volume. Information was provided on external radiation associated with each shipment, but little information was provided about the types, concentrations, and quantities of radionuclides in the waste disposed of in burial ground 4. About 50 auger holes containing higher-activity wastes are located along Lagoon Road.

A surface runoff and diversion system was installed in 1975 consisting of a shallow paved ditch along the north side of Lagoon Road (above burial ground 4) connected by culverts to three shallow paved conductor ditches across the site and a natural unlined ditch at its northeastern edge (Duguid, 1976). A recent study found that the system did not function properly; instead of diverting upslope runoff away from the burial ground, about 70 percent of the collected water was being flushed through trench areas along the southern edge, aggravating ^{90}Sr migration and discharge (Huff et al., 1982). A deep French drain along Lagoon Road was completed in 1984 to collect and channel the upslope surface runoff to White Oak Creek, either directly or via a natural tributary, and a monitoring network was installed to assess its effectiveness (Sease et al., 1984).

Burial Ground 5. Burial ground 5 consists of two distinct sections. The larger southern section is a gently to moderately sloping hillside, and it contains most of the buried waste. The smaller northern section is a fairly flat ridge top, which is still used for above-ground storage of TRU waste. Based on geohydrologic studies conducted before and during the early use of the site, the steeper slopes and areas of high water table were excluded, so the burial area is consideraby less than the nominal 33 acres of the site.

Initially, trenches containing the alpha-contaminated wastes were covered with concrete, and those containing beta-gamma wastes were backfilled and covered with excavated soil. Beginning in 1970, TRU wastes were no longer buried but packaged for retrievable, above-ground storage. Auger holes containing higher-level wastes occupy several areas. Trench lengths vary from 12 to 150 m (40 to 500 ft), and the majority are angled roughly parallel to the topographic slope. A map showing locations of individual trenches is available, but a contemporary water table contour map has not been prepared (Webster, 1976).

Records of the amounts of radionuclides originating at ORNL and placed in burial ground 5 are considered to be accurate, but the large waste volumes received between 1958 and 1964 from offsite sources appear to have been poorly characterized. For example, burial records indicate emplacement of 6×10^4 Ci of ^3H in burial ground 5, which is considered to contribute 85 to 90 percent of the ^3H discharged at White Oak Dam. Between 1966 and 1983 a total of 2×10^5 Ci of ^3H (corrected for decay to 1966) was measured at White Oak Dam (see Table 6-6), and evapotranspiration undoubtedly also accounted for additional release of ^3H from burial ground 5. Thus, more than 3 times the recorded amount of ^3H has already been released, and the annual discharge continues to be several thousand curies.

A surface runoff diversion system was installed in the southern section in 1975. Two dams were placed across a pair of adjacent trenches that were leaking ^{90}Sr and ^3H (numbers 83 and 105) to reduce their section lengths, and those trenches and the two next to them were covered with a 10-mil thick PVC plastic sheet and 0.6 m of soil to reduce rain infiltration (Duguid, 1976). A 14-trench area containing TRU waste was later sealed with bentonite-shale mixture. Drain ditches have been lined with concrete, collapsed trench caps filled, and the surface contoured for improved drainage (Evaluation Research Corporation, 1982).

Burial Ground 6. The site for burial ground 6 is a gently to moderately steep hillside immediately northwest of White Oak Lake. It was selected using the same siting criteria as for burial ground 5. Preoperational hydrogeological studies indicated that about one-third of the area was not suitable for burial of radioactive waste because of steep slopes or a high water table. It is the largest burial ground and is the only one now being used for disposal of low-level waste.

Trench lengths have generally been limited to about 15 m (50 ft), and, where possible, the long axis was not oriented parallel to the topographic slope. Accumulation of precipitation and surface runoff in open trenches has been reduced by digging temporary diversion ditches upslope of the trenches to route surface water from rainfall around them. If the trenches are to be open for several months, those with surface radiation readings exceeding 200 mR/h or containing compacted waste are covered temporarily to prevent wall collapse. The covers are removed after the trenches are filled with waste and backfill. Since 1978 the waste has been segregated and compacted to conserve burial space. Locations on high ground, where the water table is deeper, are used for the most concentrated waste. Auger holes, used for concentrated wastes, are capped with concrete after they are filled. The radionuclide inventory is considered to be reasonably accurate. The dominant buried radionuclides with half-lives longer than 1 year are rare earths and ^{60}Co, which make up 80 percent of the current inventory of 2.5 x 10^5 Ci. Tritium and ^{90}Sr are minor constituents (about 6 percent of the total). A significant amount of ^{235}U waste has been placed in burial ground 6. Near-surface clay seals have been installed above a number of trenches to reduce the amount of water percolating into the trenches. In 1983, when groundwater intrusion was also observed, a shallow drainage system was installed around a leaking 49-trench area. Two drainage trenches intersect upslope from the sealed areas; they are deeper than the buried waste, and are intended both to remove infiltrating water and to lower the water table under the sealed area. A monitoring system was installed to evaluate results. Burial ground 6 also contains experimental areas for study of burial techniques and remedial measures (Auerbach et al., 1981).

TRANSURANIC WASTE (TRU)

In recent years, solid TRU waste at ORNL has been collected in drums or concrete casks and stored in vaults or earth-shielded storage facilities. DOE criteria specify that the waste should be retrievable for at least 20 years so the containers could ultimately be shipped to a repository. Most of ORNL's TRU waste will be consigned to WIPP. The retrievable storage facilities plus the certification, handling, and shipping operations all contribute to the high cost of managing TRU waste.

With the implementation of DOE order 5820 in 1983, the definition of TRU waste was revised so that only waste containing 100 nCi/g or more of TRU radionuclides with half-lives longer than 20 years need be segregated and stored retrievably. All drums of stored TRU waste are being reclassified according to the new definition using a gamma-ray and neutron scanning assay system that, coupled with radiography, will enable all drums of stored TRU waste to be appropriately classified.

The management of contact-handled TRU waste, which includes all the TRU waste collected and stored in drums, thus does not present special problems. However, remotely handled TRU waste (greater than 200 mR/h dose at contact) has been and is being collected and stored in concrete casks. These casks may not be certifiable for acceptance at a TRU repository, so these wastes must ultimately be repackaged or consigned to some acceptable alternative disposal method. The ultimate disposition of these casks containing remotely handled TRU waste, and of the currently generated remotely handled waste, is a problem that must be resolved.

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6
Monitoring

MONITORING NETWORK

The Oak Ridge National Laboratory (ORNL) is responsible for monitoring the environment for quantities and pathways of radionuclide releases from all facilities on the Oak Ridge Reservation. The monitoring network includes continuous instrumental analysis of some liquid and gaseous effluents and sampling and analysis of others. Samples of air, water, soil, and biota from the site and from perimeter and offsite stations are routinely collected and analyzed.

Gases and Airborne Particulates

Gaseous effluents are monitored at each of the six release stacks at ORNL and by an onsite air-monitoring system that includes beta-gamma monitors and sampling at 16 locations within the ORNL complex. In addition, there are nine air samplers located on the perimeter of the DOE-controlled area, and eight remote samplers located from 19 to 121 km beyond the DOE-controlled area. At each sampler, air is forced continuously through filter papers (for particulates) and through activated charcoal (for iodine). Samples are normally analyzed weekly, but more frequently if releases are above normal. Gamma radiation measurements are made routinely at the perimeter and remote air monitoring stations. Rainwater is collected and analyzed (Union Carbide Corporation--Nuclear Division, 1983). Raw milk is monitored for ^{131}I and ^{90}Sr at 10 locations within an 80-km radius of Oak Ridge. Several species of fish from several locations in the Clinch River are analyzed annually; deer killed by automobiles on the DOE-controlled area are routinely analyzed; and vegetation samples from 14 offsite locations are analyzed annually for uranium and fluoride ion. Soil samples from the perimeter stations are analyzed semiannually (Union Carbide Corporation--Nuclear Division, 1983).

Liquid and Solid Waste

Some radionuclides in the liquid and solid waste from ORNL escape containment and are eventually discharged to the offsite environment by way of streams. Except for two unmonitored small streams that discharge from burial ground 3 into Raccoon Creek and from the 0800 cesium experimental plot into the Clinch River (ORNL, Department of Environmental Management, 1983), the liquid effluents (including entrained sediments) reach the offsite environment through the White Oak Creek drainage. Figure 6-1 shows the location of the principal ORNL effluent sampling stations and radiation monitors.

Although point source monitors are used to obtain effluent data directly, many of the contaminating sources at the ORNL site are diffuse, and precise monitoring of effluents from each would be very difficult, perhaps impossible. Estimates of the quantity of radionuclides discharged must therefore often be obtained by the difference method; for example, contaminant levels from a burial ground under consideration may be estimated by subtracting the quantities measured above it from those measured below it.

White Oak Dam Station

The primary monitoring station for the liquid effluents from ORNL is a flow-proportional sampler located at White Oak Dam about 1 km above the confluence of White Oak Creek with the Clinch River (station 5, Figure 6-1). Samples consist of both filtered water and transported sediments. Radionuclides appearing in White Oak Creek come from ORNL operations, six burial grounds, contaminated flood plains (that extend along the entire reach of White Oak Creek below ORNL), seepage pits and trenches, and other poorly defined contaminated areas. Because of the shallow circulation of groundwater in the White Oak Creek drainage, radionuclides migrating from the burial grounds and the seepage pits and trenches discharge into White Oak Creek or Melton Branch above this monitoring station. However, a portion of burial ground 3 discharges to Raccoon Creek, and a portion of burial ground 6 could discharge below White Oak Dam--either to the White Oak Creek embayment or directly to the Clinch River. Also, seepage under White Oak Dam would not be measured. The combination of radionuclide discharge via Raccoon Creek, from burial ground 6 below White Oak Dam, and seepage under White Oak Dam is not discernible in the data from continuous monitoring of the Clinch River. The ability to detect radionuclides contributed by those sources is further reduced by the reverse flow that occurs in this reach of the Clinch River due to the changing of the lake levels behind the flood control dams.

Upstream Stations

Stations for sampling radionuclides, weirs for measuring water flow, and continuous flow-proportional samplers have been installed on White

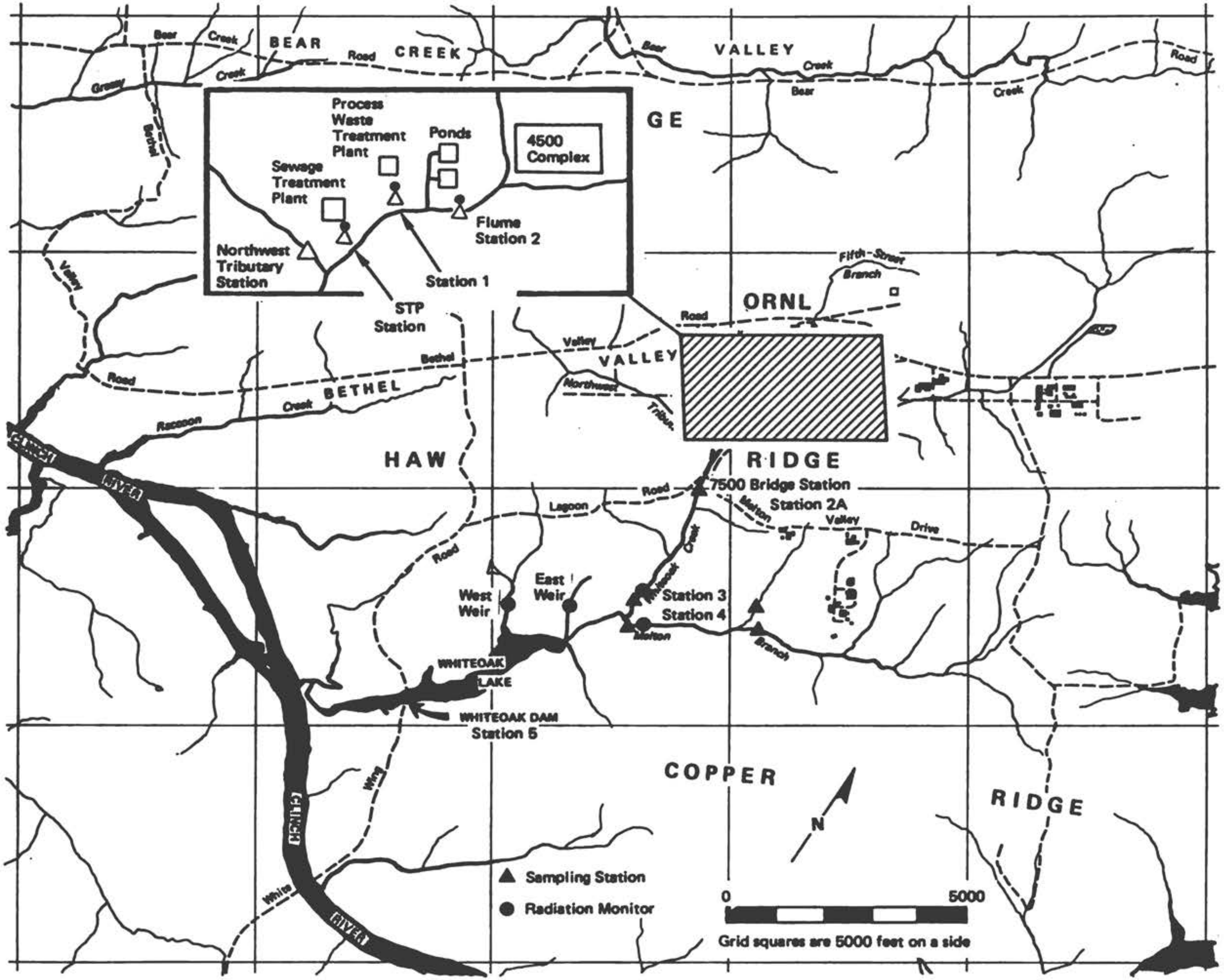

FIGURE 6-1 ORNL water sampling stations.

Oak Creek and its tributaries upstream of White Oak Dam for the purpose of differentiating between and quantitating sources of radionuclides within the White Oak Creek drainage. The present water sampling network is shown in Figure 6-1. The relationships among the monitoring stations are shown in schematic form in Figure 6-2. It should be noted that the monitoring equipment at stations 3, 4, and 5 collect samples in quantities proportional to stream flow; at other stations this is not done, and monitoring there is less accurate.

Liquid effluents from ORNL operations are now monitored at the process waste treatment plant and the 190 ponds (station 1), the flume (station 2), and the sewage treatment plant. Each of these locations has a sampler and a continuous radiation monitor; the sum of their radionuclide discharges is the total discharge from ORNL operations, apart from the underground seepage from the waste ponds and any contaminated areas near the ORNL facilities. This underground seepage is monitored at the next downstream station near the 7500 Bridge (station 2A, Figure 6-1); monitoring is by the difference method, discussed previously. A sampling station on the Northwest Tributary monitors the releases from burial ground 3 except for that portion of the discharge that moves westward down Raccoon Creek. The composite discharge from ORNL operations, burial ground 3, burial ground 1, and the contaminated floodplain between the two monitoring stations, as well as underground seepage from ORNL facilities, is monitored at station 2A. Further downstream, station 3 monitors the discharges from burial ground 4 and from contaminated floodplains along this reach of creek, as well as the discharges passing the 7500 Bridge station. The difference between the additional (upstream) monitoring stations on Melton Branch and station 4 represents the discharge from burial ground 5. Samplers at the east and west weirs measure discharges from the pit and trench area directly. The difference between the sum of the radionuclide discharges at stations 3 and 4 and that of station 5 includes the discharge from the seepage pits and trenches and burial ground 6.

Several other temporary monitoring stations have been installed on tributaries of White Oak Creek and Melton Branch to provide supplemental data as required for source identification. Stream monitoring makes it possible to calculate the amounts of ^{90}Sr and other radionuclides released from several locations in the White Oak Creek drainage. Continuous, flow-proportional sampling stations are being considered for installation in Raccoon Creek downstream of burial ground 3, and in the drainage of the 0800 experimental cesium plot (T. Oakes, ORNL, personal communication, March 5, 1984). Both of these streams flow intermittently, and water and soil samples are being collected to determine the need for further monitoring.

Offsite Networks

To verify that radionuclide concentrations in the Clinch River are correctly calculated from concentrations at White Oak Dam and the relative flow rates of White Oak Creek and the Clinch River, two

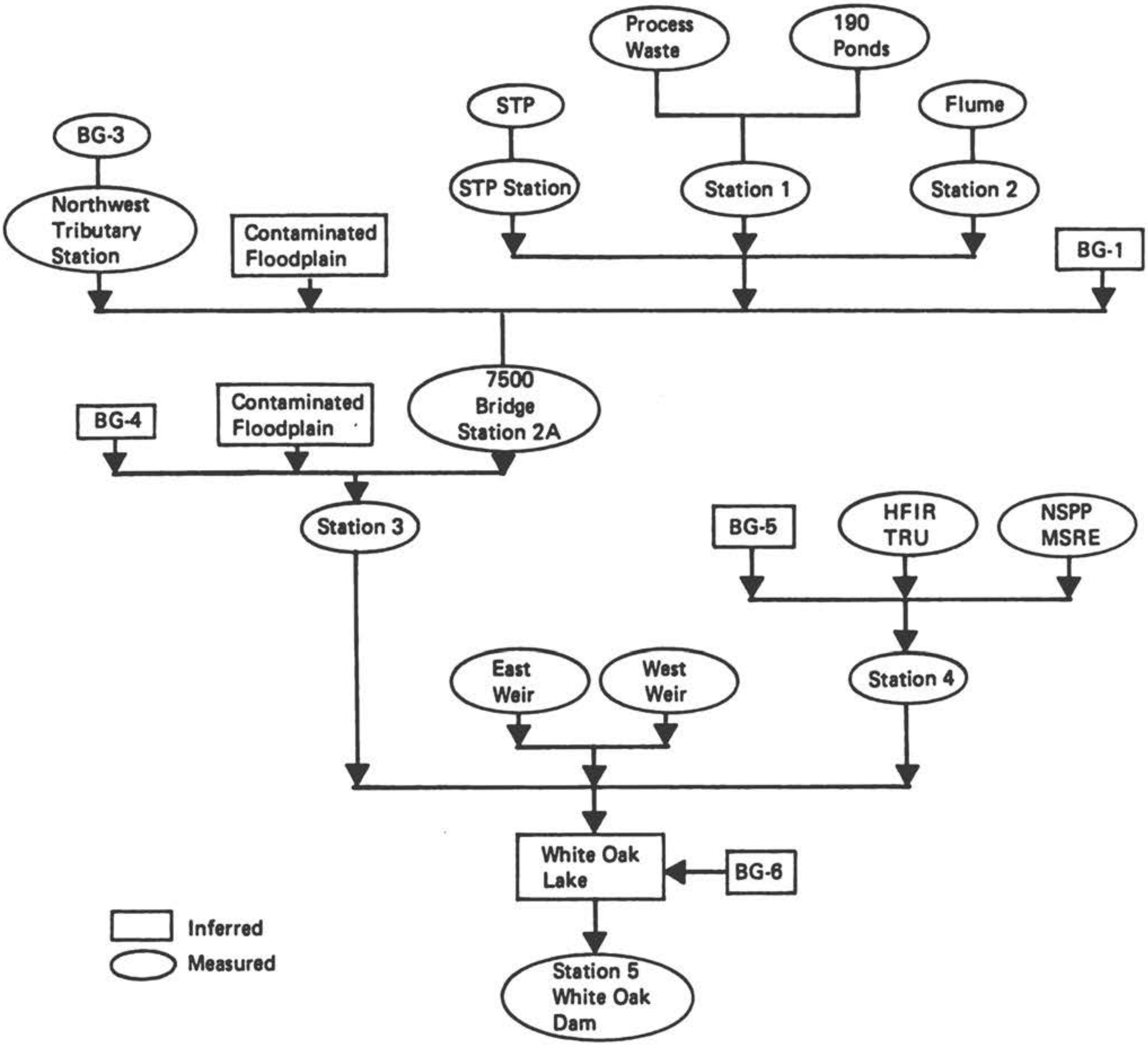

FIGURE 6-2 Liquid effluent streams to White Oak Dam. (Before 1979, the 3500 ponds discharged below station 2; after they were identified, those discharges were stopped.)

principal sampling stations are maintained in the Clinch River. A timed, continuous sampler is in place below the White Oak Creek outfall at Clinch River mile (CRM) 20.8 (Union Carbide Corporation--Nuclear Division, 1982, 1983). A flow-proportional sample collector near the water intake (CRM 14.5) of the Oak Ridge Gaseous Diffusion Plant (ORGDP, or K-25 site) is intended to provide data for establishing the concentrations of radionuclides in water for normal treatment plant use, for calculating the radiation dose to the first user downstream, and for comparison with concentrations calculated from White Oak Dam effluents and dilution provided by the Clinch River.

In addition, a "grab" sample of treated water is collected daily at the Kingston Water Plant at Tennessee River mile (TRM) 568, near CRM 0.0, to provide data concerning the average concentration of radionuclides at the nearest population center downstream. A flow-proportional sample collector in the Clinch River at Melton Hill Dam (CRM 23.1) provides an upstream control.

Radionuclide Analyses

The filtered water samples from the surface-water monitoring system, described above, are analyzed for the following radionuclides: ^{137}Cs, ^{106}Ru, ^{90}Sr, ^{131}I, ^{60}Co, ^{3}H, and isotopes of the transuranic elements. Those usually found in highest concentration are ^{90}Sr and ^{3}H. Annual release records exist from 1959 to the present for stations 2 through 5. However, over this period the monitoring system has been upgraded considerably. Not only have additional stations been added to better define migration of radionuclides from the buried waste, but stations 3, 4, and 5 were upgraded in 1983 to monitor high water flows (the 100-year flood). Prior to the improvement of these stations, high flows periodically overtopped the weirs at these monitoring stations. During these events, although samples were collected for radionuclide analysis, accurate flow measurements were not available.

Groundwater Monitoring System

Groundwater monitoring was begun on a quarterly basis in 1978, and was upgraded in 1981 to a systematic program that includes samples from 100 wells in and around burial grounds 4, 5, and 6 and the liquid waste pits and trenches. Prior to this date, groundwater monitoring was sporadic and of limited scope. Filtered groundwater samples are now analyzed for ^{90}Sr, ^{137}Cs, ^{60}Co, ^{3}H, and gross alpha activity. The majority of the sampled wells are downgradient (in the direction of flow) from the buried waste. A few upgradient wells are sampled to serve as local controls for the monitoring system.

RADIONUCLIDE LEVELS IN EFFLUENTS

Summaries of the analytical results obtained from the ORNL monitoring network have been reported annually for many years. Recent, more detailed, data appear in Environmental Monitoring Reports (e.g., Union Carbide Corporation--Nuclear Division, 1982, 1983; Martin Marietta, 1984) and in the Industrial Safety and Applied Health Physics Division (ISAHPD) Reports (e.g., Auxier and Oakes, 1982; ORNL, 1983).

Gases and Airborne Particulates from ORNL Operations

The quantities of gases and airborne particulates released annually are summarized in Table 6-1 for the years 1976 through 1983. Tritium (^3H) releases appear to have increased approximately fourfold to eightfold during that time, while releases of ^{133}Xe and alpha-active particulates do not exhibit any consistent trend, and ^{131}I releases have decreased.

Data from one onsite and two offsite monitoring systems (laboratory air monitoring, perimeter air monitoring, and remote air monitoring) show that the quantities of gaseous and airborne radioactive particulates released from the ORNL site produce only a very slight increase in airborne radionuclide concentrations onsite (Auxier and Oakes, 1982; ORNL, 1983) and no readily identifiable change in ambient radionuclide concentrations offsite (Table 6-2) in the amounts of airborne radionuclides deposited on soil or grass (Table 6-3) or on vegetation eaten by cows, as judged by milk sampling (Table 6-4), in the amount of airborne radionuclides washed out by rain (Table 6-4), or in the external exposure rate from deposited radionuclides (Table 6-5). In fact, although the total amount of each radionuclide released from stacks to the atmosphere during 1982 and 1983 exceeded that released during 1981, the perimeter stations during 1982 and 1983 showed radionuclide concentrations that were consistently less than or equal to those for 1981 (Tables 6-2 and 6-3). The 1981 results were perturbed by fallout from atmospheric weapons tests by the Peoples Republic of China, and that perturbation was still apparent in 1982. For each recent year, concentrations of most airborne or deposited radionuclides at the perimeter stations are statistically indistinguishable from the values obtained at the remote stations.

Of all the measurements of airborne radionuclides, only the external gamma radiation measurements for the perimeter stations consistently appear to be greater than those at the remote stations, and even that difference is not statistically significant when the reported uncertainties are taken into account. The panel concludes that the gaseous and airborne particulate effluents from ORNL have little influence on the offsite environment. Effluent levels are compared to applicable and potentially applicable standards and regulations in the Assessment of Atmospheric Emissions section of Chapter 8.

Tritium is being sampled at four local ORNL air monitors and will be reported in the future. The onsite air concentrations seldom exceed

TABLE 6-1 Summary of the Annual Discharges of Radioactivity to the Atmosphere

	Annual Release				
	^{3}H, kCi	^{85}Kr, kCi	^{131}I, Ci	^{133}Xe, kCi	Alpha-Active Particulates, µCi
1976	5.9	11.3	1.2	57	5
1977	2.5	8.6	1.4	41	5
1978	2.5	11.9	1.7	59	5
1979	6.2	10.5	less than 0.3	51	4.4
1980	14.9	8.9	less than 0.2	43	4.9
1981	11.3	6.8	less than 0.5	32	0.8
1982	18.9	11.6	less than 0.1	57	2.7
1983	22.2	11.9	less than 0.1	58	less than 4.3

SOURCES: ORNL Industrial Safety and Applied Health Physics Division (ISAHPD) Annual Reports for 1976-1981; Union Carbide Corporation--Nuclear Division, 1983; Martin Marietta, 1984.

3×10^{-10} µCi/cm^{3}, which is much less than the current DOE radionuclide concentration guide for uncontrolled areas (2×10^{-7} µCi/cm^{3}). Additional ^{3}H-monitoring capability would provide assurance that calculated safety assessment parameters are being tested as completely as possible against field data, especially if most of the ^{3}H is being released as water vapor.

Gaseous Emissions from Burial Grounds

Anaerobic decomposition of organic materials in buried low-level radioactive waste has been shown to be the most significant pathway for ^{3}H and ^{14}C releases from a former commercial radioactive waste

TABLE 6-2 Air Monitoring Data for Perimeter and Remote Air Monitoring Stations

	Annual Average Radionuclide Concentration in Airborne Particulates, fCi/m^3 [a]					
	1981		1982		1983	
Radionuclide	Perimeter	Remote	Perimeter	Remote	Perimeter	Remote
Long-lived gross beta	69 ± 17	70 ± 18	24 ± 1	22 ± 1	30 ± 1	24 ± 1
Long-lived gross alpha	0.89 ± 0.18	1.1 ± 0.2	0.99 ± 0.06	0.94 ± 0.06	1.17 ± 0.04	1.05 ± 0.05
^{54}Mn	0.43[b]	0.4	0.030	0.032	---	---
^{90}Sr	0.46	0.4	0.150	0.248	0.075	0.276
^{95}Nb	23	21	0.076	0.070	---	---
^{95}Zr	11	11	0.049	0.042	---	---
^{103}Ru	7.1	8.9	0.031	0.024	---	---
^{106}Ru	4.4	3.3	0.404	0.383	0.119	0.141
^{125}Sb	0.76	0.6	0.102	0.080	---	---
^{137}Cs	1.2	1.1	0.236	0.195	0.100	0.091
^{141}Ce	11	9.2	0.031	0.048	---	---
^{144}Ce	5.5	4.6	0.802	0.649	---	---
^{228}Th	0.05	0.04	0.060	0.036	0.042	0.046
^{230}Th	0.04	0.02	0.036	0.023	0.025	0.023
^{232}Th	0.03	0.02	0.050	0.030	0.030	0.030
^{234}U	0.40	0.06	0.211	0.159	0.321	0.093
^{235}U	0.04	0.01	0.020	0.012	0.040	0.004
^{238}U	0.28	0.05	0.157	0.130	0.158	0.049
^{238}Pu	0.0004	0.0006	0.0009	0.0007	0.0002	0.0002
^{239}Pu	0.01	0.01	0.0021	0.0018	0.001	0.001
^{131}I	1.3 ± 0.2	---	1.0 ± 0.1	---	1.2 ± 0.1	---

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[a] Femtocuries per cubic meter; i.e., curies per cubic meter divided by 10^{15}.
[b] Analytical uncertainties for specific radionuclides are not provided by ORNL.

NOTE: Dashes indicate not reported or not analyzed.

SOURCE: Adapted from Union Carbide Corporation--Nuclear Division, 1982, 1983; Martin Marietta, 1984.

TABLE 6-3 Concentration (pCi/g) of Radionuclides in Grass and Soil Samples from Perimeter and Remote Monitoring Stations

	Grass					
	1981		1982		1983	
Radionuclide	Perimeter[a]	Remote[b]	Perimeter[a]	Remote[b]	Perimeter[a]	Remote[b]
^{90}Sr	0.58[c]	0.68	0.27	0.50	0.16	0.39
^{137}Cs	0.13	0.09	0.10	0.10	0.27	0.037
^{234}U	0.16	0.07	0.08	0.025	0.12	0.031
^{235}U	0.020	0.020	0.008	0.007	0.012	0.0035
^{238}U	0.08	0.04	0.074	0.011	0.45	0.014
^{238}Pu	0.0011	0.0017	0.0007	0.0007	0.0009	0.0002
^{239}Pu	0.0023	0.0018	0.0006	0.0006	0.0011	0.0003

[a] Average of two samples.
[b] Single sample.
[c] Analytical uncertainties were not provided by ORNL.

burial ground in a humid environment (Matuszek, 1982; Matuszek and Robinson, 1983). Whether similar conditions exist at ORNL is not certain, because appropriate measurements have not yet been made of ^{3}H and ^{14}C concentrations in either trench voids or ambient air. Data are being gathered on trench voids.

As at West Valley (Matuszek, 1982), ORNL may find measurements of pressure differentials between trench voids and ambient air a useful means of evaluating trench cap permeability, especially if an enhanced seal of clay and/or soil is placed over the trenches at the ORNL burial grounds.

Liquid and Solid Waste

This section will deal first with the quantities and concentrations of various radionuclides passing through the weir at White Oak Dam, because this is the primary station for effluent evaluation. Next, the locations are described within the White Oak Creek basin from which radionuclides (mainly ^{90}Sr and ^{3}H) are discharged into White Oak Creek and its tributaries for release past White Oak Dam. Data from the offsite network are used for verification of dilution estimates in the Clinch River. Finally, the results of several special studies conducted in surface streams and in the groundwater system are summarized.

Soil					
1981		1982		1983	
Perimeter[a]	Remote[b]	Perimeter[a]	Remote[b]	Perimeter[a]	Remote[b]
0.04	0.2	0.28	0.23	0.23	0.15
1.3	1.4	1.2	1.3	1.1	1.7
0.6	0.6	0.48	0.45	0.87	0.55
0.03	0.03	0.074	0.063	0.11	0.065
0.4	0.5	0.34	0.41	0.46	0.45
0.004	0.004	0.0008	0.0015	0.0009	0.0013
0.04	0.08	0.023	0.021	0.014	0.016

SOURCE: Adapted from Union Carbide Corporation--Nuclear Division, 1982, Tables 32 and 33; UCC-ND, 1983, Tables 31 and 32; and Martin Marietta, 1984, Tables 34 and 35.

Radionuclide Effluents at White Oak Dam

Radionuclide concentrations measured in samples from the White Oak Dam station are combined with total flow through the weir to provide an estimate of the total quantity of radionuclides leaving the ORNL site via the water pathway (Table 6-6), exclusive of the two previously described sources outside White Oak Creek drainage.

The old and the new monitoring systems at White Oak Dam for sampling and measuring total flow were described previously. During high flow events, the estimated quantity of radionuclides released should be increased by 25 to 50 percent over that suggested by Table 6-6 for those radionuclides that are transported predominantly on sediments, and by a lesser amount for the more soluble radionuclides (Boyle et al., 1982). Although the overflow estimates are documented (Oakes et al., 1982a), they are considered to be speculative (Boyle et al., 1982). Also, as much as 10 percent of the more soluble radionuclides may be seeping out under White Oak Dam (Boyle et al., 1982), but this estimate is also uncertain. In addition to uncertainty in the total releases caused by unmeasured underflow and overflow of White Oak Dam, additional uncertainty (although the releases are likely to be small) is caused by the unmonitored radionuclides escaping into Raccoon Creek from burial ground 3, releases directly into the Clinch River from the 0800 cesium experimental plot, and potential releases from burial ground 6 into the White Oak Creek embayment downstream from White Oak Dam. Thus calculations of the total quantity of each radionuclide passing over White Oak Dam serve as good semiquantitative

TABLE 6-4 Annual Average Concentration, pCi/L of Radionuclides in Rainwater and Milk

	1981		1982		1983	
Radionuclide	Perimeter	Remote	Perimeter	Remote	Perimeter	Remote
Gross beta in rain	2.7 ± 0.8	4.2 ± 1.2	6.1 ± 1.2	9.0 ± 2.4	6.3 ± 0.3	11.5 ± 0.6
^{131}I in milk	less than 0.45	less than 0.45	less than 0.45	less than 0.45	less than 0.45	less than 0.45
^{90}Sr in milk	1.6 ± 0.2	1.3 ± 0.4	1.4 ± 0.03	1.4 ± 0.6	1.24 ± 0.06	1.1 ± 0.2

SOURCE: Adapted from Union Carbide Corporation--Nuclear Division, 1982, Tables 14, 25, and 26; UCC-ND, 1983, Tables 14, 24 and 25; and Martin Marietta, 1984, Tables 15, 26, and 27.

TABLE 6-5 External Gamma Radiation Measurements

	Exposure Rate, uR/h		
Station Number	1981	1982	1983
Perimeter Stations			
HP-31	9.7 ± 0.5	8.0 ± 1.0	11.0 ± 1.1
HP-32	11.7 ± 0.6	12.5 ± 2.8	14.0 ± 1.0
HP-33	0.7 ± 0.6	10.0 ± 1.7	10.0 ± 1.0
HP-34	17.8 ± 2.5	17.3 ± 4.0	17.0 ± 1.3
HP-35	8.5 ± 0.5	10.3 ± 4.0	9.8 ± 0.9
HP-36	8.1 ± 0.6	9.5 ± 2.6	9.4 ± 1.0
HP-37	7.9 ± 1.0	9.6 ± 2.2	8.7 ± 0.8
HP-38	8.5 ± 0.6	10.6 ± 4.0	9.7 ± 0.9
HP-39	9.0 ± 0.7	12.1 ± 4.2	9.9 ± 0.9
HP-40	--	--	8.7 ± 0.4
HP-41	--	--	11.0
Average	10.1 ± 2.0	11.1 ± 1.9	11.0 ± 0.7
Remote Stations			
HP-51	5.8 ± 0.9	5.8 ± 1.6	7.1 ± 1.6
HP-52	7.3 ± 1.7	7.3 ± 1.8	7.3 ± 0.6
HP-53	7.7 ± 1.1	7.5 ± 2.0	8.0 ± 0.6
HP-55	--	--	6.8 ± 0.2
HP-56	7.3 ± 0.1	5.2	6.9 ± 1.5
HP-57	7.7 ± 1.2	7.2 ± 3.0	7.9 ± 1.1
HP-58	10.9 ± 0.5	10.9 ± 2.6	11.0 ± 0.4
Average	7.6 ± 1.1	7.2 ± 1.4	7.8 ± 1.6

SOURCE: Adapted from Union Carbide Corporation--Nuclear Division, 1982, Table 10; Union Carbide Corporation--Nuclear Division, 1983, Table 10; and Martin Marietta, 1984, Table 11.

TABLE 6-6 Quantities of Radionuclides Discharged Annually at White Oak Dam from 1949 through 1983 (Ci)

	^{137}Cs	^{106}Ru	^{89}Sr	^{90}Sr	TRE[a] (Ce)	^{144}Ce	^{95}Zr	^{95}Nb	^{131}I	^{60}Co	^{3}H	TRU[b]
1949	77	110		150	77	18	180	22	77		N.A.[c]	0.009
1950	19	23		38	30	N.A.[c]	15	42	19			0.04
1951	20	18		29	11	N.A.[c]	5	2	18			0.08
1952	10	15		72	26	23	19	18	20			0.03
1953	6	26		130	110	7	8	4	2			0.08
1954	22	11		140	160	24	14	9	4	N.A.[c]		0.07
1955	63	31		93	150	85	5	6	7	7		0.25
1956	170	29		100	140	59	12	15	4	46		0.28
1957	89	60		83	110	13	23	7	1	5		0.15
1958	55	42	N.A.[c]	150	240	30	6	6	8	9		0.08
1959	76	520	0.3	60	94	48	27	30	1	77		0.68
1960	31	1,900	1.9	28	48	27	38	45	5	72		0.19
1961	15	2,000	2.0	22	24	4	20	70	4	31		0.07
1962	6	1,400	1.7	9	11	1	2	8	0.4	14		0.06
1963	4	430	1.0	8	9	2	0.3	0.7	0.4	14		0.17
1964	6	191	0.8	7	13	0.3	0.2	0.1	0.3	15	1,930	0.08
1965	2	69	0.6	3	6	0.1	0.3	0.3	0.2	12	1,160	0.50
1966	2	29	0.9	3	5	0.1	0.7	0.7	0.2	7	3,090	0.16
1967	3	17	0.7	5	9	0.2	0.5	0.5	0.9	3	13,300	1.03
1968	1	5	0.6	3	4	0.03	0.3	0.3	0.3	1	9,690	0.04
1969	1	2	0.3	3.1	5	0.02	0.2	0.2	0.5	1	12,200	0.20
1970	2	1	0.3	3.9	5	0.06	0.02	0.02	0.3	1	9,470	0.40
1971	1	0.5	0.2	3.4	3	0.05	0.01	0.01	0.2	1	8,950	0.05
1972	2	0.5	N.A.[c]	6.5	5	0.03	0.01	0.01	0.3	1	10,680	0.07
1973	2	0.7		6.7	N.A.[c]	0.02	0.05	0.05	0.5	1	15,000	0.08
1974	1	0.2		6.0		0.02	0.02	0.02	0.2	0.6	8,630	0.02
1975	0.6	0.3		7.2		N.A.[c]	N.A.[c]	N.A.[c]	0.3	0.5	11,100	0.02
1976	0.2	0.2		4.5					0.03	0.9	7,420	0.01
1977	0.2	0.2		2.7					0.03	0.4	6,250	0.03
1978	0.3	0.2		2.0					0.04	0.4	6,290	0.03
1979	0.2	0.1		2.4					0.04	0.4	7,700	0.03
1980	0.6	0.0		1.5					0.04	0.4	4,554	0.04
1981	0.2	0.1		1.5					0.04	0.4	2,876	0.04
1982	1.4	0.2		2.7					0.06	1.0	5,370	0.03
1983	1.5			2.5					0.08	0.4	6,090	0.06
TOTAL	691	6932	11.3	1189	1295	342	375	287	175	323	121,670	5.16

NOTE: To convert curies (Ci) to becquerels (Bq), multiply curies by 3.7×10^{10}.

[a] Total rare earths minus cerium.
[b] Transuranium nuclides.
[c] No analysis performed.

SOURCE: Adapted from ORNL, 1983; Oakes et al., 1982b; Coobs, 1983a.

assessments of deteriorating or improving conditions on the reservation and as a departure point for seeking the reasons for changing conditions. The most complete evaluations of radionuclide migration in White Oak Creek, White Oak Lake, and past White Oak Dam are provided in Oakes et al. (1982a) and Boyle et al. (1982).

Although better quality data from the station at White Oak Dam would be desirable, analysis of the trends in the data in Table 6-6 shows how total annual releases have served to identify positive as well as negative influences on radionuclide release rates. The dramatic decrease from 1960 to 1962 in the amounts of ^{137}Cs, ^{60}Co, and ^{131}I and of ^{90}Sr (Table 6-6) flowing past White Oak Dam serves to show the success of improved treatment procedures for liquid process waste (J.H. Coobs, ORNL, personal communication, November 14, 1983). The amount of ^{90}Sr discharged past the White Oak Dam station and White Oak Creek station 3 (Figure 6-3) (which includes only post-1963 releases for reasons of scale) shows the effect of increasing seepage from burial ground 4, waste transfer line leakage (1971 to 1974), releases from unmonitored sources between stations 2 and 3, and a small increase in ^{90}Sr from the process waste treatment plant (station 1, the waste basin station). The effect of efforts to mitigate the seepage is shown by the decrease in concentrations at White Oak Creek (station 3) beginning in 1975; further improvements in process treatment are shown by the decrease in ^{90}Sr released from the waste basin station beginning in 1975. Seepage from burial ground 5 is demonstrated by the sharp increase in the amount of ^{3}H released beginning in 1966, with gradual diminution as the source decayed and remedial actions were taken; the periodic "spikes" (1967, 1969, 1973, 1975, 1979, and 1983) do not appear to correlate with increased rainfall and remain unexplained. The spikes in the amount of TRU discharged as liquid are apparently due to seepage from waste trenches and/or waste transfer pipes during a period of development and fabrication of auxiliary power sources using ^{242}Cm and ^{244}Cm, possibly augmented by leaks in waste transfer lines from the Homogeneous Reactor Facility, the Molten Salt Reactor Experiment, and the TRU facility (J.H. Coobs, ORNL, personal communication, n.d.).

Average annual concentrations at White Oak Dam, where the effluents actually leave the controlled area, have ranged since 1974 from approximately 50 to 250 percent of the DOE concentration guide for water (CG_w) (Figure 6-4), with ^{90}Sr contributing about half the total (Boyle et al., 1982). Continuous time-proportional samples collected from the embayment below White Oak Dam at the confluence of White Oak Creek and the Clinch River (Figure 6-1) indicate that the average annual total concentration in the embayment is approximately 30 percent of that at the dam (Boyle et al., 1982), but specific radionuclide concentrations may differ from that value. Concentrations of ^{90}Sr measured at confluence stations during 1982 and 1983 were found by ORNL to be 33 percent of the concentrations at White Oak Dam for each year.

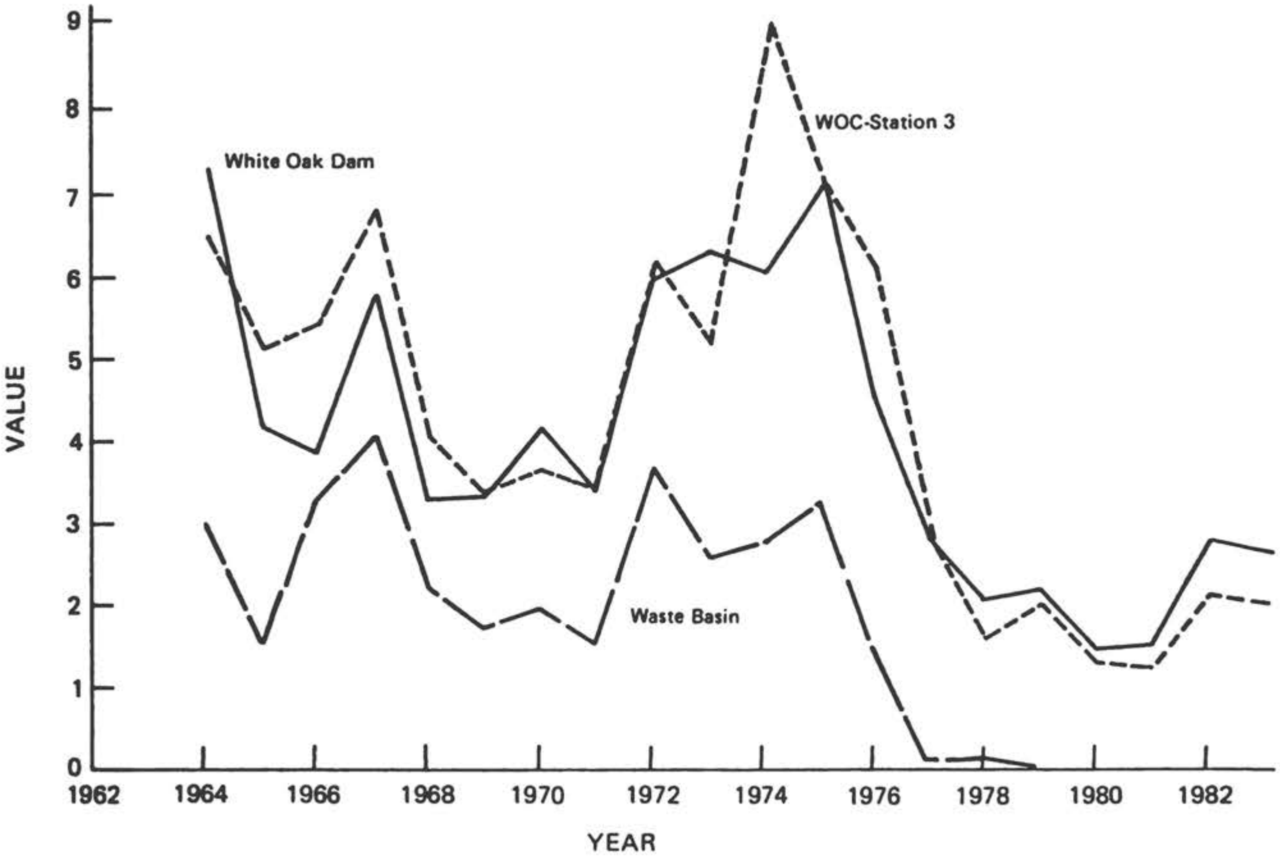

FIGURE 6-3 Total curies discharged per year (^{90}Sr). SOURCE: J.H. Coobs, ORNL, personal communication, November 14, 1983.

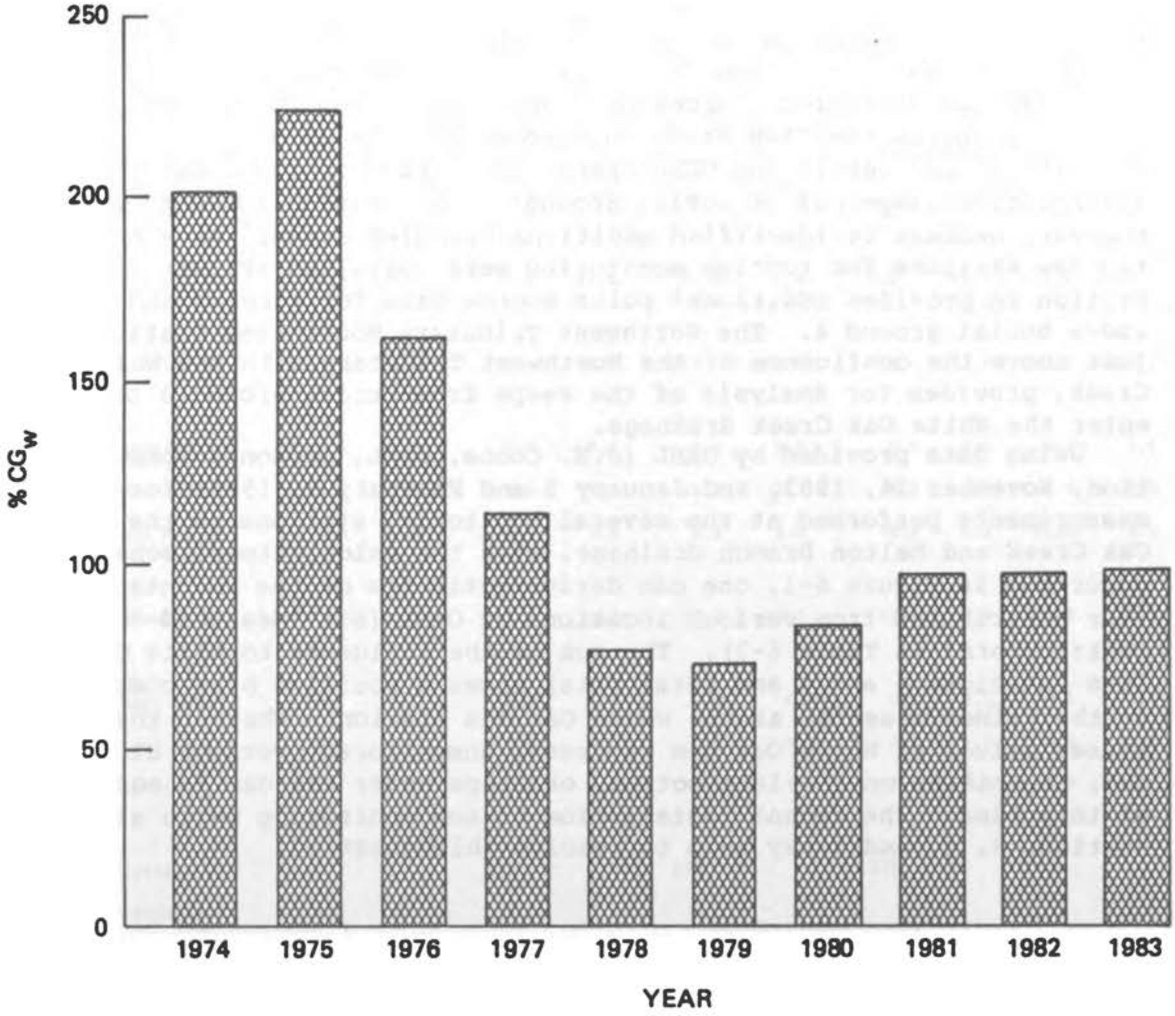

FIGURE 6-4 Percent of total CG_W over White Oak Dam. SOURCE: Adapted from ORNL DWG 79-8857AR2.

Upstream Monitoring Stations

Using the difference method, contaminant levels from burial ground 4 have been estimated by subtracting the influent quantities (stations 1 and 2 and the supplemental samples) from the quantities measured at station 3. When this method was used to evaluate the success of remedial action on burial ground 4 to curb ^{90}Sr effluents, it was found to be inaccurate (Tamura et al., 1980) due to influent from other previously unidentified sources of ^{90}Sr--mostly from the contaminated floodplain below the 7500 Bridge upstream from burial ground 4 and some unmonitored sources in the ORNL operations area and, to a lesser extent, from seeps out of burial ground 3. The evaluation was useful, however, because it identified additional problem areas. As a result, two new stations for routine monitoring were installed (Figure 6-1). Station 2A provides additional point source data for streams and seeps above burial ground 4. The Northwest Tributary Monitoring Station, just above the confluence of the Northwest Tributary with the White Oak Creek, provides for analysis of the seeps from burial ground 3 that enter the White Oak Creek drainage.

Using data provided by ORNL (J.H. Coobs, ORNL, personal communication, November 14, 1983, and January 5 and February 8, 1984) for measurements performed at the several monitoring stations on the White Oak Creek and Melton Branch drainage, with the calculational scheme described in Figure 6-1, one can derive estimates of the amounts of ^{90}Sr contributed from various locations at ORNL (see "Measured Contributors" in Table 6-7). The sum of the influents to White Oak Lake (stations 3 and 4 and total pits) shows a positive bias compared to the values measured at the White Oak Dam station. Whether the lesser values at White Oak Dam represent unmonitored overflow at the dam, deposition on the lake bottom, or seeps under the dam is not clear at this time. The recent installation of new monitoring weirs at stations 3, 4, and 5 may help to resolve this question.

Offsite Monitoring Network

Radionuclide concentrations in the Clinch River are measured in samples collected during 1982 from Melton Hill Reservoir (C-2), K-25 intake (C-3), Kingston Water Plant (C-5), and White Oak Creek outfall (W-1) and are reported both in the ORNL annual ISAHPD Reports and in the ORNL Environmental Monitoring Reports. Because ORNL changed its method of calculating radionuclide concentrations in the offsite samples, comparison of offsite annual trends to those of discharges over White Oak Dam is not possible. As more data are developed by ORNL, perhaps meaningful comparisons can be made.

Special Studies

Safety assessments performed by ORNL rely primarily on data from the routine monitoring networks described previously. However, several

TABLE 6-7 Contribution of ^{90}Sr from Various ORNL Areas

	1979		1980		1981		1982		1983	
Area	mCi/mo	Percent[a]	mCi/mo	Percent[a]	mCi/mo	Percent[a]	mCi/mo	Percent[a]	mCi/mo	Percent[a]
Measured Contributors										
Measured flume	14.9	6.3	10.1	6.1	12.9	10.6	12.5	5.4	10.2	4.0
Measured 190 ponds	1.0	0.4	2.4	1.4	0.4	0.3	0.2	0.1	0.2	0.1
Measured process waste	2.9	1.2	1.9	1.1	2.7	2.2	0.5	0.2	0.3	0.1
Measured STP	11.4	4.8	15.1	9.1	18.1	14.8	36.3	15.7	19.9	7.9
(Sum) ORNL operations	30.2	12.7	29.5	17.7	34.1	27.9	49.5	21.4	30.6	12.1
Measured station 2A	70.0	29.7	77.0	46.4	71.9	58.9	115	49.8	84.6	33.4
Measured station 3	169	71.5	108	65.1	103	84.4	178	77.1	167	66.0
Measured HFIR/TRU	0.2	0.1	0.2	0.1	0.3	0.3	0.9	0.4	6.1	2.4
Measured MSPP/MSRE	6.6	2.8	4.8	2.9	3.3	2.7	9.0	3.9	4.9	1.9
(Sum) Melton Branch	6.8	2.9	5.0	3.0	3.6	3.0	9.9	4.3	11.0	4.3
Measured station 4	67.3	28.5	51.8	31.2	17.2	14.1	49.7	21.5	82.3	32.5
Measured East Weir	NA		0.3	0.2	1.0	0.8	0.1	0.1	0.1	0.1
Measured West Weir	NA		5.9	3.6	1.0	0.8	3.1	1.3	3.6	1.4
(Sum) Total pits			6.2	3.8	2.0	1.6	3.2	1.4	3.7	1.5
Total effluents (Sum of Station 3, Station 4, and pits)	236		166		122		231		253	
Measured White Oak Dam station	200		125		123		225		208	
Inferred Contributors										
Burial grounds 1, 3 and floodplain (station 2A, minus ORNL operations)	40	17	48	30	38	31	66	29	54	22
Burial ground 4 (3 minus 2A)	99	42	31	20	31	26	63	28	82	33
Burial ground 5 (4 minus Melton Branch)	60	26	47	29	14	11	40	18	71	29
Total	199	85	126	79	83	68	169	75	207	84

[a] Percent of total effluents.

SOURCE: Developed from J.H. Coobs, ORNL, personal communications, November 14, 1983, and January 5 and February 8, 1984.

special studies have been performed to better define sources of contamination within the White Oak Creek drainage. Most of these are summarized in the Environmental Sciences Division Annual Progress Reports (see, for example, Section 9 of Auerbach et al., 1980; Section 5 of Auerbach et al., 1981; and Section 5 of Auerbach et al., 1983).

Some of these studies are relatively straightforward field measurement programs, such as the survey of the intermediate-level waste (ILW) pipeline to the hydrofracture facility--which resulted in the discovery of a contaminated floodplain on White Oak Creek resulting from a leak in the ILW pipe (Ohnesorge et al., 1981). Others are more complex.

The association of ^{90}Sr, ^{60}Co, and ^{137}Cs with streambed sediments (Cerling and Spalding, 1981, 1982; Spalding and Cerling, 1979) provides a particularly sensitive method of identifying specific sources of radionuclides (Figures 6-5, 6-6, and 6-7). But the greatest concentrations indicated in the figures do not necessarily indicate high discharge rates at those locations; high concentrations serve primarily to show locations where contamination begins. The ^{90}Sr and ^{60}Co (to a lesser degree) associate with the solid phase by ion exchange processes, but the ^{137}Cs forms a compound with one mineral constituent that is stable until the solid phase is destroyed. Thus, the concentrations of ^{90}Sr and ^{60}Co are roughly proportional (via their respective distribution coefficients) to their concentrations in ambient waters, but the ^{137}Cs concentrations in the sediments can be used only to identify sources of contamination. If conditions remain the same, the ^{90}Sr and, to a lesser degree, ^{60}Co concentrations measured in the sediments and watershed areas can be used to estimate the relative magnitude of each source (Cerling and Spalding, 1981, 1982). From these measurements, Cerling and Spalding estimate that burial grounds 3, 4, 5, and 6, contributed approximately 3, 33, 20, and 5 percent, respectively, of the discharges of ^{90}Sr in 1978-1979.

Another example is the development of concentration profiles (Duguid, 1975; Stueber et al., 1978, 1981; Tamura et al., 1980; Huff et al., 1982; Lasher and Scott, 1983) from measurements of radionuclide concentrations in water collected at various of the previously described sampling stations and from specially installed monitors. Such profiles have produced many of the data for studies leading to corrective actions, especially at burial ground 4. These studies (McClain and Myers, 1970; Duguid, 1975; Webster, 1976; Tamura et al., 1980; Huff et al., 1982; Olsen et al., 1983) have been particularly successful in locating major radionuclide sources (seeps) within a broadly contaminated land area, they also led to identification of the contaminated floodplain downgradient from burial ground 4, and have provided early indications of downgradient radionuclide migration.

Studies of radionuclide deposits in White Oak Lake and the White Oak Creek embayment, as well as sediment transport past White Oak Dam, are summarized in Oakes et al. (1982a). The same report provides a detailed evaluation of the several pathways for the exposure of plants, algae, fish, insects, and animals to radioactive material from water and sediments in the White Oak Lake/White Oak Creek drainage. A report

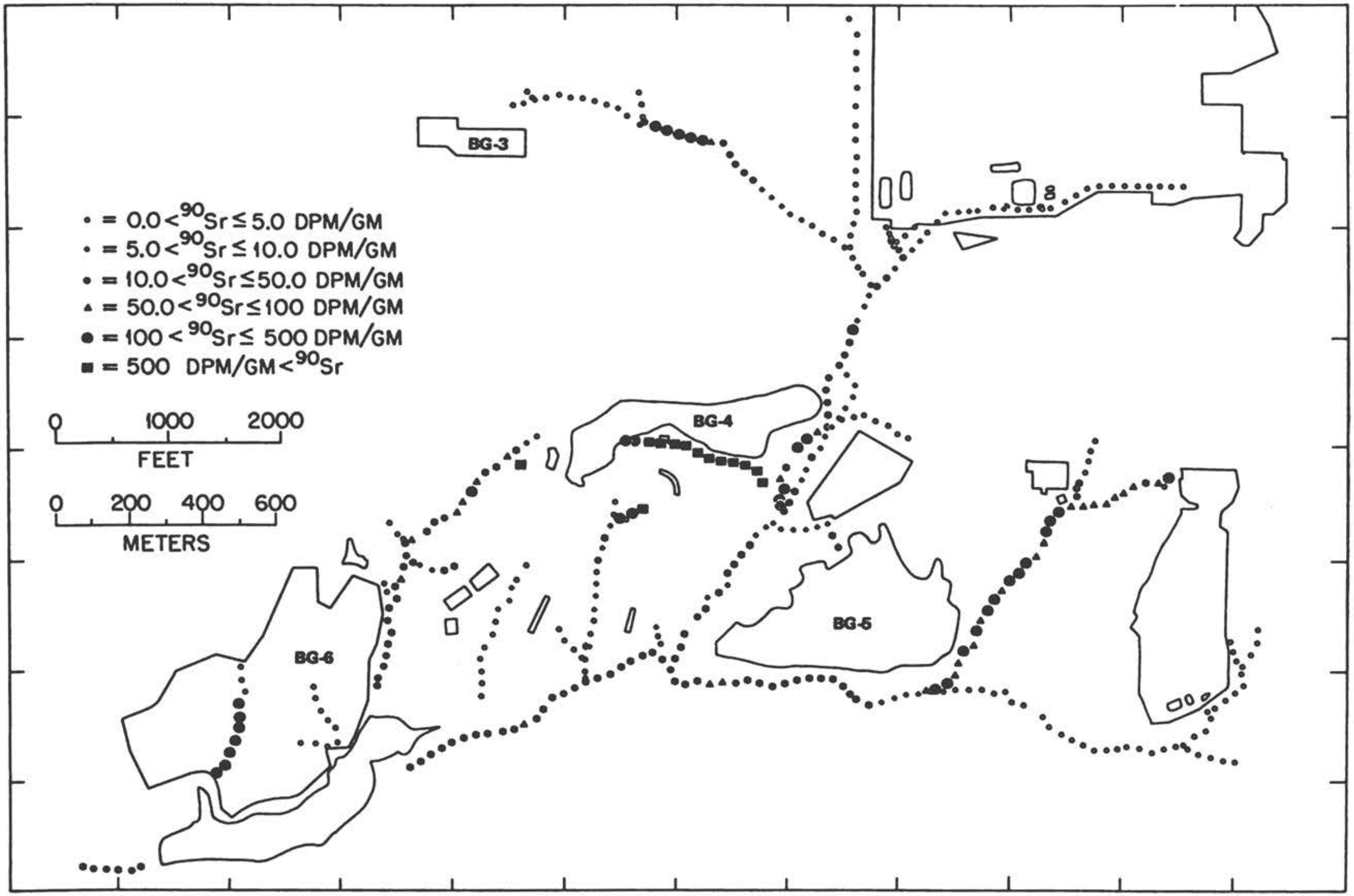

FIGURE 6-5 Areal distribution of ^{90}Sr activity in streambed gravels of the White Oak Creek watershed, expressed in disintegrations per minute per gram. SOURCE: Cerling and Spalding, 1981.

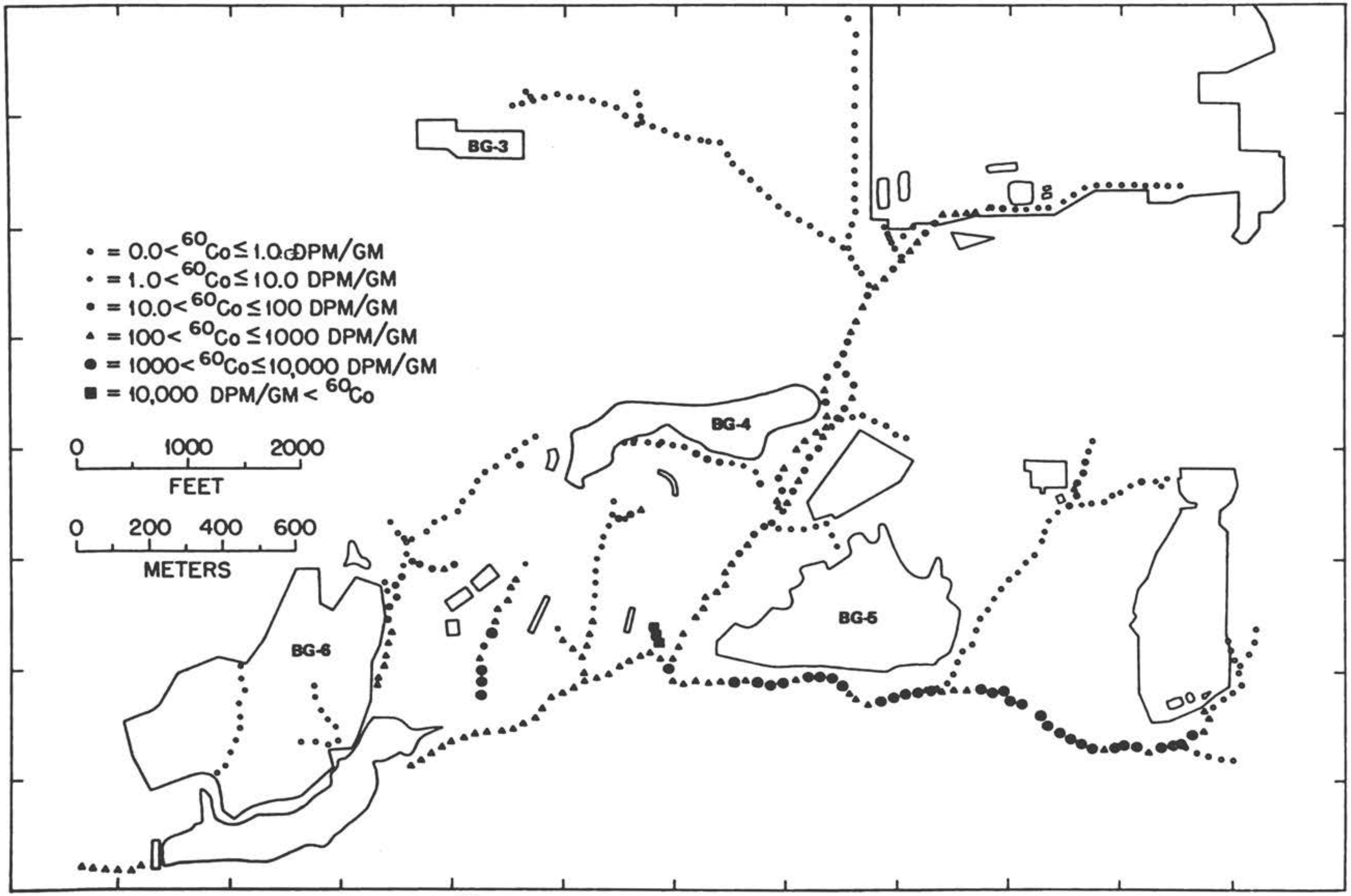

FIGURE 6-6 Areal distribution of ^{60}Co activity in streambed gravels of the White Oak Creek watershed. SOURCE: Cerling and Spalding, 1981.

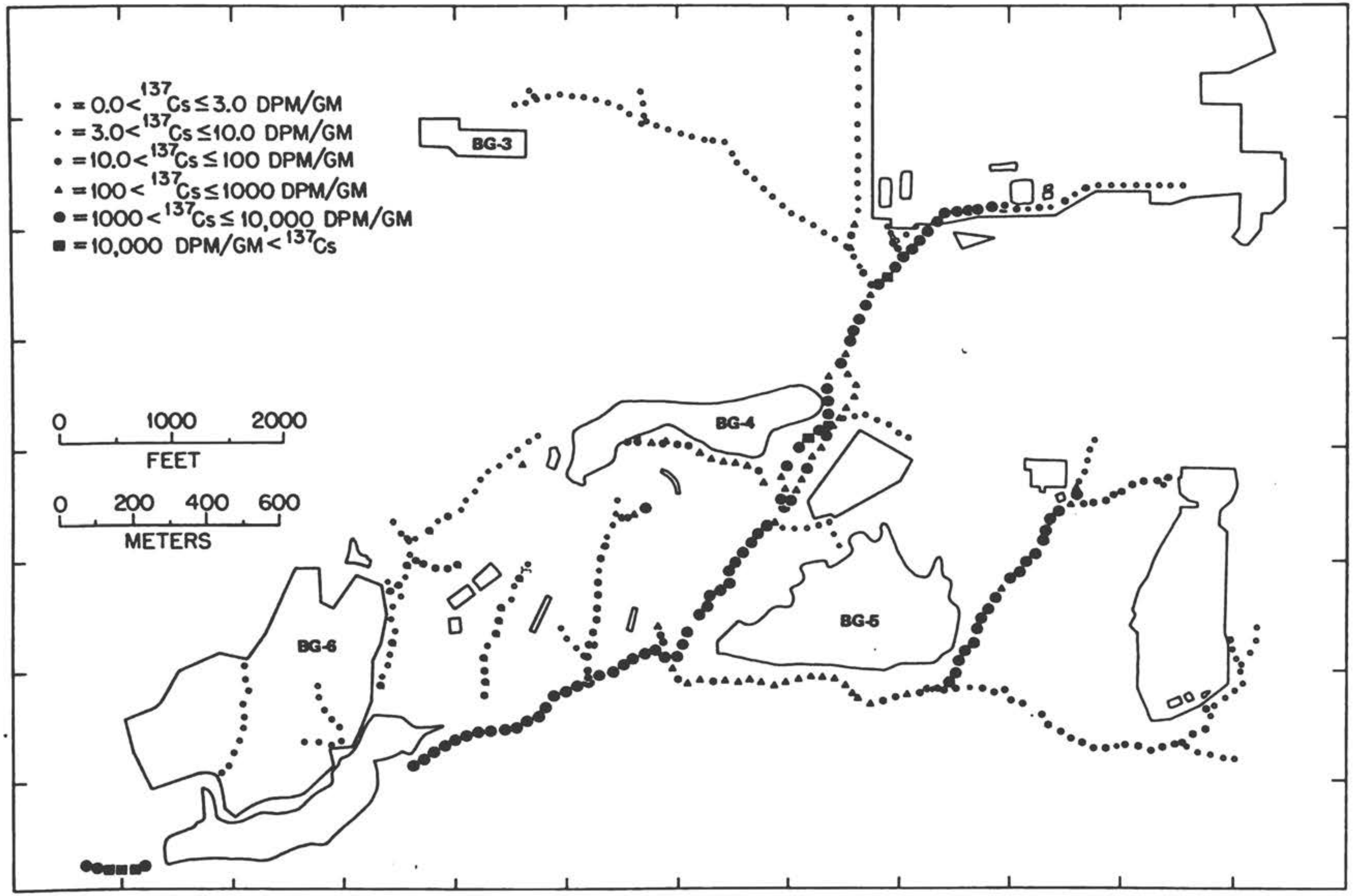

FIGURE 6-7 Areal distribution of ^{137}Cs activity in streambed gravels of the White Oak Creek watershed.
SOURCE: Cerling and Spalding, 1981.

(Oakes et al., 1982b) on Clinch River sediment deposits includes data from several early studies, as well as more recent measurements.

Groundwater Monitoring

In the past, groundwater monitoring has been sporadic, and full use was not made of the potential information. Recently, ORNL has become aware of the need for using a more comprehensive regular groundwater monitoring program. The panel has been provided with printouts from ORNL's data base system (J.H. Coobs, ORNL, personal communications, November 14 and December 8, 1983, and January 5 and 27 and February 8, 1984), which include radionuclide concentrations for samples collected from approximately 100 wells in and around the sites of the ILW pits and trenches and burial grounds 3, 4, 5, and 6. Summaries of groundwater data are now being reported (Martin Marietta, 1984).

MONITORING TO VALIDATE MODELING

Additional or more frequent monitoring has been recommended by the panel in several parts of the report, and the panel recognizes the need to describe how the route from release to human exposure can be estimated more accurately. Monitoring is a means of assuring present compliance with that which is permissible.

Over many years, ORNL has developed models that have the capability of being applied to attain additional understanding of burial ground behavior. In some instances, monitoring data would be useful in validating these models. The events already taking place at ORNL could be treated as an experiment directed toward model validation. It may be possible to set up a monitoring/modeling scheme that will yield helpful information in a relatively short time.

Designing such a modeling approach is beyond the charter and resources of this panel. ORNL should determine what measurements can be made over the next 5 years that would allow estimation of leakage in the future from the existing burial grounds, what form the leakage will take, and how fast the various radionuclides will move.

CONCLUSIONS

Groundwater flow in the White Oak drainage basin at ORNL is primarily confined to the near surface (Webster, 1976). Because of this, the combination of surface water and groundwater monitoring that is now in operation is adequate to determine releases to the White Oak drainage basin above White Oak Dam from both ORNL operations and the buried waste, with the exception that seepage under White Oak Dam is not measured.

1. The present method of estimating how much radioactive material is being discharged to the Clinch River either by seepage under White Oak Dam or by burial ground 3 leakage to Raccoon Creek is inadequate.
2. The present monitoring network fails to monitor onsite and offsite concentrations of ^3H in air.
3. Measurements of radionuclide concentrations in air onsite are not reported.
4. Detailed groundwater monitoring data are not reported. They should be included in the ORNL Environmental Monitoring Reports.
5. Spalding (1983) noted a spike in ^{90}Sr on a seep along Melton Branch below the old hydrofracture site--that should be identified and its contribution to the monitoring station 4 readings should be estimated.

RECOMMENDATIONS

1. ORNL should develop modeling programs that will use geologic, hydrologic, and geochemical test results as well as other pertinent monitoring data to predict the migration of leachate from radioactive waste.
2. A better estimate of the migration of leachate from radionuclides to the Clinch River by seepage under White Oak Dam and by leakage from burial ground 3 to Raccoon Creek should be developed.
3. The air monitoring system should be upgraded to include onsite and offsite measurements of ^3H in air.
4. ORNL should continue to seek out, investigate, and, where possible, quantitate sources of radionuclides in White Oak Creek and its tributaries.

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7

Regulation of Radiation Exposure in the United States

The purposes of managing radioactive waste are (1) to limit exposures of workers on site to acceptable levels, (2) to limit the amounts of radionuclides migrating offsite to acceptable levels, and (3) to maintain both of these levels as low as reasonably achievable (ALARA). Whether or not one considers the waste management operations at ORNL to be acceptable depends on the criteria against which the measurements and calculations are compared. Clearly, the routine offsite effluents from ORNL waste operations do not present a health hazard, i.e., there is no apparent condition that might lead to nonstochastic effects or a high probability of stochastic effects--serious risks of harm. However, it is also necessary to prove compliance with regulatory limits of radiation exposure that are well below those known to cause immediate harm or a high probability of late effects. Unfortunately, the criteria that now apply to waste operations at ORNL, and those likely to apply in the near future, are so diverse in the numerical limits and guidance that a clear-cut answer as to long-term compliance cannot be obtained as easily as the absence of a hazard can be determined.

The setting of generally applicable environmental radiation standards in the United States is the responsibility of the U.S. Environmental Protection Agency (EPA). The U.S. Nuclear Regulatory Commission (U.S. NRC) is responsible for developing criteria that, if followed, will assure that EPA standards are met for those activities licensed under the Atomic Energy Act of 1954, while the U.S. Department of Energy (DOE) is responsible for implementation and enforcement of some, but not all, EPA standards for those activities conducted at its own, usually contractor-operated, facilities.

Limits on radionuclide concentrations in air and water and, more recently, annual limits on intake have been formulated to prevent accumulation of hazardous amounts of radionuclides in the bodies of workers and the public. The conceptual bases and methods of calculating radionuclide limits are contained in recommendations of the International Commission on Radiological Protection (ICRP) (ICRP, 1959, 1977, 1979), and specific limits for occupational exposure have been adopted (ICRP, 1979). Similar limits have been recommended by the National Council on Radiation Protection and Measurements (NCRP) for use in the United States.

While federal agencies usually consider recommendations of the ICRP and the NCRP, none is obligated to adopt those recommendations, nor until recently has DOE been obligated to implement EPA's standards; only through recent congressional action (e.g., the Clean Air Act of 1977) has DOE been required to adhere to certain EPA standards. In the material that follows, both currently applicable standards and regulations and those that may become factors in the ORNL waste management program are discussed.

Typically, safety assessments outside the work place are based upon either a calculated dose to the whole body or separate organs of a maximally exposed individual in the general population (most often hypothetical) or a calculated collective dose commitment (expressed as person-rem). The latter, the collective dose commitment to a large population segment, is calculated as the sum of individual dose commitments to the number of people affected. Criteria do not exist, however, for determining whether the values of collective dose that are calculated are acceptable. Key implementation guidance has not been promulgated; for example, the size of the population group to be considered at risk is not specified. As a result, because population doses are proportional to the number of people included in the calculation, release of a given quantity of radioactive materials will yield different collective doses depending upon the population postulated to be affected and, therefore, the acceptability of the release cannot be finally determined.

For the purposes of this report, the panel has made its assessment solely on the basis of doses to individual members of the public.

DOE ORDERS

DOE requirements are in flux; the DOE orders referred to in the following discussion are current as of December 1984--there may be changes in the near future.

Specific limits on radiation exposures to the public from ORNL operations are now embodied in DOE Order 5480.1A (U.S. DOE, 1981a)--in the past, AEC, ERDA, and DOE operations manuals incorporated limits as part of their Appendix 5024, Annex A. DOE Order 5480.1A is being revised (A.F. Kluk, U.S. DOE, personal communication, 1984); the revised version will be referred to below as Order 5480.1A (Rev.).

Both occupational and nonoccupational exposure limits, developed from ICRP and NCRP occupational exposure limits, are used in DOE Order 5480.1A. The order includes a table of concentration guides that is used extensively by ORNL in its data reports; that table provides the basis for most of the data interpretation in the report of this panel. Concentration guides (CG_a and CG_w) have been used in ORNL data assessments to represent the equivalent of an annual-average whole-body dose rate of 5000 mrem/yr for the occupationally exposed or 500 mrem/yr for the nonoccupationally exposed individual.

DOE Order 5480.1A (Rev.) is, however, expected to be more restrictive. The new regulations still limit dose to an offsite individual to 500 mrem in any one year, but also require that exposure of an individual to <u>continuing</u> releases be limited to 100 mrem/yr. These exposure limits are expected to apply to an actual person rather than to a hypothetical individual. However, for reporting purposes, the offsite reference point at ORNL is likely to be at White Oak Dam. Further guidance under Order 5484.1 (U.S. DOE, 1981b), which is also under revision, is expected to address such issues as the reference points for dose calculations, conversion factors for obtaining dose values from intake estimates, and specific models acceptable to DOE for transport calculations and dose estimates. Regardless of the specific limits set by Order 5480.1A (Rev.), DOE expects that each facility will implement an ALARA program (A.F. Kluk, U.S. DOE, personal communication, 1984).

DOE Order 5820.2, Radioactive Waste Management (U.S. DOE, 1984), has been issued, but it does not provide specific limits for radionuclide concentrations in effluents. A new 5480.4 will be the applicable DOE order. In addition to dose limits, DOE Order 5480.4 is expected to provide guidance as follows:

> In instances where both DOE and non-DOE Environmental Safety and Health standards are applicable and mandatory, and there are conflicts between such standards, the ES&H standards providing greater protection shall govern. Similarly where there are conflicts between the mandatory ES&H standards of this Order, or between those of this Order and other DOE Orders or requirements, the mandatory ES&H standards or requirements providing the greater protection shall govern.

ORNL is seeking guidance on the interpretation of this new order. Depending on the extent to which EPA standards apply from the above, discharge limits at ORNL could become even more restrictive than those developed from the 100-mrem/yr mandatory limit of DOE Order 5480.1A.

DOE has also issued Order 5480.2, Hazardous and Radioactive Mixed Waste Management (U.S. DOE, 1982), which is intended to provide guidance for disposal of mixed waste; however, Order 5480.2 merely states that DOE Orders (e.g., U.S. DOE, 1983a) and EPA's RCRA requirements (40 CFR Parts 261-265) all apply; it provides little in the way of operational guidance.

EPA STANDARDS

The EPA standards that will influence most of ORNL's radioactive waste management operations, because of specific congressional mandates that they apply to DOE and contractor facilities, are 40 CFR Part 191, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; 40 CFR Part 61, National Emission Standards for Hazardous Air Pollutants (Clean Air Act); and 40 CFR Part 193, Environmental Radiation Protection Standards for Low-Level Radioactive Waste Disposal (Proposed). Although 40 CFR 61 was available to the panel in draft form, 40 CFR Parts 191 and 193 were not. EPA subsequently withdrew the radiation limits of 40

CFR Part 61 but, when faced with a court order to promulgate some standards, chose to substitute a 2.5-fold less restrictive set of standards than those originally proposed in Part 61 (25 and 75 in place of 10 and 30 mrem/yr to the whole-body and lung, respectively). Several environmental activist groups have sued to have the original standards reinstated. EPA has not, as yet, completed even a preliminary draft of 40 CFR Part 193.

Other EPA radiation standards that, because of extensive use by EPA, most states, and/or the U.S. NRC, also appear likely to influence ORNL operations are 40 CFR Part 141, National Interim Primary Drinking Water Regulations; and 40 CFR Part 190, Environmental Radiation Protection Standards for Nuclear Power Operations. These have both been issued in final form and appear in the 40 CFR series of regulations. The most restrictive of the published EPA requirements appear to be as follows: the limit of lung and bone doses, respectively, of 1 and 3 mrad/yr, 40 CFR Part 192; the limit of whole-body dose equivalent of 4 mrem/yr, 40 CFR Part 141; and the originally proposed limits for whole-body and lung dose of 10 and 30 mrem/yr, respectively, 40 CFR Part 61. How each and all of these are to be interpreted within DOE Order 5480.4 remains to be seen.

Finally, the Resource Conservation and Recovery Act of 1976 (RCRA) Public Law 94-580, calls for EPA to develop radiation standards for naturally occurring and accelerator-produced radioactive materials, but none have yet been promulgated. However, RCRA standards for nonradioactive waste, and standards being developed by EPA for control of toxic substances, for control of pollutants discharged to water systems, and for so-called "Superfund" action may influence the choice of options available for management of comingled wastes, i.e., mixtures of toxic-chemical and radioactive wastes.

Although the standards developed by ICRP and NCRP are risk-based, both organizations recommend that all radiation exposures be kept as low as reasonably achievable. This principle has been incorporated into DOE, U.S. NRC, and many state radiation control regulations. More importantly, it has been a prime factor in the development of most EPA radiation standards. Under EPA's approach, a standard is determined by the minimum dose levels attainable using current technology, with consideration given to estimated costs associated with various candidate technologies. The problem is that, since the definition of "reasonably achievable" is highly subjective, the validity of standards based upon dose levels derived from the ALARA principle can be subject to honest differences of opinion and result in extensive--and inherently inconclusive--debate, similar to that which led eventually to EPA's withdrawal of the radiation limits in the original version of 40 CFR Part 61.

As a result of this problem, dose limits set forth in regulations that meet the several EPA standards for the regulation of radioactive materials in the environment vary by a factor of nearly 10^3; some of these exceed the DOE regulatory guides by more than a factor of 10.

Regardless of the inconsistencies in the numerical values of the applicable and potentially applicable limits, it appears that ORNL may still find it necessary to meet airborne-radionuclide limits (original version of 40 CFR Part 61) equivalent to the 10-mrem/yr whole-body rate and the 30-mrem/yr organ dose rates as well as some yet undeveloped, but equally low, limits (40 CFR Part 193) for liquid releases and external radiation levels from the waste sites used for the disposal of low-level radioactive material.

U.S. NRC REGULATIONS

Several shallow-land burial sites for low-level radioactive waste are likely to be developed in the United States. The performance of these sites must conform to U.S. NRC Requirements for Land Disposal of Radioactive Waste, 10 CFR Part 61. It is likely that DOE and ORNL will be urged to accept dose and concentration limits and a waste classification system consistent with those in 10 CFR Part 61. If so, the U.S. NRC limits of 25 mrem/yr whole-body and 75 mrem/yr organ dose as a postclosure dose to an individual member of the public are likely to be extended to DOE and contractor facilities.

ACTIONS BY THE STATE OF TENNESSEE

A recent "Notice of Non-Compliance" under the Water Quality Control Act of the State of Tennessee is an immediate outfall of one of the new EPA regulations, 40 CFR Part 122, National Pollutant Discharge Elimination System.

An example of the diversity of opinion on what is or is not a "reasonable" choice of limits may be seen in the use by ORNL of the 500-mrem equivalent CG_w values for the purpose of evaluating effluent concentrations at the water intakes of the ORGDP and the city of Kingston, while the state of Tennessee and EPA go to the opposite extreme by attempting to enforce drinking water guidelines of 4 mrem/yr for each of the small groundwater seeps onsite at the burial grounds. It does seem appropriate for ORNL to apply the EPA limits for water supplies at Kingston, and at ORGDP if Clinch River water is used there for drinking purposes. Although the limits of 40 CFR Part 141 are currently to be implemented at the first real water tap of the public water supply system (i.e., credit is given for water treatment, sediment settling, and/or radionuclide decay), ORNL may wish to consider that future implementing regulations could change the applicable location to one that is more restrictive.

NOTE: Since the panel prepared this section of the report, ORNL has been required to meet the requirements of RCRA.

CONCLUSION

The regulatory criteria that now apply and those likely to apply in the future are diverse. An example of change is the recent application of the Resource Conservation and Recovery Act (RCRA) to ORNL.

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8

Effectiveness of ORNL Waste Management Practices

For the most part, the discussion in this chapter is presented in the context of radiation exposure, expressed either as dose rate (usually millirems per year) or percentage of a regulatory concentration guide for air (CG_a) or water (CG_w).

The panel's safety assessment depends almost entirely on data and calculations provided by ORNL. Except for a few independent ^3H measurements in the Clinch River reported by the U.S. Environmental Protection Agency in their quarterly publication, Environmental Radiation Data, and one set of dose estimates using ORNL data for airborne emissions (U.S. EPA, 1983), the panel did not have the benefit of any completely independent evaluations of ORNL waste management operations.

OFFSITE RADIATION EXPOSURES

Effluents from ORNL waste management systems or facilities result in radiation doses to people living nearby that are very much less than those that produce nonstochastic radiation effects (such exposures would typically be of the order of a few hundred rem, whole-body).

The ORNL radioactive effluents have, for limited time periods, exceeded one or more of the applicable EPA limits. In the present regulatory climate for control of radiation and radioactive materials, exceeding a regulatory limit is often perceived by the public and by some regulators as excessive ipso facto. Any source of effluents that would exceed a currently or potentially applicable standard, even temporarily, deserves consideration by ORNL. The incorporation of ALARA in all recommendations, and regulations limiting radiation exposure, requires that ORNL give continuing attention to the reduction of radiation doses both to workers and to persons offsite.

The methods used at ORNL for dose assessment are described in both the ORNL Annual Environmental Reports and the ORNL Annual Industrial Safety and Applied Health Physics Division (ISAHPD), now Environmental and Occupational Safety Division, Reports.

Table 8-1 provides the potential radiation doses to an adult at the points of highest potential exposure due to gaseous and liquid effluents from the Oak Ridge facilities. Beginning with the results for 1983, ORNL replaced the previously used ICRP Publication 2 recommendations with the new ICRP recommendations (ICRP, 1979) for conversion of radionuclide intake to dose (T. Oakes, ORNL, personal communication, 1984). For that and other reasons discussed below in the section "Composite Dose from the Major Facilities at Oak Ridge," the dose rates tabulated in Table 8-1 are not necessarily comparable from year to year.

MAXIMUM POTENTIAL EXPOSURE

The point of maximum potential exposure at the site boundary ("fence-post" dose) is located along the bank of the Clinch River adjacent to an experimental plot on which ^{137}Cs was distributed. The potential exposure is due, primarily, to "sky shine" from the plot (i.e., reflection of radiation to ground surface). For 1982, a maximum potential whole-body dose of 178 mrem/yr, calculated by ORNL (UCC-ND, 1983) for an individual who was assumed to remain at this point 24 hours a day for the entire year, is 36 percent of the present DOE standard, but may exceed the new limits of DOE order 5480.1A (Rev.) depending on how the new regulation is applied to ORNL. This is an atypical exposure location, and the probability of an exposure of this magnitude is considered remote, since access must be by boat.

The whole-body dose to a "hypothetical maximally exposed individual" at the same location was calculated by ORNL using "a more realistic occupancy time of 240 h/yr." The calculated dose under these conditions was 6.2 mrem/yr, which is well within the allowable DOE standards, present or anticipated, and represents a reasonable upper limit of exposure.

The greatest dose commitments to individuals continuously occupying residences nearest the site boundary would result from inhalation and/or ingestion. Calculated dose commitments for 1982 at the point of maximum inhalation exposure were 16.6 mrem to the lung (as critical organ) and 1.8 mrem to the whole body, the important radionuclides contributing to this dose are ^{234}U and ^{238}U, due mostly to Y-12 Plant discharges. The large error bounds, a factor of 3 in each case, are due to the uncertainties in the meteorological and source-term data and in modeling assumptions; despite the uncertainties, these levels are small fractions of the existing or anticipated DOE standards.

A contribution to dose from radioactive materials in the food chain comes from the atmosphere-pasture-cow-milk pathway. Measurements of the two principal radionuclides entering this pathway, ^{90}Sr and ^{131}I, indicate that, in 1982, the maximum annual dose to an individual in the immediate environs is primarily contributed by ^{90}Sr; assuming ingestion of 1 L/day of milk, the dose from ^{90}Sr is 0.06 mrem to the whole body and 1.2 mrem to the bone. The average concentrations of nuclides at the the remote stations, assumed to be background, were subtracted from the perimeter station data in making the calculations.

TABLE 8-1 Summary of the Estimated Annual Radiation Dose (mrem/yr) to an Adult at Locations of Maximum Exposure

Pathway	Location	1978 Whole Body	1978 Critical Organ	1979 Whole Body	1979 Critical Organ
Gaseous effluents					
Inhalation plus direct radiation from air and ground	Nearest resident to site boundary	0.14 ± 150%	1.0 ± 150% (lung)	0.5	5.1 (lung)
Terrestrial food chains	Milk-sampling stations	0.21	10.3 (bone-^{90}Sr)	0.2	7.3 (bone-^{90}Sr)
Liquid effluents					
Aquatic food chains	Clinch-Tennessee River system	13.6	34.5 (liver-^{137}Cs)	0.7	35 (bone-^{90}Sr)
Drinking water[a]	Kingston, Tennessee	0.0002	0.01 (bone-^{90}Sr)	0.05	2.3 (bone-^{90}Sr)
Direct radiation along water, shores, and mud flats[b]	Downstream from White Oak Creek near experimental Cs field plots	6.7	6.7 (whole body)	6.6	6.6 (whole body)

[a] Based on the analysis of raw (unprocessed) water through 1981 and treated water beginning 1982; assumed consumption of 0.4 L/day through 1980 and 1.0 thereafter.

[b] Assuming a residence time of 240 h/yr.

[c] J.H.Coobs, ORNL, personal communication, 1984.

The public water supply closest to the liquid discharges from the Oak Ridge facilities is located about 26 km (16 mi) downstream at Kingston. Before 1982, samples of raw river water were collected and analyzed; beginning with 1982, treated water was analyzed for dose evaluation. Also, before 1982, the background radionuclide concentrations measured in samples from Melton Hill Lake were subtracted from those measured at Kingston, whereas from 1982 onward the dose attributed to processed drinking water at Kingston was calculated without background correction. All measurements of radionuclide concentrations in processed water at Kingston were less than or equal to background concentrations in samples of untreated water taken from Melton Hill Lake; but the calculated dose at Kingston (shown in Table 8-1) is greater than zero, because no background correction was made. The major radionuclides released to the Clinch River from the ORR are ^{90}Sr, ^{3}H, ^{137}Cs, and ^{60}Co discharged at White Oak Dam from ORNL, and uranium isotopes released to Bear Creek from the Y-12 Plant. Ninety-five percent of CG_w in the Clinch River and, therefore, of the contribution to offsite dose is attributable to ORNL effluents (UCC-ND, 1983, 1984).

The 50-year dose commitment was calculated for an adult consuming 17 kg (37 lb) of fish per year, caught at the confluence of White Oak Creek with the Clinch River (Clinch River mile (CRM) 20.8). That amount is about 2.5 times the average national fish consumption and is used because fishing is popular in eastern Tennessee and the highest radionuclide concentrations in whole and edible parts are measured in

1980		1981		1982		1983	
Whole Body	Critical Organ	Whole Body	Critical Organ	Whole Body	Critical Organ	Whole Body	Critical Organ
1.8	16.6 (lung)	0.38	9.2 (lung)	1.8	16.6 (lung)	6.3	21 (lung)
0.02	1.5 (bone-^{90}Sr)	0.02	2.7 (bone-^{90}Sr)	0.06^{c}	1.2^{c} (bone-^{90}Sr)	0.01	0.3 (bone-^{90}Sr)
1.1	53 (bone-^{90}Sr)	4.4^{c}	76 (bone-^{90}Sr, ^{137}Cs)^{c}	5.7^{c}	31^{c} (bone-^{90}Sr)^{c}	1.4	23 (bone-^{90}Sr)
0.15	6.6 (bone-^{90}Sr)	0.22	10.9 (bone-^{90}Sr)	0.15	6.6 (bone-^{90}Sr)	0.13	3.0 (bone-^{90}Sr)
6.2	6.2 (whole body)	5.9	5.9 (whole body)	6.2	6.2 (whole body)	6.8	6.8 (whole body)

SOURCE: Based on tables in UCC-ND, 1980; UCC-ND, 1981; Auxier and Davis, 1981; UCC-ND, 1982; UCC-ND, 1983; and Martin Marietta, 1984.

fish caught at CRM 20.8. The maximum organ dose commitment to an individual due to consumption of edible parts of the bluegills sampled (the most radioactive fish sampled) was calculated to be 31 mrem to the bone from ^{90}Sr. The maximum whole-body dose was calculated to be 5.7 mrem from ^{137}Cs. These doses are small fractions of the DOE guides. Fish taken from above Melton Hill Dam are analyzed to determine background radionuclide concentrations.

Dose to the Population

The average annual whole-body dose to an Oak Ridge resident was reported by ORNL to be 0.44 mrem during 1982, and the maximum potential dose commitment to the lung of an Oak Ridge resident was calculated to be 8.7 mrem (UCC-ND, 1983).

Thermoluminescent dosimeters were used to measure dose rates in 84 residences in the Oak Ridge area; those Oak Ridge residents had a dose equivalent of 78 mR/yr, while the dose equivalent rate for all measured residences outside the Oak Ridge area was 79 mR/yr (Tsakeres et al., 1980). These rates are consistent with natural background radiation.

For perspective, the lifetime (70 year) risk to an individual of death from cancer is approximately 4×10^{-3} due to receiving, each year, the 500-mrem equivalent exposure limit set forth as the annual CG limits in the current (1984) DOE orders. This should be compared with an overall lifetime risk of about 2 x 10^{-1} of dying from cancer. Effluents at DOE's present CG levels have an associated risk level that is therefore a factor of 50 less than the cancer* risk from all sources, while the proposed guides, DOE Order 5480.1A (Rev.), will be a factor of 250 less, even before ALARA controls are applied. If the EPA limits of 10 mrem/yr for gaseous effluents (original version of 40 CFR Part 61) and 4 mrem/yr for man-made radionuclides in drinking water (40 CFR Part 141) are applied, effluents at the regulatory limit have associated risks that are even smaller--3000- and 7000-fold less, respectively--than the ordinary risk of developing a fatal cancer. It should be recognized that the estimates of cancer risk are based on the hypothesis that such low doses will, in fact, cause cancer--a hypothesis that cannot be confirmed by data now available.

Assessment of Atmospheric Emissions

Offsite exposures from atmospheric effluents for the past 6 years of operation at ORNL (Table 8-1) are well below the anticipated DOE standards and, following completion of the new ORNL venting system, they appear to meet ALARA requirements as well. The offsite exposures are 1 to 63 percent and 3 to 70 percent of the proposed but not adopted EPA limits for whole-body and critical-organ dose, respectively (the status of these EPA standards that appeared in the original version of 40 CFR Part 61 is discussed in Chapter 7). Thus, the gaseous emissions from ORNL appear to meet all applicable standards and regulations. The "umbrella" requirements of 40 CFR Part 61 (if reinstated by the courts) may require further control measures wherever they can be most economically applied. See Table 8-2 for a summary of radioactive airborne emissions from all Oak Ridge facilities during 1981.

In an independent analysis of Oak Ridge gaseous effluents emitted during 1981 (U.S. EPA, 1983), the principal dose contributions from the Oak Ridge facilities were reported to be due to ^{234}U and ^{238}U (depleted) from the Y-12 Plant and to ^{3}H, ^{85}Kr, and ^{133}Xe from ORNL. EPA's estimate of the radiation dose rate, in 1981, to the pulmonary tissue of the maximally exposed individual is 49.8 mrem/yr, a value that exceeds the potentially applicable EPA critical-organ limit of 30 mrem/yr, but does not exceed the limit of 75 mrem/yr now in force under 40 CFR Part 61. The weighted sum of all organ dose rates (assumed in the ICRP method of calculating dose to be equivalent to whole-body exposure), 17.3 mrem/yr, exceeds the whole-body dose limit of 10 mrem/yr originally proposed, but not the 25-mrem/yr limit most recently published by EPA. ORNL's estimates (Table 8-1) for 1981 are only 2 percent and 18 percent of the EPA estimates for whole-body and lung dose, respectively.

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*Genetic effects are substantially less than cancer effects (see NRC 1980, the BEIR III report).

TABLE 8-2 Radionuclide Airborne Emissions from Oak Ridge Reservation (Ci/yr)

Radionuclide	ORAU	ORGDP	ORNL	Y-12 Plant	1981 Total
^{14}C	1.2x10^{-3}	--	--	--	1.2x10^{-3}
^{3}H	5.2x10^{-3}	--	1.1x10^{4}	--	1.1x10^{4}
^{125}I	2.5x10^{-4}	--	--	--	2.5x10^{-4}
^{131}I	2.0x10^{-4}	--	6.0x10^{-1}		6.0x10^{-1}
^{85}Kr		25	6.6x10^{3}	--	6.6x10^{3}
^{239}Pu[a]	--	--	7.8x10^{-8}	--	7.8x10^{-8}
^{99}Tc	--	3.6x10^{-2}	--	--	3.6x10^{-2}
^{234}U	--	3.7x10^{-3}	--	1.2x10^{-1}	1.2x10^{-1}
^{235}U	--	1.2x10^{-4}	--	--	1.2x10^{-4}
^{236}U	--	2.4x10^{-5}	--	--	2.4x10^{-5}
^{238}U	--	8.1x10^{-4}	--	4.0x10^{-2}[b]	4.0x10^{-2}[b]
^{133}Xe	2.0x10^{-3}	--	3.2x10^{4}	--	3.2x10^{4}

[a] Reported as "unidentified alpha."
[b] Preliminary estimate.

Assessment of Routinely Released Liquid Effluents

Radionuclide concentrations in liquid effluents released at White Oak Dam now equal the CG_w values (UCC-ND, 1982, 1983; Martin Marietta, 1984). Further downstream, at the confluence of White Oak Creek and the Clinch River, water concentrations are approximately one-third of the DOE limits, but would exceed potentially applicable limits of DOE Order 5480.1A (Rev.) by nearly a factor of 2 and of 40 CFR Part 141 by a factor of 40, if those limits were applied at that point.

Liquid effluents, both those emanating from the process or sewage waste streams and leachates from buried solid or liquid waste, when diluted in the Clinch River, resulted in offsite radionuclide concentrations that are 0.5 to 25 percent of the more restrictive of the DOE standards proposed in Order 5480.1A (Rev.) during the most recent 5-year period (Table 8-1). The concentrations reported annually by ORNL would also meet the potentially applicable and more restrictive standards developed by EPA for drinking water (4 mrem/yr in 40 CFR Part 141) and by U.S. NRC for commercial burial sites (25 mrem/yr in 10 CFR Part 61), but by a much smaller margin.

The conservative calculation by ORNL of the radionuclide concentrations in the Clinch River under no-flow or low-flow conditions could, however, pose compliance problems if more stringent limits are applied; in that event, a revised calculation technique will be required. Figure 8-1 shows the effect of such conservatism, as

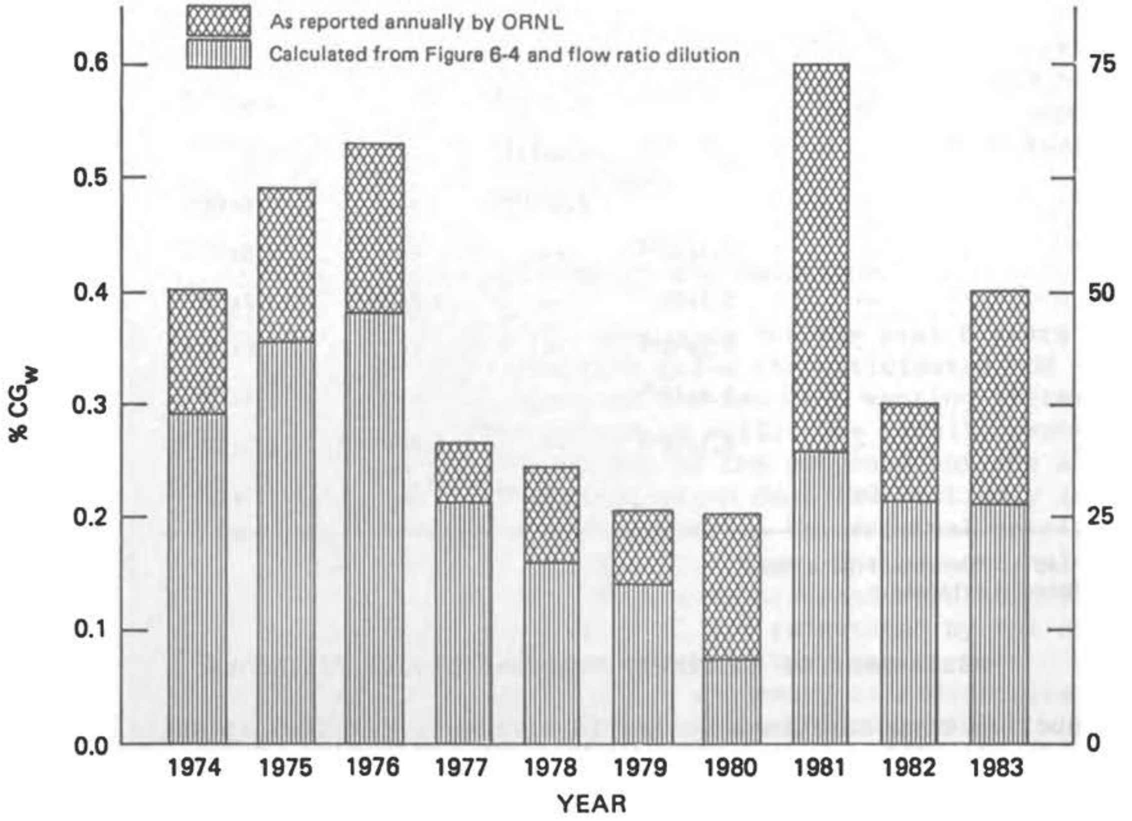

FIGURE 8-1 Clinch River water as percentage of guide (concentration, drinking water) levels. Calculations are based upon measured radionuclide concentrations at White Oak Dam, and Clinch River dilution factors of 688, 646, 423, 537, 481, 511, 1130, 306, 463, and 454 for 1974 to 1983, respectively. SOURCE: Adapted from ORNL drawing 83C-10635.

calculated by the panel, and its relationship to two possible guides, DOE's 500-mrem/yr limit as CG_w and EPA's 4-mrem/yr limit for drinking water; the White Oak Creek to Clinch River dilution factors provided by ORNL for use in the panel calculations for the 10 years from 1974 to 1983 range between 300 and 1100.

No independent calculational analysis was found for the routinely released liquid effluents, so the panel was unable to compare with any others the models and assumptions ORNL used for dose calculations. An attempt was made by the panel to correlate ^{3}HOH concentrations measured independently by ORNL and EPA at the Kingston water intake both with each other and with calculated values based on dilution of White Oak Dam discharge by Clinch River flow. Although the ORNL data are for daily grab samples composited quarterly for analysis while the EPA data are for quarterly grab samples, the respective annual average concentration values for the period 1974 to 1983 agree remarkably well. Both sets of data show periodic fluctuations in ^{3}HOH concentration collected from the Tennessee River at Daisy, some 100 miles downstream from Kingston. Within the uncertainties created by sampling and analysis, the annual average ^{3}HOH concentrations at Daisy from 1974 to 1983 are much the same as those for precipitation samples collected by EPA during the same time period. Although the concentrations at Kingston average approximately fourfold greater than those at Daisy, all are well within EPA's guidelines for drinking water.

Composite Dose from the Major Facilities at Oak Ridge

The composite dose during 1983 from the three major nuclear facilities at Oak Ridge to the maximally exposed individual, provided to the panel by ORNL (W. Ohnesorge, ORNL, personal communication, 1985), was the most current available at the time this section was written.

In addition to the 0.1-mrem whole-body dose contributed by ORNL, the Y-12 Plant and ORGDP contributed 0.63- and 0.03-mrem whole-body doses, respectively. Beginning with 1983, extrapolation from lung dose to whole-body dose is carried out according to ICRP-30 recommendations. It is possible now to equate (through comparable risk) the whole-body dose from gaseous emissions from ORNL, which is primarily from ^{3}H as water vapor, to that for lung dose, which is primarily from ^{234}U and ^{238}U emitted from the Y-12 Plant (W. Ohnesorge, ORNL, personal communication, 1985).

The composite dose to the maximally exposed individual from liquid effluents, for practical purposes, arises entirely from operations at ORNL (J.H. Coobs, ORNL, personal communication, January 5, 1984). The ORNL calculations assume that "liquid effluents (are) not considered an exposure threat" while those from ORGDP are trivially small. Data were not available to the panel to substantiate these calculations.

The cumulative population dose from liquid effluents was 3.9 person-rem, arising entirely from operations at ORNL on the assumptions stated previously.

The cumulative population dose, mostly from airborne emissions, to the 80-km (50-mi) population around ORNL, ORGDP, and the Y-12 Plant was estimated by ORNL to be 120 person-rem for 1983; approximately 82 percent of that value was due to releases from the Y-12 Plant, 15 percent from ORNL, and the remainder from ORGDP (W. Ohnesorge, ORNL, personal communication, 1985). Approximately 25 percent of the collective 80-km population dose from the effluents of the Oak Ridge facilities is estimated to be distributed among the people living in the city of Oak Ridge.

Comparison from year to year of annual values for the cumulative population dose is not possible, because of the changes made by ORNL in plume-dispersion models and the dose-conversion factors used for dose calculations, none of which are documented in the annual reports. For example, the cumulative population doses for the years 1978 through 1983 are 5.6, 5.3, 8.8, 31.5, 50.2, and 120 person-rem, respectively. The nearly fourfold increase from 1980 to 1981 is apparently due to a change in the dispersion model used for 1981 releases as well as to a change in dose-conversion factors (W. Ohnesorge, ORNL, personal communication, 1985). The fourfold increase between 1981 and 1983 is mostly due to the use, for 1983, of ICRP-30 dose-conversion factors. In any event, the cumulative population dose from the Oak Ridge Reservation is inconsequential when compared to the 87,000 person-rem dose to the same population from natural background.

Assessment of Special Conditions

The panel requested that ORNL provide evaluations of the potential annual average doses delivered for three cases not normally considered in annual ORNL monitoring reports--use of Clinch River and/or White Oak Creek water for irrigation, a washout of White Oak Dam, and the dose produced by the 1983 release of ^{131}I to White Oak Creek.

A reference document by the State of Tennessee indicates that no crop irrigation is conducted along the lower reaches of the Clinch River; therefore, there is no resulting dose from this type of activity (J.H. Coobs, ORNL, personal communication, January 5, 1984). ORNL plans, however, to study the problem in more detail.

Catastrophic washout of the water and sediments behind White Oak Dam would produce maximum committed doses of 3 mrem to the whole body and 9 mrem to endosteal cells from drinking the water. Consumption of Clinch River fish exposed to the effluents from the washout would lead to a committed dose of approximately 2 mrem to the whole body, while consumption of fish released from White Oak Lake would result in a dose commitment of 5 mrem to the whole body and 170 mrem to the endosteal cells. If fish bones were not removed, doses to the endosteal cells would be 3 to 30 times greater--with lesser increases in the whole-body doses.

The accidental release of ^{131}I during August 1983 was 19 percent of CG_w for the 5 or 6 days during which it occurred, and resulted in total dose of approximately 1.5 mrem to the thyroid of the hypothetical maximally exposed individual (T. Oakes, ORNL, personal communication, 1984).

Each of these special conditions would lead to very small increases in the postulated dose commitment and associated risk to any member of the public.

EVALUATION OF PRESENT OPERATIONS AND TRENDS

This section highlights those areas that warrant more attention to assure that radionuclides in effluents and dose commitments remain small and in compliance with DOE and other applicable regulations.

In recent years, ORNL has reduced liquid releases through more thorough decontamination of process water streams; e.g., direct releases of ^{90}Sr from ORNL operations have been reduced and shallow land burial of radioactive sludges from the treatment processes has been eliminated. Also, the quantity of radionuclides in gaseous effluents has been reduced by modification of the collection and treatment processes in the 3039 stack.

Radionuclide concentrations in effluents from ORNL now approach or exceed some potentially applicable regulatory standards, although not those currently in use by DOE. Consequently, the panel concludes that ORNL may have to take further steps to improve their radioactive waste management practices if they are to be in compliance with potentially applicable regulations.

Gaseous Emissions

As indicated in a preceding section, EPA estimates that gaseous emissions from Oak Ridge facilities would exceed critical organ limits under the regulations currently in litigation (U.S. EPA, 1983).

The identification by EPA of ^{3}H released from ORNL stacks as one of three major contributors to the offsite dose commitment (U.S. EPA, 1983) is not reflected in ORNL ISAHPD and Environmental annual reports--ORNL identifies only ^{234}U as making an important contribution to dose. This highlights the need for more detailed reporting of available data and upgrading the monitoring capability for airborne ^{3}H at ORNL.

The panel notes a problem in the ORNL safety assessment as reported in the ISAHPD annual reports, in that DOE Order 5480.1A (Rev.) requires that public exposure in controlled areas meet the dose limit for nonoccupational exposure--a value consistent with the nonoccupational CG_a. Although many of the ORNL staff are not directly involved in radiation work, the ISAHPD reports incorrectly compare calculated onsite doses with the 5.0-rem/yr occupational CG_a for a radiation worker.

The panel further notes that in DOE Order 5480.1A (Rev.) the point of release is considered to be the point at which the effluents pass beyond the site boundary. However, state regulators are more and more frequently adopting as the point of release the stack, tube, pipe, or similar conduit from which the release occurs. Since ORNL does not report the concentrations at each stack mouth, it was not possible for the panel to determine whether or not the gaseous effluents from ORNL would meet limits at the more restrictive control point.

When the Oak Ridge facility is treated as a single unit under the Clean Air Act, the total dose commitment composited for all airborne emissions will require testing against potentially applicable EPA limits. Under such conditions, reduction of emissions from one source on the Oak Ridge reservation may be more cost effective than reduction at another source--a decision that could affect ORNL operations. Possible improvements due to the 1983-1984 modifications to ORNL's gas-waste-handling system had not been established at the time the panel's work was performed, so the panel can only emphasize the need for early evaluation of performance of the new emissions control system.

Liquid Effluents from the ORNL Operations Area

As the quantities of process waste radionuclides discharged to White Oak Creek have been reduced by the improved treatment of the waste streams, the total amount of radioactive material released at White Oak Dam has declined sharply since 1963 (Table 6-6). The resulting dose commitments from effluents at White Oak Dam and further downstream in the Clinch River have been reduced proportionately.

For the past 5 years, the "flume" area and the Sewage Treatment Plant (STP) have been the principal sources of radionuclides from the ORNL operations area (Table 6-7). The releases from the operations area are now so small that it does not appear productive to attempt further reductions beyond those that are expected from replacement of leaking waste transfer lines.

The radionuclides in effluents from the Sewage Treatment Plant appear to enter the sewer system by percolation through soil previously contaminated by leaking pipes in the process waste delivery system. During 1981 and 1982, effluents from the STP rivaled those in seeps from burial ground 5 in the amount of ^{90}Sr delivered to White Oak Lake; during 1983, releases from the STP appear to have decreased somewhat, but they are still significant.

Sewer system in-leakage also appears to have been the pathway for an accidental release of ^{131}I during August 1983. Evaporator condensate, contaminated as a result of abnormal operation, leaked through a break in the condensate drain line into the sanitary sewer line. A total of approximately 5 mCi of ^{131}I was eventually discharged, resulting in an increased concentration at White Oak Dam equivalent to 3 percent of the annual average DOE CG_w. Although the uncontrolled release of ^{131}I in this instance did not cause a harmful increase in offsite dose, the accident reinforces the apparent need for ORNL to consider eliminating leaks in the pipes at the ORNL operations area.

The flume station, which measures effluents from ORNL operations upstream from the discharge point of the waste process stream, results in a relatively small ^{90}Sr effluent stream, similar in magnitude to that from the STP (Table 6-7).

Effluents from Wastes Placed in the Ground

At ORNL most of the rain (up to 88 percent) penetrates the ground, but the weathered soil layer is generally thin, and in the Melton Valley shale formations the underlying bedrock is sparingly permeable and the water table is shallow; the region is hilly so that distances from infiltration to discharge at the nearest surface stream are short. Surface and groundwater flows are so closely coupled that distinctions between them tend to be artificial. Therefore, in the discussion that follows, the three forms of monitoring--sampling of surface streams, surveys of streambed gravels, and analyses of groundwater and soils--have been combined to analyze the past and present behavior of the areas in which radionuclides have been placed in the ground near the land surface and to learn whether future performance can be predicted. In this section ^{90}Sr is emphasized, because the CG_w for ^{90}Sr is the most restrictive (among the radionuclides released in liquid effluents by ORNL) and ^{90}Sr contributes most of offsite radiation dose from ORNL effluents, and because measurements of ^{90}Sr in water constitute the most complete set of data available for assessment of trends.

The panel has noted previously that the overall releases of radionuclides (except for ^{3}H) at White Oak Dam have declined sharply since the early 1960s. Releases of ^{90}Sr from ORNL operations have also declined and, as a result, the relative importance of ^{90}Sr releases from the burial grounds has increased, even though the magnitudes of such releases have not changed much (see "Inferred Contributors" in Table 6-7 for data since 1979).

A number of variables complicate analysis of trends in burial ground behavior. For instance, the additions of seals and dikes to control water and radionuclide discharges from some trenches of burial ground 5 and the diversion of surface water at burial ground 4 may have altered the release rates. Also, variations in rainfall and associated runoff over the annual cycle exert a strong influence on releases from year to year (Figures 8-2, 8-3, and 8-4).

The important role played by the hydrologic system in radionuclide transport must also be understood. For the Conasauga shale group of Melton Valley, underlying burial grounds 4, 5, and 6, the system is characterized by highest permeability and groundwater flow near the surface, and by declining permeability with depth.

Quantitative studies of near-surface groundwater flow during storm events are still in progress, but it appears that most storm-related subsurface flow occurs in a near-surface region that extends to a depth of about 5 m. Preliminary data gathered by D. Webster of the USGS for the deeper subsurface flow system also suggest that radionuclide penetration has not extended below 30 to 45 m in burial ground 5, and that most of the transport would be expected in the zone above those depths. The general hydrologic picture is that of a rather closely coupled surface water and groundwater system, where circulation is rather shallow, much of the transport occurs in the near-surface zone during the wetter part of the year (late November through April), and the more traditional concept of a subsurface contamination plume as a

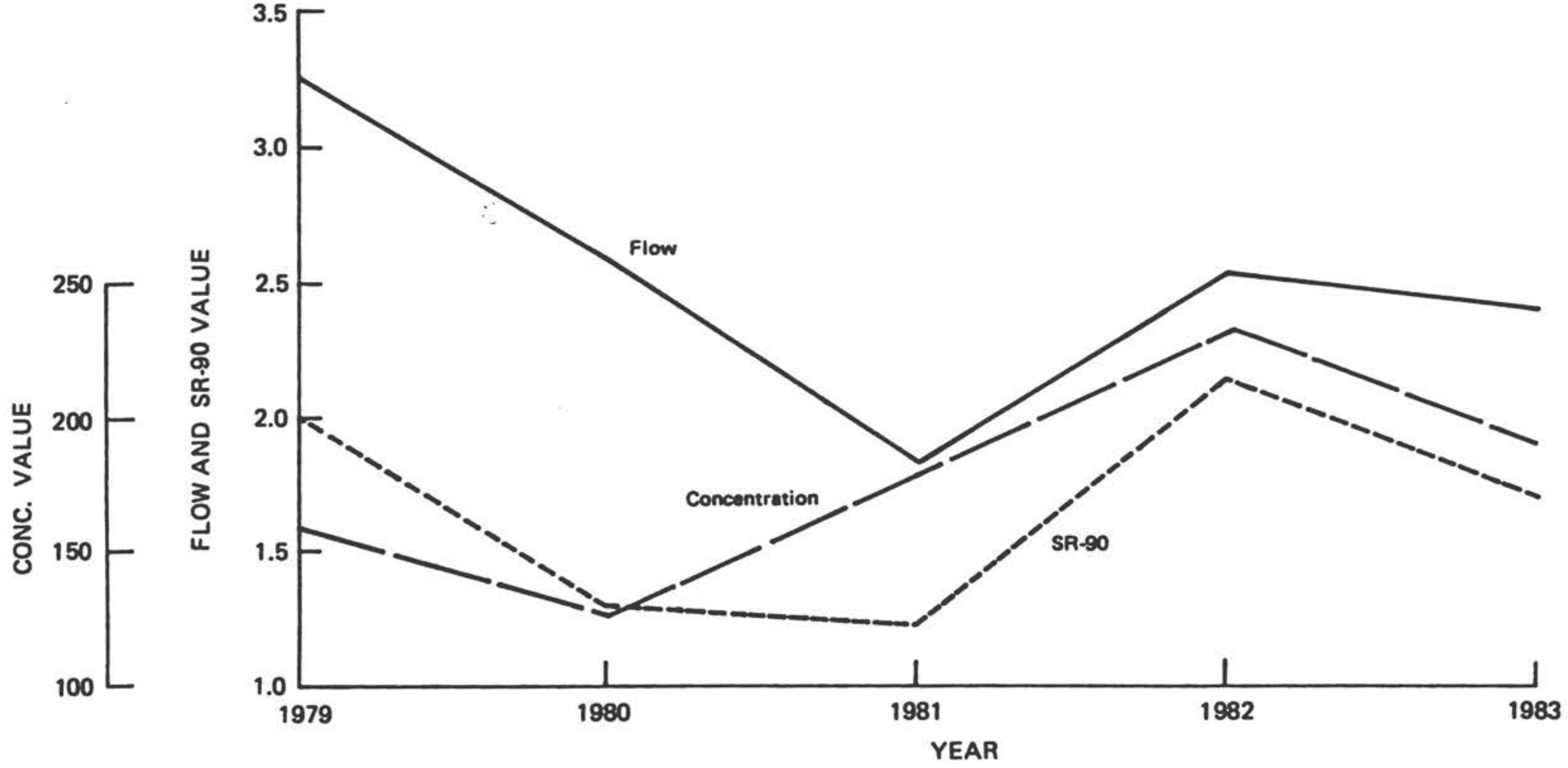

FIGURE 8-2 Flow (billions of gallons), ^{90}Sr discharge (Ci), and concentration (pCi/L) at station 3 as a function of time.

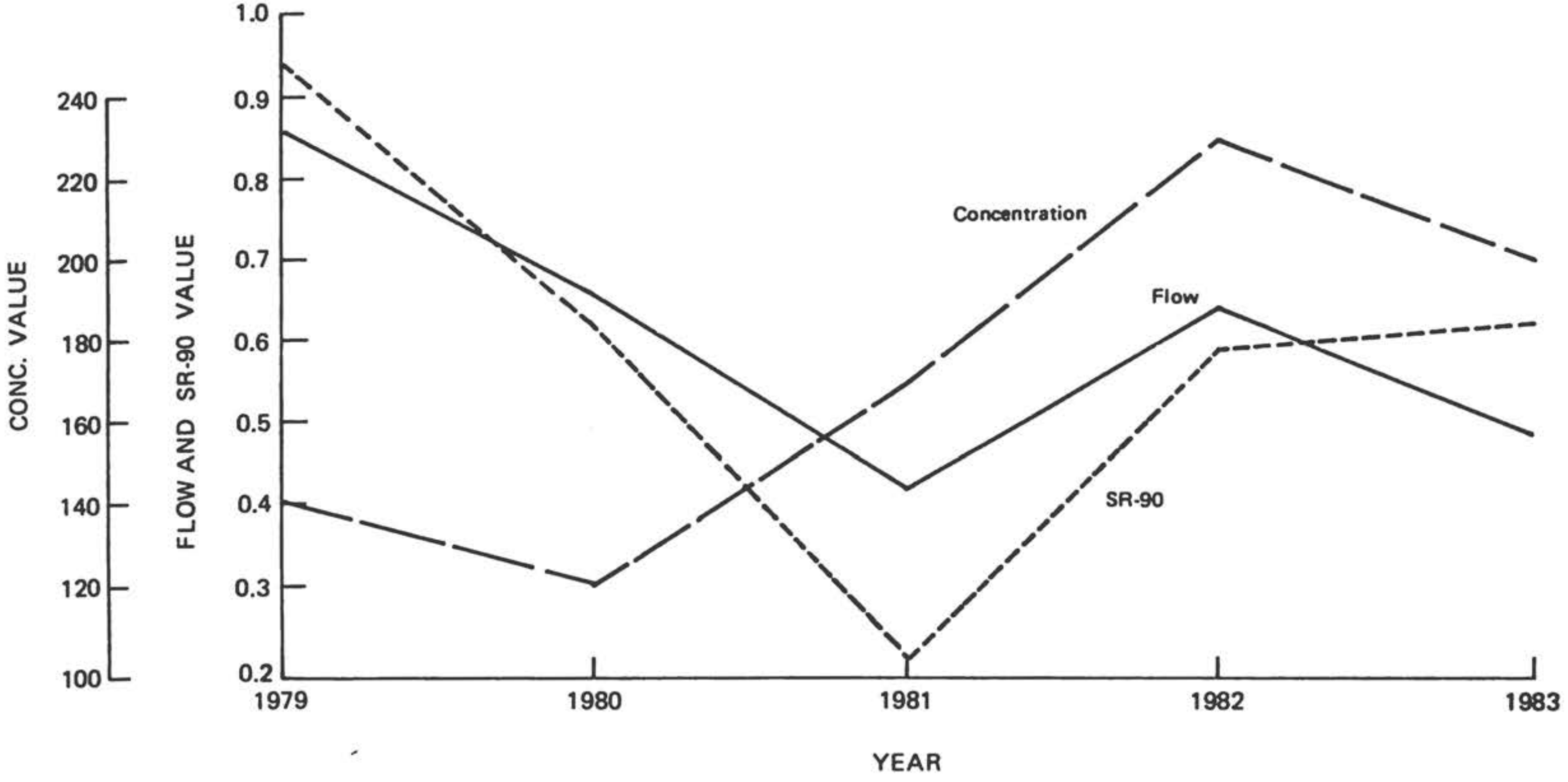

FIGURE 8-3 Flow (billions of gallons), ^{90}Sr discharge (Ci), and concentration (pCi/L) at station 4 as a function of time.

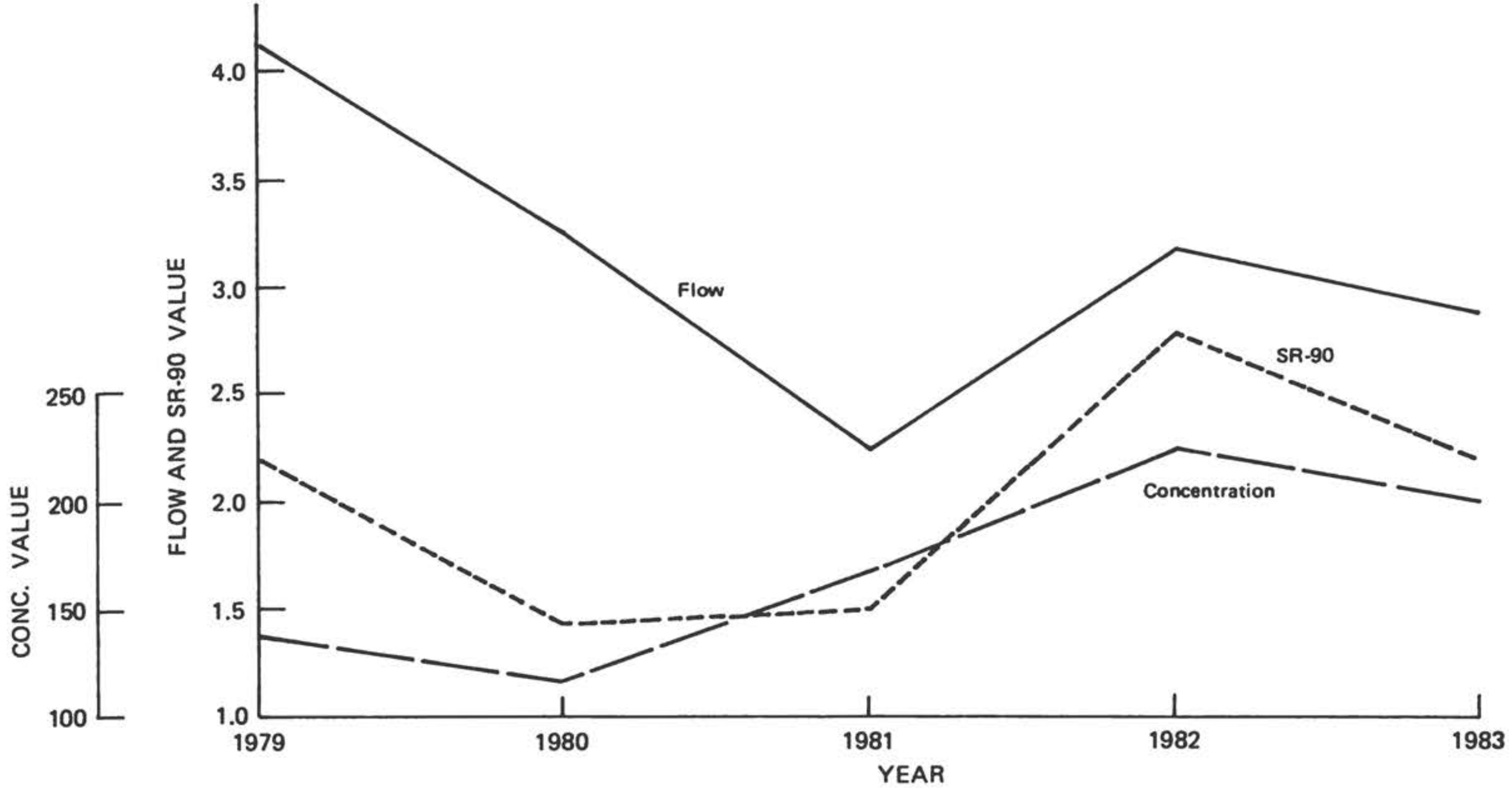

FIGURE 8-4 Flow (billions of gallons), ^{90}Sr discharge (Ci), and concentration (pCi/L) at station 5 as a function of time.

primary pathway for migration is probably not appropriate. The hydraulic conductivity of the less-weathered material is about 2 cm/day, while the near-surface zone is characterized by hydraulic conductivities of 20 to 40 cm/day, or more. Furthermore, the distribution coefficients for cations in the Conasauga shale-groundwater system are rather high, suggesting that deep migration of most radionuclides would occur very slowly. Thus, the surface-water monitoring system is a reasonably good indicator of radionuclide migration and can be used effectively to identify sources of radionuclide releases from the burial grounds. It also appears that trench overflow ("the bathtub" effect) during storm events has played a significant role where transport has been observed. In this effect, infiltrating water percolates downward, during wet periods, until the less permeable level of the trench bottom is reached; the trench then fills and overflows. The effect is accelerated where, as at Oak Ridge, trenches are inclined and act like tilted bathtubs that fill rapidly and discharge downslope over land surfaces.

The panel sought to determine trends in the releases of ^{90}Sr from the burial areas by recasting the ORNL data in different formats. The result (see Table 6-7) is a summary of both the absolute and the relative importance of each of the areas that discharge ^{90}Sr in liquid effluents into White Oak Creek. The following discussion will focus on the areas outside the ORNL operations area.

In the past, significant quantities of other relatively mobile radionuclides have been released from the buried waste. Over the last few years, however, the single most significant contributor has been ^{90}Sr. Over a 20-year period, from 1964 through 1983, a total of 77.6 Ci of ^{90}Sr were released to the Clinch River from all sources at ORNL (i.e., operations, burial grounds, and seepage pits and trenches). The average release was 3.9 Ci/yr (Table 8-3). Of this amount, about one-half was contributed by burial grounds 3 and 4 and their associated floodplains, one-fifth by burial ground 5, and the remainder by ORNL operations. Burial grounds 1 and 2, the seepage pits and trenches, and burial ground 6 apparently have not discharged significant amounts of ^{90}Sr over the 20-year period; the surface-water monitoring system, however, is not capable of detecting seepage from burial ground 6.

When the estimated amounts of buried ^{90}Sr are considered (10^3 Ci in burial ground 4 and 4×10^4 Ci in burial ground 5), there appears to be no relationship between the amount buried and the current amounts released annually. This discrepancy is more likely to reflect differences in the ages and management of the individual burial grounds (see discussions of individual burial grounds below) than significant variations in their hydrogeology. The physical and chemical forms of the buried waste are believed to have been similar; large volumes were interred in each burial ground.

The data in Table 8-3 do not demonstrate an obvious relationship between annual precipitation and ^{90}Sr discharge over the 20-year period. However, data provided by ORNL for the period 1979 through 1983 (J.H. Coobs, ORNL, personal communication, 1984) show that the total amount of ^{90}Sr released is roughly correlated with the total volume of water passing each sampling station (see Figures 8-2, 8-3,

TABLE 8-3 Release of ^{90}Sr from Operations and Buried Waste at ORNL from 1964 Through 1983. ^{90}Sr releases are for calendar year (Jan-Dec) rainfall is for water year (Sept-Aug)

	Precipita-, tion (cm) yr	White Oak Dam, Ci/yr	Burial Grounds 1, 3 and 4 and 7500 Floodplains,[a] Ci/yr	Burial Ground 5, Ci/yr[b]
1964		7	3.3	0.7
1965		3	3.4	0.3
1966		3	2.0	0.5
1967	154	5	2.7	1.0
1968	115	3	1.7	2.8[c]
1969	103	3.1	1.3	0.9
1970	122	3.9	1.4	0.7
1971	123	3.4	1.7	0.6
1972	120	6.5	2.2	0.9
1973	180	6.7	2.0	1.3
1974	175	6.0	5.4	1.3
1975	148	7.2	3.6	2.1
1976	125	4.5	4.3	0.7
1977	130	2.7	2.6	0.5
1978	156	2.0	1.2	0.5
1979	170	2.4	1.7	0.7
1980	97	1.5	0.9	0.6
1981	110	1.5	0.8	0.2
1982	155	2.7	1.5	0.5
1983	105	2.5	1.6	0.9
20-year total		77.6	45.3	17.7
Average Ci/yr		3.9	2.3	0.9
Contribution, percent of White Oak Dam total			58	23

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[a] Calculated by difference, monitoring station 3-ORNL operations (Sum).

[b] As measured at monitoring station 4-Melton Branch.

[c] The result of an accident.

and 8-4). The figures show the discharge of ^{90}Sr (in curies) and the flow (in billions of gallons) for the primary measuring point of each drainage system (station 3 for White Oak Creek, station 4 for Melton Branch, and station 5 for White Oak Lake). Concentrations (ratio of curies of ^{90}Sr discharged to flow) decreased marginally with increased flow; in some years, concentrations appeared to increase with increased flow (precipitation).

In recognition of the fact that, at least for the past 5 years, ^{90}Sr discharges and the average annual concentrations of ^{90}Sr in the streams fluctuate in some proportion to stream flow, the panel attempted to evaluate the discharge patterns for the burial grounds. Multiplying the monthly average discharge values for "Inferred Contributors" in Table 6-7 by 12 and dividing by the annual amount of precipitation (in centimeters) yield the annual ^{90}Sr discharge per centimeter of precipitation (plotted in Figure 8-5). The patterns are similar to the stream results for ^{90}Sr discharges and ^{90}Sr concentrations shown in Figures 8-2, 8-3, and 8-4, with the exception of an increase during 1980 for burial ground 5 and for the mixed seepage from the 7500 floodplain and burial grounds 1 and 3. The quality of these correlations suffers because ORNL evaluates the ^{90}Sr discharges for calendar years, while precipitation data are collected for "water years" (September through August).

The data suggest that after an extended wet period, such as occurred from 1973 through 1979, flushing of the trenches tends to decrease their ^{90}Sr concentrations. During drier periods (e.g., 1980 and 1981), there is less flow and an initially low concentration, which combine to decrease the rate at which ^{90}Sr is discharged from the trenches. Concentrations apparently increase sufficiently during drought (e.g., 1981) so that total flow, total ^{90}Sr discharges, and concentrations in the streams all increase when the rains come.

The implications for remedial actions or new burial grounds are that temporary retention of water in contact with waste, such as may occur in sealed or diked trenches, may only delay discharge for a short time. When discharge finally occurs, radionuclide concentrations may actually be greater than those that would otherwise occur. It appears that, in the hydrogeologic environment in Melton Valley, the waste must be placed in high-integrity containers to isolate it from water for times long enough to meet regulatory requirements.

Intermediate-Level Waste Pits and Trenches Area

The seepage pits and trenches represent one of the largest concentrations of fission products that have been disposed to ground at ORNL (J.H. Coobs, ORNL, personal communication, February 8, 1984). The available data indicate that little or no ^{90}Sr is currently being discharged to White Oak Creek from these sources, and it is believed that the alkaline environment attained during disposal is responsible for the lack of ^{90}Sr migration. High pH in groundwater downgradient from trench 7 indicates that the trench may be losing alkalinity because of infiltration of precipitation (Olsen et al., 1983), slightly

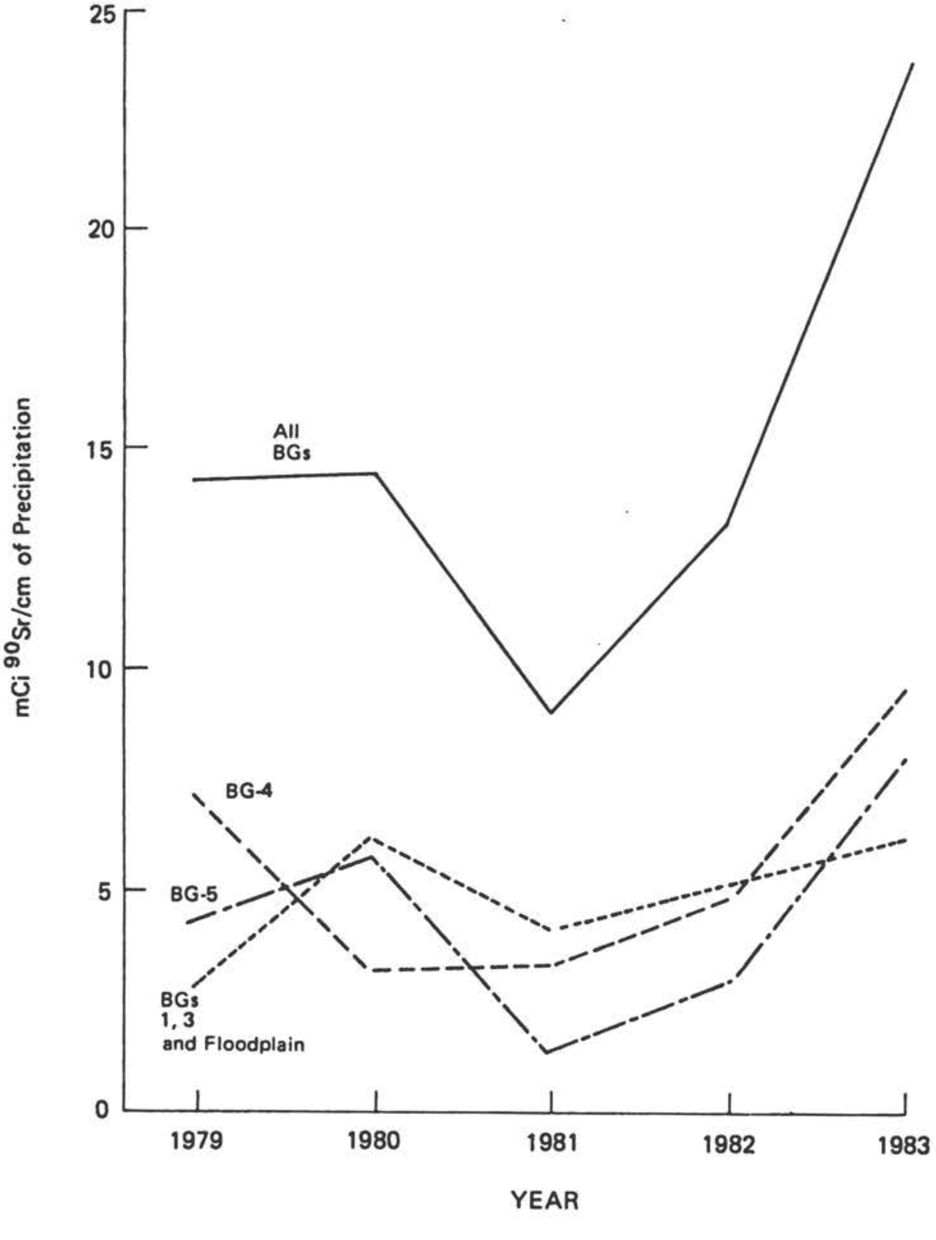

FIGURE 8-5 Discharge of ^{90}Sr from burial grounds.

acidic in itself. The rate of loss of alkalinity, and thus the future behavior of ^{90}Sr in the pits and trenches area, is uncertain. An ORNL study has estimated that from 10 years to one million years will be required before ambient pH conditions are reestablished in the surrounding shale (Olsen et al., 1983). An early return to ambient pH conditions could significantly increase the discharge of ^{90}Sr from these sources and significantly increase the annual release of ^{90}Sr at White Oak Dam.

Contributions of the intermediate-level waste (ILW) pits and trenches area can be evaluated by considering differences between the flux of radionuclides in surface water upstream and downstream of the area, as well as by direct measurement of stream flow from the area. Data are obtained from routine monitoring at stations 3, 4, and 5 (White Oak Creek, Melton Branch, and White Oak Dam), and from the East and West Weirs (locations are shown in Figure 6-1). Past releases from stations 3 and 4 have equaled or exceeded those measured at White Oak Dam, foreclosing evaluation by differences. Recent data available to the panel have not indicated any change in this pattern. Surface-water samples from the newly installed monitoring weirs indicate that ^{90}Sr discharge from the pits and trenches is small (see Table 6-7). During 1983, for example, the average monthly discharge of ^{90}Sr detected at the East and West Weirs combined was only 1.5 mCi of a total of about 153 mCi flowing into White Oak Lake. Thus, there is no present indication of significant ^{90}Sr discharge from the pits and trenches to the White Oak Creek drainage.

A second, sensitive, indicator of radionuclide migration is the concentration of radionuclides in streambed gravels (Cerling and Spalding, 1982). Distributions of ^{90}Sr, ^{60}Co, and ^{137}Cs in these gravels in 1978-1979 were presented in Chapter 6 (Figures 6-9, 6-10, and 6-11). Because the streambed gravels act as an integrator of surface-water transport history, they are sensitive to spatial distribution of inputs and can reveal probable pathways for migration associated with pits and trenches. Examination of these figures suggests that some migration is occurring at pits 1 and 3 and trenches 5, 6, and 7. Pits 2 and 4 may have some migration associated with them as well, but indications are not strong. According to Cerling and Spalding (1982), the pits and trenches area contributed approximately 0.1 percent of the ^{90}Sr leached into White Oak Lake during 1978-1979, which is much lower than that obtained from the surface-sampling stations (see Table 6-7).

Burial Ground Areas

<u>Burial Grounds 1 and 2</u>. Burial grounds 1 and 2 are assumed not to contribute a significant amount of ^{90}Sr to the release at White Oak Dam. Stream monitoring has not revealed any radionuclide releases from these burial grounds. Because of the small amounts of ^{90}Sr in burial grounds 1 and 2, and because of their age and proximity to surface streams, ^{90}Sr discharge from them would not be expected to increase

in the future (discharge would have been observed by now if it were going to occur).

Burial Ground 3. Stueber et al. (1981) present data on radionuclide migration from burial ground 3 and ^{90}Sr concentrations in the Northwest Tributary and in Raccoon Creek. During the period from June 1978 to May 1979, only 6 or 7 mCi/month of ^{90}Sr were discharged from burial ground 3 into White Oak Creek--a value that represents only 2 to 5 percent of the total past White Oak Dam at that time. Discharges to Raccoon Creek appear to be, at most, one-tenth of those to White Oak Creek. Deficiencies in the monitoring program for burial ground 3 appear to be coming under control as new groundwater monitoring wells and two new stream monitoring stations are put into operation (T. Oakes, ORNL, personal communication, 1984). Cerling and Spalding (1982) attribute to burial ground 3 approximately 3 to 4 percent of the ^{90}Sr leaching into White Oak Creek drainage during 1978-1979.

Burial Ground 4. Inasmuch as burial ground 4 has been identified as the most significant contributor of ^{90}Sr, radionuclide transport has been extensively studied there. Burial ground 4 represents an extreme example of radionuclide migration and has been examined to obtain a qualitative picture of postclosure behavior.

Strontium-90 migration patterns in both surface water and groundwater have been examined (Huff et al., 1982). An important finding was that surface-water flows annually accounted for 70 percent of the water flow and 56 percent of the ^{90}Sr transport. It was estimated that a large fraction of the annual ^{90}Sr transport from burial ground 4 could be eliminated by diverting upslope surface runoff away from the disposal area. In other words, at burial ground 4 the transport problem has been shown to be associated primarily with over-surface flow, not with groundwater migration. More recent, as yet unpublished, studies emphasize that finding even more (D. Huff, ORNL, personal communication, 1983). The patterns of ^{90}Sr contamination clearly show that the primary mode for ^{90}Sr and other radiocontaminant migration is via the bathtub effect. When trenches collect enough water, overflow occurs at the lower end of the trench. Surface contamination spreads out in a characteristic pattern from the lower end of the source trench. Vertical profiles consistently show the highest contamination at the surface and a sharp decline with increasing depth. This is exactly the reverse of expectation if contaminants were rising to the surface via a groundwater seep. Thus, the kind of transport commonly associated with solute migration in groundwater is only part of the transport process in the Melton Valley at Oak Ridge. It should be possible to estimate optimal trench sizes and orientations for avoidance of overflow from precipitation (annual or seasonal) seepage rates (inflow at the sides and outflow at the lower sides and bottom), trench void volume, and slope angle. This pattern is expected to hold at burial grounds 5 and 6.

In burial ground 4, water originating in an upslope catchment was collected in surface diversion channels and then conveyed and discharged into trenches and contaminated areas at the lowest topographic portion of the disposal area. A surface and subsurface water diversion system to divert these flows from and around the disposal area was completed in September 1983, thus removing the most important transport mechanism. Based on this action, a significant reduction in ^{90}Sr losses from burial ground 4 is expected in the short term. Proof of longer term reduction will require continued data collection.

Only limited data are available to address the question of ^{90}Sr release trends. A section from an ORNL report by Lomenick and Cowser (1961) that deals with releases in the stream south of burial ground 4 states that the average ^{90}Sr concentration in stream flow was 42 disintegrations per minute (dpm) per milliliter (or 19 pCi/ml) during the period from August 22, 1959, to January 22, 1960. Data from Huff et al. (1982) show, for the period from June to November 1979, that the flow-weighted concentration was 7.9 pCi/ml for nonstorm periods and 5.5 pCi/ml during storm periods. Recent ^{90}Sr releases, calculated in the old way from stream monitoring [station 3 minus (station 2 + station 1)] to be 1.6 Ci/yr for the years 1979 to 1983, are about one-half of those calculated for 1964-1965. Both sets of data suggest a long-term declining trend (Table 8-3). Thus, there was a twofold to threefold decrease in ^{90}Sr concentrations in the runoff from burial ground 4 during this 19-year period. The panel believes that the effect of storm flow dilution serves to highlight one potential anomaly for the long term--reducing the influx of water to the burial trenches may only delay radionuclide migration for a short time. Later migration may again develop at the same rate (except for the effect of source reduction due to radioactive decay), but at higher concentration in the immediate area of each burial ground, because there is more time for leaching.

Groundwater movement will still play a role in ^{90}Sr transport. The evidence suggests that the main mode will still involve overflowing of trenches. However, when trench caps provide a seal in the vertical direction, groundwater may still intrude from inflow through trench walls, with subsequent movement of water along the trench bottom to the lower edge. When sufficient water is collected, overflow would still be expected. This suggests that the use of relatively short trenches (current practice in burial ground 6) may initially control overflow in Melton Valley formations.

The highest surface contamination zone found at burial ground 4 is at the end of what appears to be a trench that was being flushed directly by one of the asphalt channels that formerly (until 1983) conveyed water across it. This problem developed because trench locations were not known and the channels had not been extended far enough--although they had been thought to span the burial ground. Inasmuch as water has now been diverted from the tributary at the lower edge of burial ground 4, recharge to the groundwater system in that area will be reduced. This should have a favorable impact on water table elevations at the lower edge of burial ground 4. Studies of migration in that area will continue as part of the evaluation of the effectiveness of the burial ground 4 diversion project. Releases of ^{90}Sr from burial ground 4 during 1978-1979 were found to be similar whether calculated from surface-water measurements, 42 percent (Table 6-7), or streambed gravels, 33 percent (Cerling and Spalding, 1982).

Burial Ground 5. Conditions at burial ground 5 appear to be better than those described for burial ground 4 because a smaller fraction of the recorded ^{90}Sr buried has been released. Surface-water management problems are not as severe at burial ground 5 as they are at burial ground 4; nonetheless, bathtub overflow that has been observed there contributes to significant releases of ^{3}H and ^{90}Sr.

Trench lengths vary from less than 12 m (40 ft) to more than 150 m (500 ft). However, the majority of the trenches are oriented more or less parallel to the topographic slope and at right angles to the strike of the formation (Webster, 1976). This configuration has caused the development of numerous seeps along the edge of the floodplain that are believed to be associated with the bathtub effect. The water in one of these seeps contained measurable amounts of alpha-emitting radionuclides (primarily ^{244}Cm and ^{238}Pu), as well as high concentrations of ^{90}Sr, ^{3}H, and ^{125}Sb (Duguid, 1976). Tritium and ^{90}Sr are believed to be the major radionuclides migrating from the site, and burial ground 5 is the major contributor to the ^{3}H concentrations measured at White Oak Dam.

Corrective actions described in Chapter 5 were taken in 1975 to eliminate the seep, and two underground dams were installed across two parallel trenches, which were then covered with a PVC membrane. A near-surface seal consisting of a bentonite-shale mixture was placed over 14 trenches in the TRU waste area to prevent excessive infiltration. These corrective actions at first decreased the amount of ^{3}H and ^{90}Sr migrating from burial ground 5, but annual migration of both radionuclides has apparently recovered to earlier rates. Table 6-6 shows that the ^{3}H levels (nearly all from burial ground 5) fluctuate widely--they must, however, continue to be monitored. Table 6-7 indicates that the amount of ^{90}Sr released to surface effluents from burial ground 5, which reached its nadir in 1981, has increased again, so that the value for 1983 exceeds that for 1979. The 1979 streambed gravel study by Cerling and Spalding (1982) provided an estimate (approximately 20 percent) of ^{90}Sr discharged to White Oak Creek that is similar to the results of surface-water measurements (26 percent) during that period.

Burial Ground 6. No monitoring data are available from which one can calculate the contribution of ^{90}Sr seepage from burial ground 6 to surface-water effluents. Because of the lack of adequate monitoring data for surface streams, radionuclides transported from burial ground 6 to White Oak Lake in the surface and near-surface flow are presumed by ORNL to be negligible in relation to other sources. The study of streambed gravels for 1978 and early 1979 indicated that burial ground 6 contributed a little less than 5 percent of the ^{90}Sr discharged into White Oak Creek and/or White Oak Lake (Cerling and Spalding, 1982), although that estimate could be low by a factor of 3 to 4 and still not be detectable by the surface-water monitoring system (see Table 6-7). Whether that percentage has increased or decreased during the past 5 years is unknown.

The work of Spalding and Cerling has shown that one area in burial ground 6 predominates in the transport of ^{90}Sr to White Oak Lake. This is near a 49-trench area in burial ground 6 that was sealed with a compacted bentonite layer, followed by a 60-cm earth-filled cover. Water has been observed in trenches under this seal, and it is believed that much of the inflow is from lateral subsurface flow during wet season storms. A French drain was installed at the site in late September 1983 to intercept lateral flow and also to act as a groundwater suppression zone around the seal area. Early observations of flow rates from the drain system show that it responds rapidly to rainfall events, probably via interception of lateral flow. It has also been noted that trenches under the seal, that had some water in them prior to construction, no longer contained water. Although conclusions are not warranted until data have been collected for at least one full winter season (i.e., when the period of highest water table occurs), early indications are that the groundwater control project will have an effect on contaminant mobilization, at least in the short term.

The western portion of burial ground 6 appears to contribute ^{90}Sr at half the rate of that described above (Cerling and Spalding, 1982).

The relation of seasonal changes in precipitation to the migration of radionuclides has been studied, but the effects of catastrophic weather conditions need additional study. It would be prudent to develop a conceptual model or reasonable projection of erosional damage in the burial grounds and of radionuclide migration caused by a large one-day storm yielding as much as 15 cm (6 in.) of precipitation.

Subsurface Migration of Radionuclides

The migration of radionuclides in the shale of the Conasauga group is controlled by the velocity of groundwater and the degree of sorption of radionuclides along the flow path. The velocity of the groundwater is controlled by the porosity of the shale, its permeability, and the groundwater gradient. The permeability and porosity of the shale are functions of the degree of weathering, the orientation of the bedding planes, and the amount of fracturing.

The groundwater table in the White Oak drainage can be described as a shallow subdued replica of surface topography. Most of the groundwater flow is in the weathered zone, and it discharges to surface streams locally.

Groundwater flow in the areas of the seepage pits and trenches, burial ground 5, and burial ground 6 is similar, while flow at burial ground 4 differs, in that the gradient there is probably less and the area is a catchment for a small watershed. In general, the four areas can be assumed to have similar porosities and permeabilities, except where there are major fractures.

Sorption of radionuclides along the flow path in the shale has been reported (Olsen et al., 1983). In the presence of the neutral to slightly alkaline groundwater with its significant concentrations of calcium, magnesium, and carbonate, sorption on the solid phase of the important radionuclide constituents of wastes buried or placed in the ground at ORNL is in the following order: ^{137}Cs, actinide and lanthanide elements, ^{60}Co, ^{90}Sr. Tritium migrates freely with the groundwater. Of the radionuclides considered, ^{60}Co and the transuranics form the most stable chemical complexes with groundwater constituents or laboratory chemicals, a process that can significantly reduce the respective distribution coefficients. In general, and with due consideration to complex formation, to the specific groundwater flow situation, and to the distance over which flow occurs, the radionuclides should migrate, based upon their distribution coefficients, with decreasing rapidity as follows: (1) ^{3}H, (2) ^{90}Sr, (3) ^{60}Co, Am, Cm, and Pu, and finally (4) ^{137}Cs.

Intermediate-Level Waste Pits and Trenches Area

Migration of radionuclides from the seepage pits and trenches was retarded primarily by sorption on the shale along the flow path between the pits and surface springs. Also, NaOH was added to the liquid waste in the pits and trenches to raise the pH to about 12, to enhance reaction with the fill, and to coprecipitate strontium with added calcium carbonate and calcium phosphate (Evaluation Research Corporation, 1982). During pit operations, the only radionuclides detected in springs near the pits were ^{106}Ru, ^{60}Co, and ^{125}Sb; however, ^{3}H analyses were not performed on any of the seep samples collected during operations. However, the mobility of ^{3}H in the groundwater (for which it is used as a tracer; Olsen et al., 1983) and current ^{3}H concentrations in the groundwater of the pit and trench area indicate that significant amounts of ^{3}H were also being discharged at that time. Ruthenium migration was reported from the beginning of the pit operations, and in 1959 the pits became "overloaded" and led to large releases of ^{106}Ru. The pulse of ^{106}Ru (1959-1965) from the seepage pits and trenches can be observed from data collected at the monitoring station at White Oak Dam (Table 6-6). Corresponding declines in the amounts of ^{137}Cs and ^{90}Sr discharged past White Oak Dam occurred during this same time period. Those declines of ^{137}Cs and ^{90}Sr discharged are probably due to a combination of two factors: (1) disposal of these radionuclides into seepage pits and trenches rather than directly to surface streams served to delay their discharge, and (2) gradual flushing of these radionuclides from the drainage ceased after direct release of wastes to White Oak Creek was discontinued.

Migration of radionuclides is still occurring in the vicinity of the seepage pits and trenches. The pits and trenches are now covered with asphalt, so water flowing through the immediate area is largely lateral subsurface flow from higher elevations. The migration is primarily along the strike of the Conasauga shale, and discharge occurs in small hillside seeps and springs. Although waters from these seeps and springs, sampled in 1975, contained minor amounts of ^{90}Sr, ^{137}Cs, and, in some cases, a high concentration of ^{60}Co, they were considered by ORNL to be a negligible component of those radionuclides passing White Oak Dam (Duguid, 1975). A study of water from wells around trench 7 indicated that ^{60}Co was migrating as a complex of ethylenediamine-tetracetic acid (EDTA), which is commonly used in decontamination at ORNL (Means et al., 1978). This same study also suggested, but did not prove, that the trace levels of plutonium, americium, curium, thorium, and radium found in soil from the seep near trench 7 were accompanied by EDTA. Recent well-logging data in the vicinity of the seepage pits indicate that ^{137}Cs, as well as ^{60}Co, is migrating in fractures and faults in the shale (Olsen et al., 1983; D.A. Webster, USGS, personal communication, 1984).

Contaminated soil indirectly associated with the seepage pits and trenches resulted from leaks in the line used to transfer waste to the seepage pits and hydrofracture site (see Figure 5-1 and Duguid and Sealand, 1975). When leaks occurred, the shale played an important role in limiting the spread of radionuclides. Strong sorption on the shale caused high concentrations of radionuclides in the immediate vicinity of the leak, and delayed their transport to surface water. Data from a shallow monitoring well downgradient (near White Oak Creek) from one of these leaks provide substantiation. These data showed that the contaminant concentration in groundwater decreased nearly to background levels within 3 months after the source, approximately 85 m^3 (3000 ft^3) of contaminated soil from around the leak, was removed and disposed in burial ground 6 (Duguid and Sealand, 1975).

Both the absolute and the relative contributions of radioactive effluents from the pits and trenches, as shown in Table 6-7, support the ORNL view that seepage from this area does not make an important contribution to the contaminant flow past White Oak Dam at this time. The panel, however, is concerned about the potential for much greater leakage in the future from the pits and trenches area into White Oak Creek.

Many radionuclides, including plutonium isotopes and ^{137}Cs, which are both normally considered quite immobile in shale, are moving to the surface and at depth. The studies by Cerling and Spalding (1982) of radioactively contaminated streambed gravels, when considered in context with the apparent downgradient migration of contaminants, raise the question as to whether the effluent levels from the pits and trenches will remain small, or will at some later time show a marked increase as some of the methods used to inhibit migration lose their effectiveness (e.g., when pH decreases to natural levels).

Wells located along likely flow paths are being examined by ORNL for the presence of radionuclides, and more wells are being added to the monitoring system. Groundwater data made available by ORNL are plotted in Figure 8-6. The sources for this and similar figures are the ORNL Department of Environmental Management (1983) and personal communications by J.H. Coobs (November 14 and December 8, 1983, January 5 and 27 and February 8, 1984). The symbol representing each well location is coded according to the radionuclide(s) present in groundwater samples collected recently from that well.

Direct flow along fractures has been extensive during and following operations at the area, as is shown by the variety of radionuclides present in wells far downgradient from each of the pits or trenches.

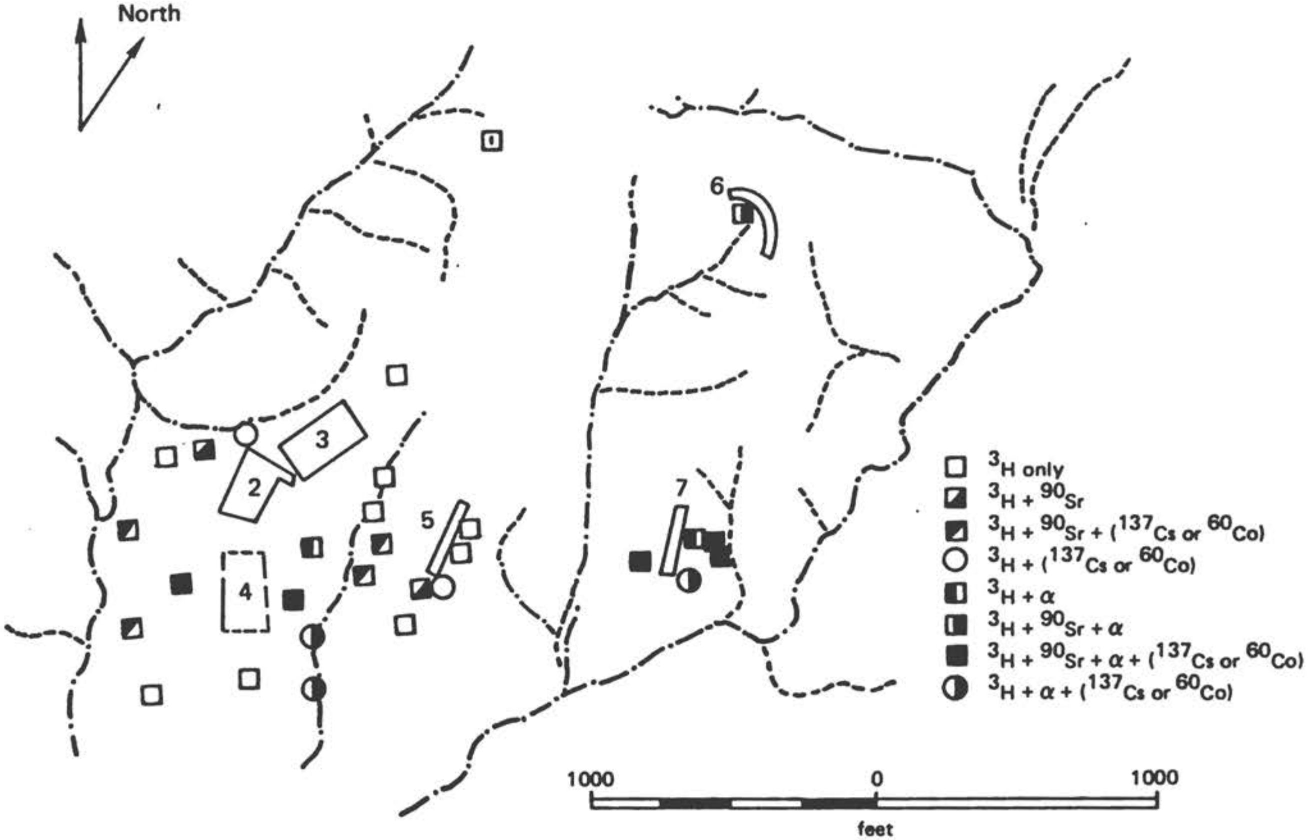

FIGURE 8-6 Radionuclides present in groundwater monitoring wells--ILW pits and trenches area.

The patterns of flow in this area probably developed from rapid transport of contaminants to the surface or near-surface shales, flushing of the fractures by precipitation runoff (or simply from overflow during operations), followed by downwash into the fractures around each well.

It is apparent that many normally sorbed radionuclides have migrated further than would have been expected in view of the retentive capabilities of Conasauga shale. This shale is know to be weathered, on the basis of exploratory drilling results, at the depths of interest.

ORNL should determine the extent of the migration observed to date in more detail through more extensive sampling of existing wells.

Burial Ground Areas

Burial Grounds 1 and 2. Limited groundwater monitoring has been performed around burial grounds 1 and 2, but the data are sufficient to indicate that these areas do not contribute significantly to offsite discharges of leached radionuclides.

Burial Ground 3. In 1964, well water samples from around burial ground 3 showed the presence of small quantities of rare earths, ^{90}Sr, ^{89}Sr, and ^{3}H. In 1973 well water samples contained only ^{90}Sr, at concentrations up to 3.0 dpm/ml, and ^{90}Sr was also found in groundwater samples draining both to White Oak Creek and to Raccoon Creek (Webster, 1976).

Groundwater measurements show that both the direction and the quantity of ^{90}Sr migrating from burial ground 3 are strongly influenced by water flow along fractures and solution openings in the bedrock below the burial ground (Stueber et al., 1981). The implications of the preliminary studies of subsurface flow in the Chickamauga limestone appear to be of much greater consequence to ORNL's plans for the Central Waste Disposal Facility (CWDF) than they are for actual discharges from burial ground 3. Since the Knox dolomite along Chestnut Ridge (the proposed CWDF site) contains solution openings of substantially larger size than those found in the Chickamauga limestone, the potential for rapid radionuclide migration in the Knox could be much more serious than that anticipated in ORNL's evaluations of Chestnut Ridge as a disposal site.

Although the amount of radioactive waste in burial ground 3 and the amount of ^{90}Sr discharged are apparently small, the demonstrated migration of ^{90}Sr along solution cavities indicates the need for more detailed investigations of subsurface flow at burial ground 3.

Burial Ground 4. Analyses of water samples from seeps downslope from burial ground 4 have indicated migration of ^{3}H, ^{90}Sr, alpha-emitting radionuclides, ^{137}Cs, ^{106}Ru, and ^{60}Co. Some seeps also contained ^{210}Po, ^{239}Pu, and rare earth elements (Duguid, 1976). Although other radionuclides are present in the water discharged from burial ground 4, only ^{90}Sr and ^{3}H are present in quantities sufficient to affect offsite dose (Webster, 1976). Calculations based on concentration data and on precipitation and stream monitoring data indicate that burial ground 4 was, at the time this report was written, the largest contributor of ^{90}Sr to the White Oak Dam drainage (Duguid, 1976). However, recent estimates (Table 6-7), which account separately for seepage from the White Oak Creek floodplain near the 7500-area bridge, show that the relative contribution of ^{90}Sr from burial ground 4 has decreased somewhat during recent years, in part, because the relative contribution of other burial sites appears to have increased and, in part, because leachate from the 7500 floodplain that had been previously ascribed to burial ground 4 has not been separately monitored. The absolute contribution of ^{90}Sr from burial ground 4 does not appear to have decreased significantly, and may be increasing from a nadir reached in 1980 and 1981 (see Figure 8-5).

Groundwater monitoring data (Figure 8-7) exhibit a downgradient flow of radionuclides accompanying the shallow near-surface water flow; as in Figure 8-6, only a qualitative depiction of subsurface migration is attempted. The three asphalt drainage channels are shown as solid lines.

All of the monitoring wells downgradient from burial ground 4 contain ^{3}H, ^{90}Sr, and alpha-emitting radionuclides at concentrations that range up to several orders of magnitude over background.

The panel interprets the groundwater data from burial ground 4 as representing a relatively "mature," badly managed burial ground--one in which extensive surface and near-surface flow has caused radionuclides to migrate downgradient, bypassing sorption by the shale (see Figure 8-7). Because changes in burial practices at burial grounds 4, 5, and 6 may only alter the time of initial discharge, burial ground 4 serves as the example against which present and anticipated performance of other existing and proposed burial grounds can be measured. Unfortunately, the groundwater data available are insufficient to derive a more quantitative analysis of migration as a function of time. What is needed, for example, is a plot of concentrations of ^{3}H, ^{90}Sr, and alpha-emitting radionuclides as a function of time and season (or amount of precipitation), in order to determine whether specific radionuclide concentrations are decreasing or increasing in each well. Also, more monitoring wells would be desirable. A new groundwater monitoring program by ORNL may serve to resolve these questions.

Burial Ground 5. As described previously, a large seep in the southeast corner of burial ground 5 showed evidence of early discharge of radionuclides into Melton Branch. Here, shortening the trench length by using impermeable dikes as dividers and covering the area with a PVC liner was effective in slowing water infiltration; it is believed to be responsible for a significant reduction in the amount of ^{90}Sr transported from burial ground 5. It remains to be seen whether the reduction is permanent. If bathtub overflow is the key mechanism for radionuclide migration from this disposal site, the major indicator of potential migration from the disposal area will be concentrations of radionuclides in trenches at the lower edge of the burial ground.

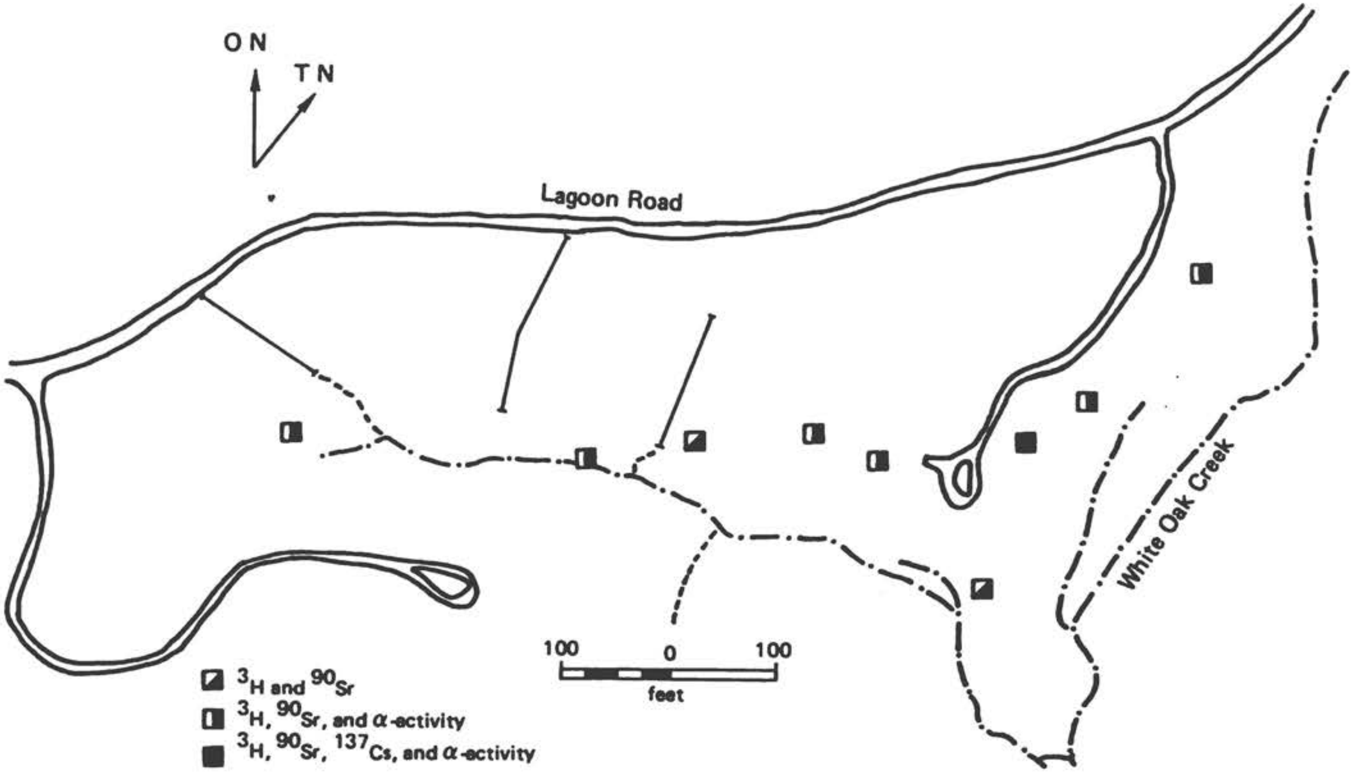

FIGURE 8-7 Radionuclides present in groundwater monitoring wells--burial ground 4.

Examination of water intrusion and associated radionuclide concentrations in these trenches over time should reveal possible trends.

Groundwater monitoring at burial ground 5 (Figure 8-8) implies much the same downgradient drainage as at burial ground 4. Only ^{3}H and ^{90}Sr have been mobilized sufficiently in burial ground 5, however, to cause concentrations significantly above background in the monitoring wells. The presence of ^{90}Sr in many of the more recent samples from wells where it had not previously been detected is consistent with the increase of ^{90}Sr being discharged from burial ground 5 to surface streams (as measured at Melton Branch monitoring station 4). While the monitoring wells along the south edge and the southeast corner of the burial ground have contained ^{90}Sr as a contaminant for some time, the wells along the small drainage in the middle of the site and those in the drainage to White Oak Creek have only recently shown "breakthrough" of ^{90}Sr. Recent samples from one (and perhaps two) of the wells in the middle drainage of the burial ground also seem to contain traces of ^{137}Cs. The presence of these radionuclides in particular wells seems to indicate that even more radionuclides will be discharged to surface streams as time goes on.

It appears that conditions at burial ground 5 have not "matured" to the extent that they have at burial ground 4. It is too soon to know whether corrective actions have resulted in lasting improvement of conditions at either burial ground.

Burial Ground 6. The setting of burial ground 6 is similar to that of burial ground 5; indicators of contaminant movement trends are likely to be similar also, with the added consideration that burial ground 6 is "younger" than the others. Recently collected (1979-1983) groundwater samples (Figure 8-9) show that ^{3}H is present in some of the downgradient wells, similar to the migration patterns that probably developed some years ago at burial ground 5. Consistent with the smaller amount of ^{3}H in burial ground 6, the concentrations of ^{3}H in the wells are lower in burial ground 6 than in burial ground 5. Only two wells contain significantly measurable ^{90}Sr concentrations above background; therefore data are insufficient to develop quantitative assessments of the amounts of ^{90}Sr leaving the burial ground.

Following the logic that near-surface water flow pathways are the best early indicators of migration from Melton Valley disposal sites, examination of data from wells in topographically low-lying trenches in burial ground 6 should indicate the potential for future radionuclide migration. Periodic water table measurements in a section of burial ground 6 indicate that water was present in most of the trenches throughout the year. In an attempt to decrease infiltration of precipitation, a near-surface seal consisting of a bentonite-shale mixture was applied to three sections of the burial ground. Water remained in the trenches after installation; it is thought that lateral migration along fractures is responsible for the influx of water. In 1983, a drainage system was also installed to reduce lateral migration; the effectiveness of the combination of the near-surface seal and the drainage system remains to be evaluated.

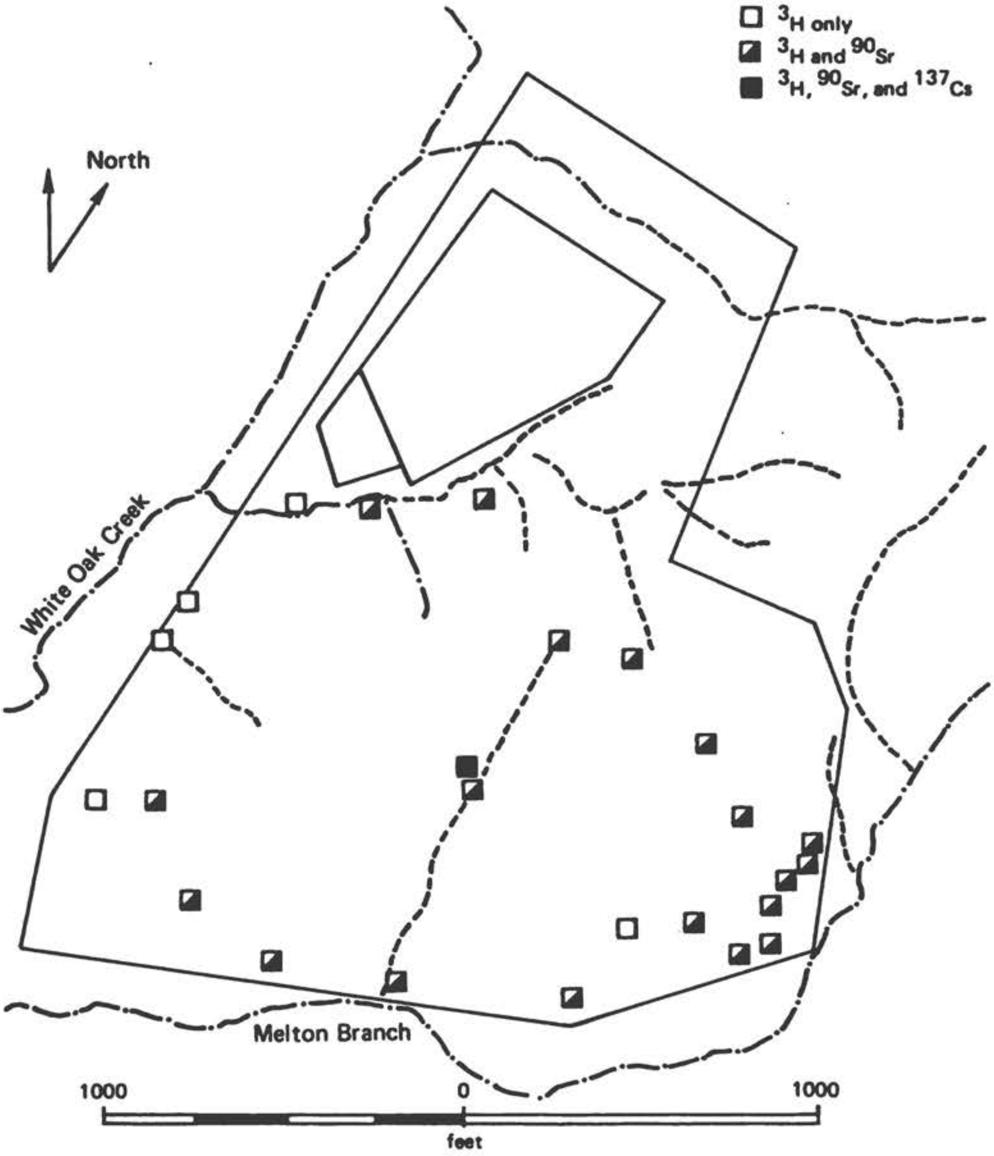

FIGURE 8-8 Radionuclides present in groundwater monitoring wells--burial ground 5.

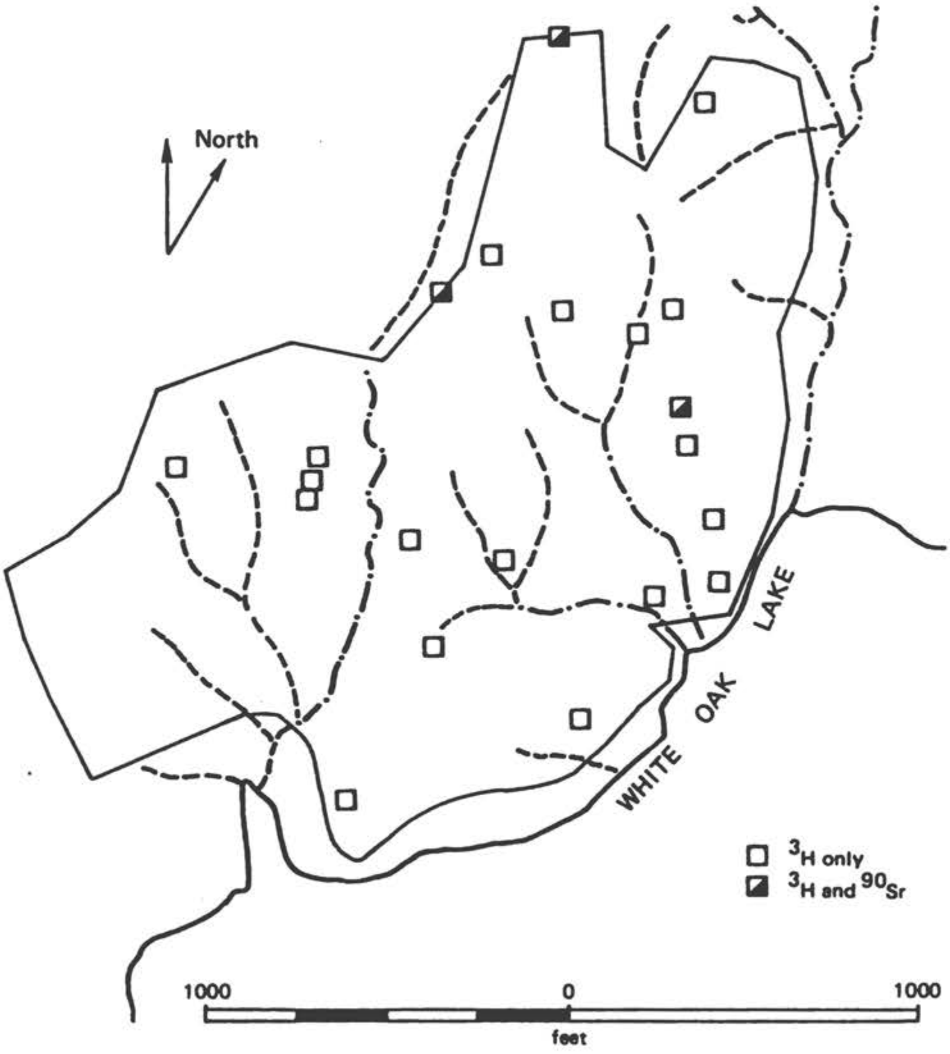

FIGURE 8-9 Radionuclides present in groundwater monitoring wells--burial ground 6.

It seems likely that burial ground 6 will release some radionuclides, and therefore adequate surface stream monitoring data must also be available. Surface monitoring stations to assess effluents from burial ground 6--located as it is directly above to White Oak Lake--will be difficult to construct, and seeps under White Oak Dam may prohibit calculation of the difference between radionuclide concentrations discharged at the White Oak Dam station and the sum of that entering through stations 3 and 4. Therefore, very careful consideration and thought are needed to devise subsurface water monitoring techniques to assess future burial ground discharges and to develop correlations between various sets of water monitoring data.

CONCLUSIONS

1. The routine offsite effluents from ORNL radioactive waste operations do not present a health hazard.

1a. An EPA evaluation of gaseous effluents from the Oak Ridge reservation during 1981 found that the annual radiation doses to a maximally exposed individual exceeded the potentially applicable EPA standards promulgated under the Clean Air Act. ORNL's calculations, however, indicate that the EPA standards are not violated.

1b. Neither calculated nor measured cumulative radiation doses to residents of Oak Ridge appear to be different from natural background radiation levels.

1c. The additional cumulative population dose resulting from releases from ORNL along any, or any combination of, pathways is very small in comparison with natural background radiation levels in Tennessee.

2. Based on stack measurements of gaseous effluents, airborne ^3H appears to be a significant contributor to the offsite dose commitment.

3. The ISAHPD reports incorrectly apply the <u>occupational</u> CG_a criterion to the onsite doses received by <u>all</u> site employees from gaseous effluents.

4. The aquatic food chain is the most critical exposure pathway.

5. ORNL's method of calculating annual average radionuclide concentrations in the Clinch River is conservative in that it underestimates the amount of dilution that occurs even under low-flow or no-flow conditions. Although this conservative calculational approach is appropriate when referring to present, relatively liberal, DOE Orders, it appears inappropriate for generating values for comparison to the more conservative standards set by EPA or planned by DOE. There is, however, some question as to whether or not the Clinch River is the appropriate location for assessing compliance.

6. Catastrophic washout of White Oak Creek sediments would produce 3 and 5 mrem, respectively, to people consuming drinking water and eating fish from the Clinch River.

7. The accidental release in August 1983 of ^{131}I in liquid effluents would have produced a dose of approximately 1.5 mrem to the thyroid of a hypothetical maximally exposed individual--a small value for a single incident, however, one that could create additional problems from regulatory considerations if a similar incident recurs.

8. During the past 20 years, ORNL has achieved large reductions in the amount of radioactive material released as process waste. These reductions cause the contribution from burial grounds and the pits and trenches area to take on greater significance. Further efforts to reduce the small amount of radioactive material released from the process waste systems do not appear to be necessary.

9. Radioactive effluents from the sewage treatment plant, which should contain no radionuclides, result in ^{90}Sr releases. (See Table 6-7.)

10. Ground contamination around leaks in waste transfer pipes is likely to be of regulatory concern.

11. Groundwater migration from contaminated areas within the ORNL operations area (such as ponds and transfer leaks) could enter White Oak Creek above the 7500 bridge sampling station, where contaminants entering the surface drainage would be attributed to floodplain discharge.

12. Studies of the ^{90}Sr, ^{60}Co, and ^{137}Cs content of streambed gravels in the pits and trenches area indicate that radionuclide migration may be occurring from pits 1 and 3 and from trenches 5, 6, and 7, but there is no evidence from surface-water monitoring to indicate a significant release of ^{90}Sr from the ILW pits and trenches area to the White Oak Creek drainage.

13. Radionuclide transport from waste burial trenches is primarily due to filling of the trenches with water (the bathtub effect) and subsequent surface flow from the lower end of the source trench. Surface flows may be supplemented by flow along fractures.

14. Shorter burial trenches and trench cover seals have apparently reduced, at least temporarily, the rate at which radionuclides are transported from the burial grounds.

15. Attempted mitigating actions such as shortening trench length, placing impervious covers over trench caps, or diverting surface water around burial trenches, may provide temporary reduction in ^{90}Sr outflow for a few years; however, the effectiveness of these measures over much longer periods of time remains to be proven.

16. Well monitoring data from burial grounds 4, 5, and 6 and from the seepage pits and trenches indicate a sequence of releases that could be predicted from the distribution coefficients of the emplaced radionuclides.

17. Strontium-90 appears to be the primary radionuclide that may cause effluents to exceed current or future standards for release at White Oak Dam. Any new source of ^{90}Sr buried in the near-surface shale can be expected to add to the total discharge at White Oak Dam, unless adequate measures are taken to control its release.

18. Tritium, as the next most important contributor to offsite dose from liquid effluents, must also be disposed with more consideration given to reducing its discharge to White Oak Creek.

RECOMMENDATIONS

1. ORNL should evaluate onsite exposures from releases to the atmosphere against concentration and dose limits for uncontrolled areas in assessing doses to onsite personnel who are not considered to be radiation workers.

2. ORNL should improve its monitoring capability to better establish the contribution to onsite and offsite doses due to ^3H in gaseous effluents.

3. ORNL should provide better documentation in its annual reports of the changes that are made in radionuclide transport calculations (e.g., airborne dispersion models) and in its dose calculations (e.g., the change in 1983 to ICRP-30 dose conversion factors). Documentation should include not only reference to the changes made, but also new estimates of dose values reported in previous annual reports.

4. Each annual report should include tables or figures that indicate trends in individual dose estimates for at least the previous 5 years (e.g., Table 8-1 in this report) as well as a tabulation of cumulative population doses from Y-12, ORNL, and ORGDP, separately and collectively. All dose estimates in such tables or figures should be corrected for any changes in calculations as recommended in 3 above, so that all the data presented are consistent in the methods used for calculation at least within that annual report.

5. ORNL should make a comprehensive, reservation-wide evaluation of its currently installed atmospheric emission control equipment with a view to determining which installations may be improved in a most cost-effective manner. Such an evaluation will be necessary to prove compliance with ALARA requirements regardless of the status of EPA's 40 CFR Part 61.

6. ORNL should take action to ensure that process waste pipes do not leak into the sanitary sewer system.

7. Prior to establishing new burial grounds in the White Oak drainage basin, future releases of ^{90}Sr and ^3H from burial grounds 3, 4, 5, and 6 and the seepage pits and trenches must be predicted quantitatively--and shown not to exceed regulatory standards.

8. Corrective actions should be taken on burial grounds either where future releases of ^{90}Sr and ^3H are expected to increase or where a substantial decrease of current ^{90}Sr and ^3H releases can be attained at reasonable cost.

9. ORNL should evaluate precipitation data monthly to correlate better the total ^{90}Sr discharges, average annual ^{90}Sr concentrations, and seasonal variations with stream flow.

10. ORNL should obtain the field data necessary to evaluate quickly whether or not diking, or shortening of trenches along slope gradient, enhances or decreases the amounts of ^{90}Sr eventually released at White Oak Dam.

11. ORNL should reduce the uncertainty in its estimate of the time required for the leachate from the pits and trenches to return to ambient pH conditions, and should determine whether this time is of importance relative to potential radionuclide release.

12. Groundwater migration at burial ground 3 should be studied in detail to obtain a better understanding of the influence of solution cavities on radionuclide transport from burial trenches.

13. More extensive use should be made of groundwater monitoring at burial ground 6 to compensate for the limitations of the surface-water monitoring system at that site.

14. ORNL should determine the extent to which radionuclide migration has occurred from the pits and trenches area. This should be done through the installation of a properly located and constructed monitoring system. There should be more frequent sampling of existing and new wells, as well as gathering of data from seeps, surface water, and lysimeters.

15. Research should be conducted with the aim of obtaining a better understanding of the implications of both the groundwater and the streambed sediment data, so that they can be coupled and put to effective use in predicting long-term trends in releases.

16. Inasmuch as the experience gained at ORNL can be of value to other groups involved in low-level waste disposal facility design, construction, operation, and regulation, it should be analyzed comprehensively and made freely available. ORNL should review the doses appearing in their previous annual reports and update them to reflect current calculational techniques.

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9

Disposal of Radioactive Waste in Hydraulically Fractured Shale

Hydraulic fracturing ("hydrofrac") in oil and gas field enhanced recovery practice is accomplished by the application of very high fluid pressures to potential reservoir rocks surrounding a borehole and the subsequent initiation and propagation of dominantly vertical fractures, followed by the preservation ("propping") of the fractures by the introduction of sand or other particulate material to create and maintain improved communication between fluids in the rocks and the well bore. Hydrofrac technology has reached highly advanced states through decades of experience and its application to tens of thousands of wells each year, and by continuing development for its application to ultradeep (greater than 8 km) boreholes. The technical literature is extensive, but many aspects of the method remain unsupported by theoretical studies. Petroleum industry and service company interest is almost wholly concentrated on deep applications and vertical fractures.

The results of natural hydraulic fracturing are found in rocks of the earth's crust where high fluid pressures at depth create fractures that are occupied by tabular masses of igneous rocks. Where magma viscosity is relatively low (e.g., molten basalt) and stratified rock successions exist, magmas rise to within a kilometer or two of the surface and spread laterally along stratification planes in the form of sills and laccoliths without ever reaching the surface. Great volumes (10^3 to 10^6 km^3) are disposed in this way, and are commonly preserved intact for periods of tens to hundreds of millions of years.

Although application of hydraulic fracturing to radioactive waste disposal is generally similar to oil field practice, the goal in radioactive waste disposal is the creation of impermeable geologic containment, while industrial hydrofrac is intended to increase effective permeability. There is also a similarity to the injection of naturally occurring sills and laccoliths; both involve emplacement of reactive liquids, gases, and solids, and both form stable, long-term methods of isolation destined to remain in place for millions of years.

APPLICATION OF HYDRAULIC FRACTURING TO RADIOACTIVE WASTE DISPOSAL

Hydraulic fracturing as a methodology for the disposal of low-level and intermediate-level radioactive waste has been investigated at ORNL for about 20 years and has been practiced, with significant success, for about the past 15 years. Figure 9-1 is an artist's concept of a hydrofracture facility. A considerable body of engineering documentation, usefully integrated and summarized (Sun, 1982; Weeren et al., 1982; Doe and McClain, 1984) has emerged from this research and development and is the basis for this section of this report.

As practiced at ORNL, disposal of radioactive liquids and slurries follows the sequence of steps outlined below:

1. Drilling and casing of a borehole to a depth of "several" hundred meters in the Pumpkin Valley shale of the Conasauga group by standard industry methods.
2. Selection of the borehole depth to be used.
3. Perforation of the casing and cement at the selected depth.
4. Initiation and propagation of horizontal fractures in host shale by injection of over a thousand liters (a few hundred gallons) of water under high pressure (approximately 20 MPa).
5. Injection of a slurry containing cement, ion-exchange clays, and intermediate-level waste (predominantly ^{137}Cs with minor proportions of ^{90}Sr and other radionuclides) at approximately 0.25 Ci/L and neutral to high pH. The initial injection rate is 1000 L/min. The injection process continues for 8 to 10 hours, and is terminated when the bins containing the dry material to be injected are empty.
6. Release of postinjection pore and fracture pressures by fluid bleed-back.
7. Detection and verification of the position of the fractures by gamma-ray logging in observation boreholes 45 to 60 m from injection well.

Four (occasionally as many as nine) injections are routinely made through the same slot (360°), after which that injected depth is plugged off and a new slot is cut 3 m uphole. In this manner, approximately 8×10^6 L (about 600,000 Ci) of radionuclides were injected between 1966 and 1982, at which time new surface facilities were installed and slurry and waste injections were continued.

THEORETICAL AND EMPIRICAL CONSIDERATIONS

Fracture in Isotropic Rocks

Induced rock fractures are created and propagated by hydraulic pressures that exceed confining pressures and the tensile strength of the host rocks. The orientation of induced fractures in rocks isotropic with respect to fracture strength is governed by the ambient state of stress at the point of application of hydraulic pressure. Major

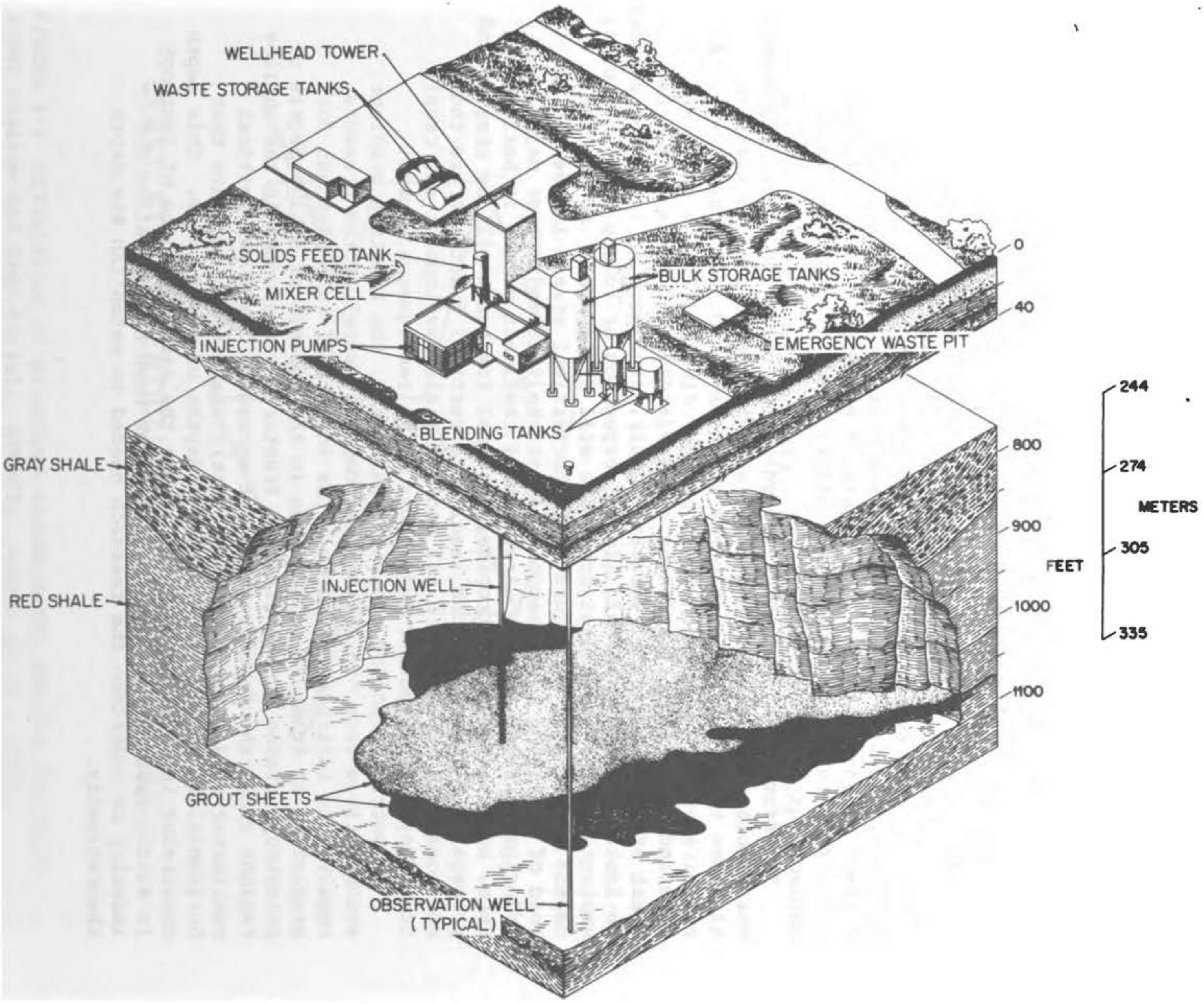


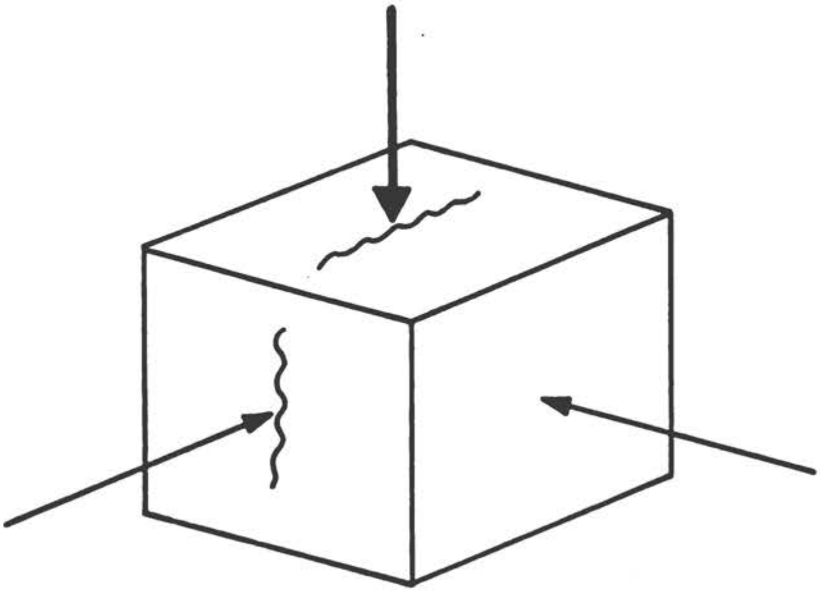
FIGURE 9-1 Artist's concept of hydrofracture facility.

components of the state of stress are gravitational, deviatoric, and hydrostatic. Gravitational stress (lithostatic pressure) is the product of the weight of the overlying rocks (in some places augmented by relict pressure, which may represent a once thicker overburden that has since been removed by erosion and/or by the transient weight of glacial ice, lakes, and seas). In the context of hydraulic fracturing, deviatoric stress refers to directed stress imposed by tectonic forces within the earth's crust. Hydrostatic pressure is the pressure on fluids in the pores of the rocks.

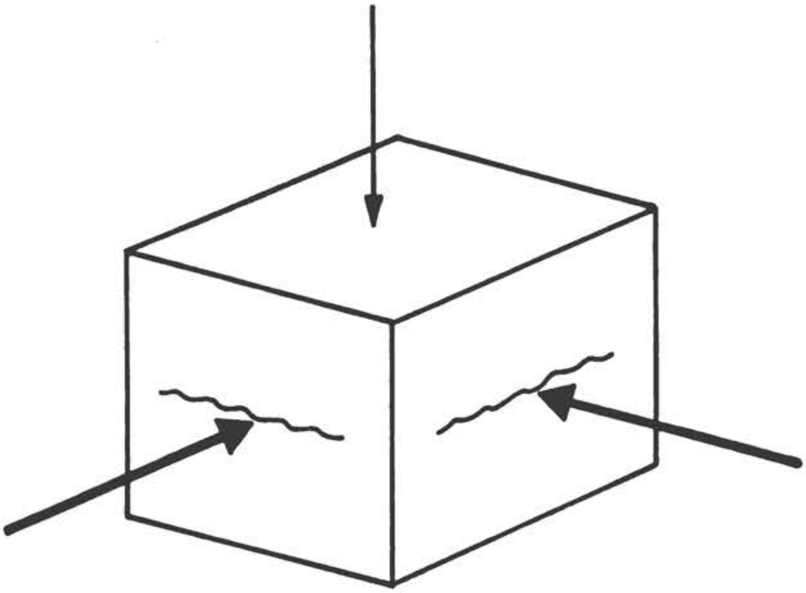
In the absence of significant relict stress, lithostatic pressures are a simple function of depth and the density of overlying rocks; the latter is readily determined by a variety of borehole measurements. Tectonic stress is commonly a poorly understood but determinable resultant of stresses imposed at the margins of lithospheric plates by interaction with adjacent plates. The pressure on pore fluids of rocks may be no more complex than the potential ("head") created by the overlying groundwater column, or the pores may be either "overpressured" or "underpressured" by virtue of hydraulic isolation from the pore systems of adjacent rocks. Hydrostatic pressures have little effect on hydrofracture in the impermeable shales used for grout and waste emplacement in the ORNL area.

The state of stress prior to hydraulic fracturing, then, represents measurable, predictable, and verifiable lithostatic and deviatoric stresses that are responsible for a stress field (see Figure 9-2). At relatively shallow depths (lower part of Figure 9-2) the major and intermediate principal stresses are deviatoric and horizontal, the least stress is vertical (gravitational). Inasmuch as induced fractures in isotropic rocks are unfailingly perpendicular to the least principal ambient stress, horizontal fractures will be created. At greater depths (upper part of Figure 9-2) the vertical stress imposed by the load of overlying rocks becomes either the intermediate or major principal stress, and the direction of the least stress is horizontal. Here, again assuming isotropism, vertical fractures will be created and propagated. The conditions leading to vertical fractures are those most commonly exploited in oil and gas field development and result from deep-seated tabular injections of molten igneous magmas.

Industrial practice applies a parameter, the fracture gradient, which derives from "formation breakdown pressure" or the pressure required to initiate fractures. The industrial rule-of-thumb for prediction of fracture orientation in the absence of a high degree of anisotropy states that horizontal fracturing is assumed in the shallow regions where the fracture gradient exceeds 0.3 kPa per vertical centimeter (1.4 psi per vertical foot); the formula suggests that horizontal fracturing is limited to depths of about 150 m. This depth constraint is rarely operative because the assumed degree of isotropy is seldom approached; further, there has been no motivation for industry to undertake the research needed to establish the depth theoretically.



LEAST STRESS HORIZONTAL; FRACTURE VERTICAL



LEAST STRESS VERTICAL; FRACTURE HORIZONTAL

FIGURE 9-2 Orientation of principal stresses and induced fractures under shallow and deep burial. SOURCE: Weeren et al., 1982.

Fracture in Anisotropic Rocks

Most rocks of the earth's crust are strongly anisotropic with respect to fracture genesis and propagation. Fracture in anisotropic (layered) rocks may be discussed in terms of two end-member states between which there is complete gradation.

Fracture in Homogeneous Successions

Stratified rocks, dominantly sedimentary, may constitute successions of nearly homogeneous layers. Fracture anisotropy in such successions is the result of the nature of the fabric of constituent mineral grains or of discontinuities in the succession representing surfaces of erosion and renewed deposition, or surfaces of temporary interruption of deposition. Of these, mineral fabric is the more important.

The most frequently encountered successions of homogeneous anisotropic rocks are shales, which commonly attain thicknesses from tens of meters to kilometers. Shales are made up of clay minerals in small (10 µm) plates that come to rest with their long dimensions parallel to the dispositional surface, imparting a strong preference for horizontal fractures if the shale beds have not been subsequently tilted or folded. Experimental data indicate that the tensile strength of shales normal to lamination (bedding) varies from 20 to 80 percent of bedding-parallel strength; 30 percent, a differential sufficient to strongly influence fracture orientation, is commonly assumed. Experience indicates that lamination-plane fractures are induced in homogeneous shale at depths significantly greater than those predicted by state-of-stress determinations or by the rule-of-thumb quoted above.

Fracture in Heterogeneous Successions

In the great majority of sedimentary rock successions the tendency to orient continuous fractures, natural and induced, parallel to stratification is greatly enhanced by vertical variability of successive layers of differing rheology. Variability and rheologic contrast are the product of differences in grain size, mineralogy, and degree of cementation representing changes in the environment of deposition and of the materials brought to the depositional site. Such successions inherently favor bedding-parallel fractures and inhibit the propagation of fractures that cross bedding planes. Bedding-parallel fractures are promoted by the natural fissility of shales discussed in the previous section plus the tendency of fractures to terminate at the plane contacts of beds or laminae of differing rheology.

Natural fractures (joints) exist in all bedded rocks, and two or more sets commonly cross bedding planes and create potential pathways for injected grout to intersect aquifers or the ground surface. However, joints capable of lateral extension to accommodate injected grout are almost exclusively confined to the more brittle strata in an inhomogeneous succession; they end as potential conduits on encountering ductile beds or laminae. Experience with inhomogeneous successions such as the Pumpkin Valley shale suggests that induced bedding-plane fractures may be propagated and grout filled for more than 100 m, whereas random encounters with joints in brittle fracture-prone beds result in grout injections that persist vertically for less than a meter, commonly no more than a few centimeters.

Effects of Inclined Bedding Planes

To this point, the discussion has considered only undeformed stratified successions in which the horizontality of ancient despositional surfaces is preserved. Inclined seafloor topography or, more commonly, tectonic deformation leads to inclined strata that may influence the orientation of induced fractures and grout emplacements.

Bed inclination is described by the strike (compass bearing of the trace of bedding on horizontal planes) and dip (inclination of bedding planes with respect to the horizontal). Rock mechanics theory predicts the depths given in Table 9-1 as limits of fracture propagation parallel to bedding planes in inclined strata penetrated by vertical drill holes.

Experience gained in markedly anisotropic and inhomogeneous successions such as the Pumpkin Valley shale suggests that these limits can be exceeded by as much as a factor of 2. Thus, it is possible that grout injection in the moderately to severely deformed strata at ORNL can be carried as deep as 1000 m or more.

Theory would also predict that fracture propagation and grout injection would be preferably upward from the injection point (toward a lower vertical stress component) at any relatively shallow injection site. The updip asymmetry of grout distribution about the injection point has been observed at ORNL where elliptical grout sheets with an axial ratio of 2:1 have been formed.

TABLE 9-1 Maximum Depths of Fracture Propagation Parallel to Bedding Planes in Inclined Strata

Dip, degrees	Depth, m
0 (horizontal bedding)	329
15	370
30	640
40	1800

SOURCE: Modified from Weeren et al., 1982.

HYDRAULIC FRACTURE AS A DISPOSAL METHODOLOGY AT ORNL

Geologic and Hydrologic Considerations

The Pumpkin Valley shale, the host strata employed thus far at ORNL, constitutes a succession of more than 100 m of anisotropic and heterogeneous beds, including a high proportion of clay-rich units. The latter are dominated by a mineralogy of illite, smectite, chlorite, and white micas with minor amounts of quartz and carbonates. The claystone units have intrinsic permeabilities of 10^{-3} to 10^{-6} mdarcys, which, in the absence of effective fracture permeability, means that water movements within the claystones would be less than 1 cm per 100 years. The clay minerals represented have high ion-exchange capacities for ^{137}Cs and ^{90}Sr, and presumably for many other radionuclides. The claystone beds of the Pumpkin Valley shale are interbedded with thin (up to 1 m) beds of more brittle siltstones, sandstones, and carbonates cut by joints normal to bedding; as noted in an earlier section, these joints do not participate effectively in hydraulic fracturing and grout injection.

A general rule of hydrology states that the rate of groundwater movement decreases exponentially with depth below the water table. The water table is very shallow at the ORNL injection site. Under natural conditions, given the moderate dips and modest topographic relief prevailing at the site, there should be no appreciable discharge from the potential aquifers (sandstones and carbonates) in the Pumpkin Valley shale; therefore, there would be no groundwater movement at depth. Again, under natural conditions, the primary movement of water from the injection site to Melton Branch would be by surface runoff and through the zone of partially weathered rock at and near the soil-bedrock interface.

Results of Slurry and Waste Injection at ORNL

At ORNL, individual injections of 300,000 to 600,000 L each have formed grout sheets that extend out to 200 to 250 m from the injection well. Limited drilling to determine the shape of grout sheets at an experimental facility at ORNL has indicated that the sheets are elliptical in shape and may extend asymetrically updip from the injection borehole.

Inasmuch as bedding-plane fractures induced at relatively shallow depths are achieved by lifting overlying strata, a detectable ground surface bulge is created during pumping and grout emplacement. The bulge, about 1 cm high, requires very precise leveling and/or the employment and interpretation of tiltmeter data acquired during injection for the production of an accurate map. The swelling of the ground surface is roughly centered over the injection well, rather than over the grout sheet.

The injection of water under high pressure and the subsequent injection of grout place stresses on the strata of the Pumpkin Valley shale. One result is the lifting of beds and the ground surface as noted above. Another product is an increase in the pressure of waters held in pore and fracture space of the injected beds. The elevated pressure field may be initially confined to a radius of 200 to 250 m from the injection well; completion of injection is accompanied by decay of the surface bulge and spread of elevated pore and fracture pressures well beyond the radius initially affected and by concomitant propagation of the injected fracture over a greater area. Logically, it is predictable that fluids, including contaminated water derived from the solidifying grout, spread beyond the grout sheet. This has been confirmed; a series of injections, through the same casing slot, were performed in January 1984 and were not followed by bleed-back of injection pressure. When monitoring wells were subsequently drilled at distances of 300 m from the injection well, low levels of ^{90}Sr and ^{3}H were encountered. Available data indicate that ^{90}Sr- and ^{3}H-contaminated water migrated, presumably by way of fractures created by the initial fracture-propagating pressures in the host shale, to the two monitor wells northeast and southwest of the injection well. The chemical composition of the water strongly indicates that the source was fluid emanating from the injected slurry. Excessive expansion of the contaminated zone may be attributed to the large volume injected at a single slot position, or to failure to follow normal bleed-back practice, or to both of these factors. Further, the monitoring wells themselves may have created pressure reduction outlets to which fluid moved preferentially. In any case, no contaminated water left the Pumpkin Valley shale, and no release to the shallow groundwater is detectable. However, the 1984 experience clearly demonstrates the need for further research to support the continued use and expanded application of hydrofracture as a disposal technology. Suggested avenues of investigation are included in "Recommendations."

Potential for Development of Other ORNL Sites

Large volumes, of the order of cubic kilometers, of the Pumpkin Valley shale and other similar units of the Conasauga group are available within the ORNL reservation, at appropriate depths. Detectable groundwater circulation in these shales is essentially limited to the relatively thin weathered zone. More information is required to define better the site-specific groundwater hydrology. Clearly, there are multiple opportunities for duplication of the successful operation established at the present disposal site; it is highly probable that other sites for similar hydrofracture disposal can be located in the Oak Ridge area and that low-level (and nonradioactive hazardous) waste can be disposed for decades to come; however, site-specific studies are needed to determine the future potential of this technology.

Extension of Hydrofracture to Other Waste

There should be little difficulty in concentrating liquid waste and reducing the volumes for grout injection. Solid waste, perhaps after incineration, can be ground to suitable grain size for injection. In current practice the injected grout contains a significant proportion of solids (cement, fly ash to retain strontium, a clay to control viscosity, a second clay to retain cesium, and a minor amount of gluconolactone to regulate setting time); these materials, in commercially available forms, are powderlike (passing 200 mesh and finer) in order to maximize grain surface areas. No such quality would be required of waste materials, which could be of any grain size compatible with the pumps, valves, and other equipment employed and capable of free access to the fracture space. In oil industry practice, much larger grains (up to 1 mm) are routinely introduced to prop open induced fractures and thus promote flow of fluids to the borehole.

There would seem to be no insurmountable barriers to adaptation of the methodology to higher-level radioactive waste in the form of both liquid and slurried, finely divided, solids, although safety factors involved in transport, storage at the injection facility, mixing, and pumping at high pressures all require attention. There is a possibility that heat generated by radionuclide decay might alter the physical and chemical composition of the grout and surrounding rocks, imperiling the hydrologic isolation of the injected material. However, the geometry of the grout sheets is such as to present very large areas per unit mass of grout for diffusion of heat. For example, no changes are observed in the wall rocks of igneous dikes and sills that would compromise their hydrologic properties, although such bodies are commonly orders of magnitude thicker than injected grout sheets and are emplaced at temperatures in excess of 1000°C. In fact, there are examples of oil and gas reservoirs in igneous dikes and sills; here, low-viscosity fluids at high pressures have been retained for tens and hundreds of millions of years. If the hydrofracture option were applied to the disposal of hazardous chemical waste, problems associated with waste heat generation would not be a factor--in the absence of possible exothermic reactions at depth.

EXTENSION OF HYDROFRACTURE TO OTHER SITES

It is implicit in this analysis of the hydrofracture experience at ORNL that the geologic and hydrologic conditions that make possible the disposal of intermediate-level waste are logically capable of duplication elsewhere. Field experimentation in Devonian shales at West Valley, New York (Sun and Mongan, 1974), for example, largely supports the findings of ORNL. Consideration of transfer of hydrofracture technology to other geographic locations would include the following partial checklist of required properties:

1. A water table shallow enough that fractures produced below it are subhorizontal rather than vertical.
2. The presence, at depths below the water table and in the zone of bedding-plane fracture, of potential host rocks embodying: (1) stratification of heterogeneous beds such that numerous rheologic barriers to fracture propagation across bedding exist; (2) low

dips--preferably ranging from horizontal to 30°; (3) anisotropy with reference to fracturing imparted by internal fabric of beds (fissility) as well as by heterogeneity; (4) abundance of clay minerals with high ion-exchange capacities; and (5) thicknesses of at least tens of meters.

These qualifications could be met, with greater or lesser difficulty, in every state of the Union. If the availability of thoroughly compacted water-laid sediments composed of the "normal" suite of detrital grains (quartz, clay, carbonate, and feldspar) is requisite, the greatest difficulty would be anticipated in parts of New England, Nevada, and Arizona. Elsewhere the opportunities are all but limitless.

RESEARCH NEEDS

Although the ORNL staff and their consultants have anticipated and resolved many of the engineering problems involved in hydrofracture and grout emplacement at ORNL, there remain a number of questions to be addressed before broad acceptance can be expected.

Radionuclide Ion-Exchange Potentials of Shales

The science of clay mineralogy has accumulated a large body of data on the behavior of specific ions in specific clays. These data are not representative, however, of systems in which grout containing radionuclides are placed in contact with a complex of clay minerals. In such systems, water from the grout invades the enclosing claystones and may result in ion exchange between the claystone and grout minerals. Research supported by experiment is needed to make possible predictions about the behavior of multicomponent solutions in contact with several, perhaps competing, clay species.

Effect of Prolonged Heat on the Permeability of Potential Host Rocks

As previously discussed, the heating of enclosing strata and alteration of critical properties, even by the radioactive decay of high-level waste, would probably be of a low order because of the high surface-to-mass ratio of thin grout sheets. Waste disposal literature abounds in hypotheses and model-generated data on the evolution of heat from "standard" waste forms. Studies are needed on thin grout sheets and the heat-conductive properties of potential host formations.

Given the level and rate of heat generation, further work is required to permit prediction of the nature and hydrologic significance, if any, of thermally imposed alteration of potential host rocks.

Determination of the Limits of Subhorizontal Versus Vertical Fractures

As noted, industry is little concerned with hydrofracture at relatively shallow depths; therefore, there is an insufficient body of data and theory to permit useful generalizations on the orientation of induced fractures, the influence of ambient crustal stresses, and the effects of various degrees of dip, heterogeneity, and anisotropy of host rocks.

Determination of the Extent and Position of Injection Sheets

Surface bulges created by fracture development and propagation are transient features and are not adequate descriptors of emplaced grout sheets. Precise leveling and tiltmeter surveys following grout injection and bleed-back indicate a correlation of such post-bleed-back data and grout sheet location and geometry. Microseismic monitoring during grout injection is also useful in tracking grout sheets during injection. Further refinement of early location of the position of emplaced grout can take advantage of continuing advances in high-resolution reflection seismic mapping that may offer possibilities of adaptation to the monitoring of grout sheets. High-frequency sources and recording, integration of P-wave and S-wave data, and the employment of downhole sources or detectors merit intensive investigation. It is likely that sufficient acoustic impedance contrast (reflection coefficient) is created at the upper and lower surfaces of grout sheets (especially before setting of the cement) to produce readily detected reflection-seismic events and refraction anomalies.

Earth movements during grout injection are accompanied by very low amplitude tremors. Such microseismic events are detectable by appropriate seismographic arrays: the resulting data are applicable to mapping of the extent and limits of the grout sheet.

Application to Volcanogenic Sediments

Enormous volumes of stratified tuffs and other fine-grained sediments of volcanic origin are available as possible host rocks for waste disposal--particularly in areas relatively poor in "normal" sediment successions. Some knowledge of the engineering properties of tuffs, breccias, and ignimbrites has been gained in the course of geothermal investigations; such rocks commonly have a high glass content, and much is known about the behavior of glass in the presence of heat-generating radionuclides, but there is no background of experiment or experience in the special context of grout injection.

The Lawrence Berkeley Laboratory (LBL) workshop on the rock mechanics aspects of waste disposal by hydraulic fracturing (Doe and McClain, 1984) has identified other research needs and proposes an extensive research program including extensive field studies, numerical modeling, and subsequent laboratory experiments. Prior to undertaking any site-specific study, it is imperative to understand the basic principles involved in the fracturing process. Published literature is available on this subject from such sources as the proceedings of the previously cited workshop.

SUMMARY

1. Grout emplacement of low- and intermediate-level waste has been conducted for more than 15 years at ORNL, and substantial volumes of waste containing significant amounts of radionuclides (including the two major fission products, ^{90}Sr and ^{137}Cs) have been disposed. Release of radionuclides to the biosphere, hydrosphere, or atmosphere, if any, is below detectable limits, and it would be difficult to formulate a scenario that would alter this fail-safe pattern.

2. Hydraulic fracturing has a long history of industry application and is continuously being upgraded; state-of-the-art technology is available through a number of nationwide service companies.

3. Grout injection is a close analog of naturally occurring igneous sills, some of very great age relative to the time scale of concern in radioactive waste disposal. Where such bodies have been emplaced in sedimentary strata of low permeability below the water table, there is no evidence of physical or chemical alteration without the intervention of postinjection thermal or hydrothermal events. There has also been no evidence of exposure to circulating water and the atmosphere. Where radioactive minerals occur in igneous bodies, the decay products, including gaseous argon, are commonly preserved.

4. Occurrence of ancient connate waters in shales and in porous and permeable rocks surrounded by shales is witness to the lack of hydrologic circulation in the absence of a discharge mechanism, and the most convincing demonstration is found in the occurrence and preservation for millions of years of natural fluids (oil, gas, and water) under high pressures in sedimentary successions.

5. The technique of hydrofracturing seems applicable to the disposal of other kinds of waste and to other areas besides eastern Tennessee, but additional research is needed before such extension of the method can be strongly advocated.

CONCLUSIONS AND RECOMMENDATIONS

The panel concludes that the placement of low- and intermediate-level radioactive waste by hydrofracture at ORNL has been satisfactory to date. Further application of this process at ORNL requires better understanding of the effects of the emplacement on the host rocks and on the groundwater system.

Application of the methodology to other waste forms and other sites has potential but must be supported by appropriate research.

The panel recommends that the following research be undertaken to support hydrofracture emplacement of low-level radioactive wastes at ORNL and other possible sites by hydrofracture:

1. Determination of the effects of bleed-back on the lateral dimensions of injected grout sheets and on the confinement of fluids derived from the grout.
2. Determination of the volumetric limits and maximum number of multiple injections through the same well-slot.
3. Determination of the depth above which significant vertical fractures are unlikely to be induced and propagated.
4. Determination of deep groundwater (emplacement depth) behavior under natural conditions.
5. Determination of the perturbation of deep groundwater behavior caused by grout injection.
6. Determination of factors affecting the long-term physical-chemical stability of the grout sheets and of the host shale in the presence of groundwater, injected fluids, and fluids released from the grout.

The panel recommends that the following research be undertaken to support application of hydrofracture emplacement to other waste and waste forms:

1. Determination of the effect of prolonged heat on the physical characteristics of the host rocks, for possible extension of the process to the disposal of high-level waste.
2. Determination of optimum injection particle size, for extension of the process to the disposal of solid waste.
3. Determination of waste-grout-groundwater-host rock interactions, for extension of the process to the disposal of chemical waste.

The panel further recommends that the continuing evaluation of the suitability of the hydrofracture process for the disposal of radioactive waste at ORNL be the subject of periodic peer review. When this process has been completed, the results should be published and given maximum dissemination.

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10
Waste Management Planning

The Oak Ridge National Laboratory is a major manufacturing and research site, within which waste management is a service function, albeit an important one. Operations at ORNL may continue long after the remaining areas hydrogeologically permissible for the disposal of waste are exhausted. The panel recognizes that the accumulation of radioactive waste began at ORNL approximately 40 years ago. Waste management problems exist--they cannot now be avoided by choosing a more favorable site for the operations.

In this chapter, the major issues facing ORNL in dealing with its radioactive waste management problems are reviewed. The management of gaseous, TRU, and liquid process wastes has been discussed elsewhere in this report, and it was concluded that these waste streams are now well managed. In the case of the problems that now pose the greatest difficulties--management of solid low-level waste and decontamination of contaminated surface soils and sediments--several of the different strategies that ORNL could pursue are examined. Review of laboratory plans has been greatly aided by the report, published in 1983, of the ORNL Committee on Radioactive Waste Long Range Planning (Planning Committee) (Ad Hoc Committee, 1983). ORNL plans to update this report biannually; the first update was published in June 1984 (ORNL, 1984). The reports identify and summarize the need for, and status of, plans for both management and project-type actions to improve waste management. While the panel commends this approach and concurs with many of the analyses and emphases of the committee, there are questions relative to the thrust of those plans, and certain omissions are evident. The focus in this chapter will be on these topics.

Especially important among the omissions is an institutional one--the failure by ORNL to integrate the evaluation of environmental impacts for various options that are interactive. For example, a draft environmental impact statement (DEIS) has been prepared for the Central Waste Disposal Facility (CWDF). However, no similar statement has been prepared for burial ground 7 or for the continued operation of burial ground 6, even though the effluents from the two burial grounds will be markedly altered by the directing of certain waste to the CWDF.

Several important aspects of ORNL waste management practices are mentioned in the panel report: offsite health impacts, conformance to regulations, compliance costs, and effects of waste management decisions on continuing ORNL operations. Impacts on the health of people living offsite are so small as to be trivial. Nevertheless, the burial ground effluents contribute concentrations of radionuclides in surface streams that approach or exceed various regulatory limits. The need to meet regulatory limits therefore was emphasized--although associated compliance costs and effects on continuing ORNL operations were also considered. Some other aspects, such as occupational exposures and public acceptance, are not considered here.

In its Five-Year Project Plan (ORNL, 1984), ORNL proposes a number of capital projects for facility and systems improvements whose costs would total approximately $161,000,000 for fiscal years 1985-1989. Many of these items can be categorized as "housekeeping" requirements (e.g., stack emission control and treatment, $45,000,000; environmental upgrade of monitoring systems, $8,500,000; replacement of the low-level waste system, $48,000,000; and low-level waste transfer and processing projects, $12,000,000). Some generic, mostly supportive, comments have been provided in Chapters 6 and 8 of this report on many of the issues to which these items apply. For many of the items the need for such work is so closely related to specific needs at the site that the panel could not, in its limited time, consider their justification; this is particularly true for the many cases where total expenditures are large, but individual items cost only a few hundred thousand dollars each. In general, the panel supports the bulk of these proposed projects.

Some capital projects (e.g., Central Waste Disposal Facility, $7,500,000, and backup to hydrofracture, $10,000,000) are so at odds with the panel's findings that they will be given special consideration in this chapter. Also, some of the proposed projects under "Operating Costs" are so poorly supported (e.g., cleanup of White Oak Lake, $49,700,000, and contaminated ponds, $55,570,000) that they also deserve comment.

CRITERIA FOR ASSESSING ORNL PLANS AND PRACTICES

Reducing the health risk to the population from radioactive effluents to acceptable levels and maintaining them there is the goal of waste management. In Chapter 8, the risks posed by current releases were found to be small. The 0.13-mrem/yr whole-body exposure from the Kingston water supply increases the lifetime (70 year) cancer risk for any individual there by no more than one in one million, a very small increment over the "normal" risk of approximately one in five that anyone will develop cancer. The estimated dose to Oak Ridge residents from gaseous emissions is 0.44 mrem/yr. It should be recognized that the estimates of cancer risk are based on the hypothesis that such low doses will, in fact, cause cancer--a hypothesis that cannot be confirmed by data now available.

Meeting regulatory requirements is another criterion for assessing the effectiveness of a waste management program. It was noted in Chapter 7 that some regulatory limits are based on the hypothetical maximally exposed individual who lives at the site boundary, whose exposure comes in the case of ORNL from consuming large quantities of fish and water from the most highly contaminated accessible areas. The current standard for the maximally exposed individual in the environs of DOE facilities is 500-mrem/yr whole-body exposure (U.S. DOE, 1981), but 100 mrem/yr to the whole body is being considered in draft DOE orders for continuous long-term exposure of an individual living offsite (A.F. Kluk, U.S. DOE, personal communication, 1984).

The panel does not discuss what standard is more appropriate but recognizes that regulatory requirements are tending toward lower dose limits and reviews the implications of using different standards. Not only are the standards in flux, but the choices of dose limits involve symbolic and political issues as much as they do questions of associated health risks. However, assessment of ORNL's plans for waste management, and the consequent costs to the taxpayers, depend crucially upon what standards are likely to apply now and in the future--which we cannot predict. In addition to the issue of the dose limit itself, two other factors that affect regulatory compliance are the method used for converting radionuclide intake into dose equivalents and the location at which exposures are measured or calculated.

ORNL has adopted new methods recommended by the ICRP (ICRP-26 and -30) for calculation of effective whole-body and organ doses from intake of radionuclides. The chief consequence for ORNL of the new ICRP dose conversion factors is a substantial reduction in the calculated whole-body dose from consumption of food and water containing ^{90}Sr--one of the principal radionuclides present in effluents from ORNL burial grounds. The doses from some other nuclides (e.g., ^{60}Co) are increased by the new ICRP conversion factors, but these increases are not as large a change as the reduction for ^{90}Sr. New methods used by ORNL for calculating radionuclide transport and uptake have compensated for the impact of the dose conversion factors, so that the net effect is small, if any, on the calculated doses associated with ORNL releases.

Another, more arbitrary and less scientific, parameter is the choice of where to measure exposures. If the location where institutional control is lost is considered to be White Oak Dam, the last point at which release measurements are made, the estimated exposure rate is threefold greater than at the mouth of the White Oak Creek, where it empties into the Clinch River, and more than 400-fold greater than in the Clinch River, where even more dilution occurs. Using measurements at the dam, ORNL is in close compliance with the existing 500-mrem annual dose limit. Change to a 100-mrem/yr standard might put ORNL over the limit, if application of the limit is stipulated to be at White Oak Dam or in the embayment. Measurements in the Clinch River might ensure compliance with either standard, if mixing were complete at the point of release into the Clinch River.

There is a certain irony about the focus on exposure levels, when decisions about where to measure have an equally important effect on the regulatory consequences. Both are policy decisions that need to be addressed in the standards, not left to the discretion of each facility. Until the issue is resolved, officials at ORNL will not have the guidance that they need to make planning decisions. Regulation will be incomplete unless these questions are resolved when applicable DOE orders are published in final form.

Waste management plans must balance both public acceptability and the costs of different methods for reducing exposures to workers and the public. The panel notes that ORNL, in its Five-Year Project Plan (ORNL, 1984), has included as remedial actions the cleanup and stabilization of White Oak Lake and certain holding basins and ponds. Many proposed remedial actions, such as those just cited, are expensive and provide little, if any, real reduction in offsite exposure to radioactive materials. It is recognized, however, that various agencies, both federal and State of Tennessee, are also considering the effects of hazardous chemical contamination of these areas--this report considers only the value of the suggested actions in reducing radiological risks.

Some of the more expensive, low-risk, items from the planning document are addressed in more detail in the discussion below.

ALTERNATIVES FOR DISPOSING OF SOLID RADIOACTIVE WASTE

The Problem

Currently, releases from the solid radioactive waste burial grounds contribute most of the radioactive material that reaches the Clinch River. Hydrogeological conditions that characterize much of the ORNL site are responsible for most of this release because waste previously buried was not packaged for this hydrogeological regime. The lack of better sites, combined with the uncertain success of efforts to compensate for site defects, suggests that the radionuclides from waste buried at ORNL will continue to escape into surface waters--unless future burial practices are radically different from past ones. ORNL is unable at this time to make an accurate analysis of the levels of future releases from waste either already buried or to be buried in the future. Releases from burial grounds appear likely to remain the major source of potential offsite exposure.

The information in Chapters 6 and 8 suggests that hilly terrain, a relatively impermeable fractured burial medium, a shallow water table, heavy rainfall, and proximity to surface water all make the ORNL site a poor hydrogeologic choice for shallow land radioactive waste burial. There is evidence that all of the burial grounds have leaked. When major improvements in the treatment system for process waste were made in the 1960s, the burial grounds became the prime source of the remaining releases. During the last decade, and especially the last few years, a number of remedial actions at the burial grounds have been undertaken. Their success remains questionable, largely because of the difficulty in predicting what releases would have occurred without them and, in the case of burial ground 4, because a design error in the remedial runoff diversion system installed in 1975 appears to have increased rather than decreased releases. In any case, remedial actions at the burial grounds prior to 1983 have not sufficed to completely shut off the flow of leachate--and the success of the 1983 actions remains to be evaluated.

Converting a long trench whose axis is sloped downhill into several short ones may temporarily reduce the amount of water escaping over the lower rim of the trench, because a longer time is required to fill the several smaller "bathtubs" so created. It may, however, place more of the waste in contact with water, and thus cause a long-term increase in radionuclide escape when the chain of bathtubs begins to overflow or when water seeps through the fractured shale.

The extent to which the release of radionuclides depends on the volume of water entering a trench is not understood. If no water enters the trench, the waste will not dissolve and radionuclides will not migrate. However, it is not known whether larger quantities of water carry out more radioactive material or merely serve to dilute its concentration.

It is possible that some of the releases from the burial grounds have been due to poor waste-handling techniques--e.g., random placement of half-empty drums into the trenches or absence of waste treatment and packaging--which current practice now attempts to control. However, the data provided so far by ORNL provide no assurance that future releases will decrease as a result of the remedial actions already taken or planned.

Present and Projected Waste Generation

Table 10-1 presents the volume and radionuclide (Ci) content of various categories of waste generated annually at ORNL, grouped according to contact dose rate into Type I (less than or equal to 200 mR/h) and Type II (more than 200 mR/h). ORNL assumes for planning purposes (Ad Hoc Committee, 1983) that these generation rates will continue in the foreseeable future. The volume will be further increased if major facility decontaminating or decommissioning effort is undertaken.

The Central Waste Disposal Facility Situation

ORNL has joined with the Y-12 Plant and with ORGDP in plans for a Central Waste Disposal Facility in which the lowest activity waste (that termed Class A in 10 CFR Part 61) will be placed--a volume of about 5700 m^3 (200,000 ft^3) per year containing a total of only 500 to 600 Ci, primarily ^3H, ^{137}Cs, ^{90}Sr, and a large quantity of uranium.

The chosen site--Chestnut Ridge--is located between ORNL and the Y-12 Plant. Selection of Chestnut Ridge was based on the following advantageous features:

1. It is an unused and undeveloped area.
2. It is readily accessible.
3. Surface and subsurface drainage is not into White Oak Creek.
4. The depth of soil and weathered rock exceeds 20 m in many areas.

TABLE 10-1 Annual Generation of Waste at ORNL

	Volume, m^3 (ft^3)	Quantity, Ci
Type I Solid Waste (surface dose rate less than 200 mR/h)		
Combustibles	420 (15,000)	7
Metals	570 (20,000)	360
Glass	57 (2,000)	40
Rubble	590 (21,000)	400
Type II Solid Waste (surface dose rate of 200 mR/h or more)		
Combustibles	71 (2,500)	2,500
Noncombustibles	170 (6,000)	2,000
Sources	0.3 (10)	50,000

SOURCE: Chandler et al., 1982.

5. The water table is relatively deep, lying below the bedrock surface in many places.
6. The high silt and clay content may provide good sorptive and ion-exchange capacities.

In contrast to these favorable considerations, however, there are several features that are unfavorable; for instance, the proposed CWDF site does not meet the hydrogeologic criteria established by DOE for selection of low-level radioactive waste sites because the setting is that of a karst area, where sinkholes occur on the land surface and cavernous solution openings occur beneath the surface. Locally high and erratic permeability results from the preferential flow of water and from extensive solution along joints and bedding planes in the Knox dolomite. Water seeping through the soil is weakly acidic and enters the fractures and solution openings, where it can flow quickly to a spring or continue underground in channeled flow to the Clinch River, bypassing much of the sorptive and ion-exchange capacity of the soil.

The design of a surface waste facility must consider a catastrophic event common to this type of karst setting as well as potential leaks to the underlying groundwater system. In the southeastern United States, in geologic settings similar to that at Chestnut Ridge, catastrophic collapse of surficial unconsolidated material into underlying sinks and caves is common.

Despite intensive studies of the site now in progress, uncertainties as to the precise behavior of the groundwater in the Knox will continue to exist. The site therefore has serious geologic limitations, including the unsuitability of karst settings for waste sites in general and the uncertainties about groundwater movement. These limitations must be weighed carefully before the Chestnut Ridge site can be accepted for the Central Waste Disposal Facility. In addition, studies in progress must demonstrate that attenuation by sorption on the clays as well as dispersion and dilution adequately reduce released radioactive material to limiting levels at the point where the entraining water must meet regulatory controls. The DEIS for the CWDF failed to address attenuation satisfactorily because the impact calculations have been performed only under conditions where the entrained radioactive material exchanges with the surficial soils.

A separate question is whether the facility would, in fact, be restricted in perpetuity to low-activity, low-level waste. Such restriction may make possible, as discussed below, some degree of tolerance for leakage from the waste.

Current plans for the CWDF are to excavate 90 m (300 ft) by 45 m (150 ft) trenches at the top of the ridges. The trenches will be provided with thick plastic side liners to reduce the likelihood of water infiltration and with a gravel and sand base for water removal if it does accumulate. The lifetime of the liner is uncertain.

The trenches are to be covered with plastic and protected by a sand and gravel cap. However, an attempt to use plastic covers to seal existing trenches at a closed commercial radioactive waste burial site at Maxey Flats, Kentucky, has failed. Similarities in geology and hydrology between ORNL and Maxey Flats raise questions about the adequacy of this method for controlling water intrusion.

Inasmuch as the site does not drain into the White Oak Creek system, the establishment of a new and extensive monitoring system would be mandatory. Shifting potential discharges to another drainage basin might prove advantageous, however, because it would reduce discharges of radioactive material over White Oak Dam.

A key question is whether the concentrations of radionuclides in the waste to be buried at Chestnut Ridge are so low that poor confinement would not constitute a serious release problem regardless of its hydrogeologic deficiencies. For example, only 7 Ci of activity will be buried in the 420 m^3 (15,000 ft^3) of compactible (combustible) Type I wastes from ORNL. Metal waste contains considerably more activity, but should leach at a slower rate than other waste; if necessary the readily mobilizable surface activity could be removed and the decontamination liquids directed to the hydrofracture facility. Glass waste could be crushed and diverted to hydrofracture, as has been suggested (Chandler et al., 1982). Current plans call for less than 20 Ci/yr of uranium and transuranics from the Y-12 Plant and less than 5 Ci/yr of uranium and ^{99}Tc from the ORGDP; rubble from ORNL would be the only remaining significant contributor of activity. ORNL has not performed an analysis of the health impact from the collapse of the burial ground into a karst.

The Burial Ground 7 Situation

The site proposed for the location of burial ground 7 (which is intended to supplant burial ground 6 when it is full) is in the Melton Valley, within the White Oak Creek monitoring system used for the other burial grounds. Burial ground 7 is to receive all of the higher-activity solid waste from ORNL (mostly Type II, or Class B and C in 10 CFR Part 61 terminology). The average concentration of radionuclides per cubic foot of waste is expected to be much greater in burial ground 7 than it is now in burial ground 6, resulting in much more radioactive material emplaced per acre. Water intruding into the more highly contaminated waste at burial ground 7 could lead to greater discharge rates over White Oak Dam.

Although studies are not yet complete, the site appears to be geologically and hydrologically similar to the other burial grounds. It is on the same ridge alignment as burial ground 5 and burial ground 6, and therefore some of the same beds may underlie each site. The trenches would be located as little as 300 m from the nearest stream. The water table may be slightly deeper on the uplands than at other burial grounds, but the surface slope is usually steeper.

Shortcomings of the site might be compensated for by using better waste forms and waste packages and by improving on the engineering methods at emplacement to minimize leaching. Consideration of such compensation factors would be aided greatly by preparation by ORNL of a planning document similar to that prepared for the CWDF.

The Burial Ground 6 Situation

In burial ground 6, the highest activity waste (over 5 R/h at contact) is placed in steel drums, which are stacked in narrow auger holes and capped with concrete plugs. Waste that is less than 5 R/h, but more than 0.2 R/h, at contact is placed in 5-m-deep trenches in 83-L (22 gal) pails or in boxes, casks, or thin plastic wrapping. The volume of the Type II waste going into burial ground 6 was estimated to be either approximately 54 m^3 (1900 ft^3) per year (Clancy et al., 1980) or approximately 240 m^3 (8500 ft^3) per year (Chandler et al., 1982).

If the CWDF is opened for operation, the waste going to the remaining space in burial ground 6 will consist entirely of the Type II (or Class B and Class C) waste. As with burial ground 7, the much greater concentration of radionuclides in the Type II waste will lead to a greater amount of radioactive material per acre in the remainder of burial ground 6; this could result in increased concentrations of radionuclides released past White Oak Dam. The present practice of auger-hole emplacement may be successful at burial ground 6, in part because only a small portion of the site (and that at the highest elevation above the water table) is used and in part because the greatest proportion of the acreage is used for trenches that serve as a drain field that transmits groundwater to lower elevations. Unfortunately, no data are available to judge the amount of leakage (or absence of leakage) of the higher-level wastes that have been packaged in durable containers and emplaced in capped auger holes in the older burial grounds. It is not clear whether auger holes will remain the option of choice for emplacement in lower-lying ground or whether more holes will fill with water when trenches are no longer available to drain the new sections of the burial ground.

Alternative methods considered for burial ground 6 (Clancy et al., 1980) include concrete modules, which could be placed above ground. This method has been endorsed for further study by the Planning Committee (Ad Hoc Committee, 1983), which recommended converting a current small-scale program investigating the use of concrete boxes for below-ground waste burial into a research and demonstration project for above-ground disposal. Although it may be argued that above-ground disposal is only a temporary storage method, it may be the most cost-effective way at ORNL to prevent excessive releases from the high-activity waste.

Disposal Alternatives for ORNL Solid Waste

The following discussion of disposal alternatives provides suggestions for reducing radioactive effluents from future disposal operations. Because the data now available are insufficient to predict whether effluents from existing burial grounds will increase or decrease, the panel could not assess whether adoption of the alternatives by ORNL would assure meeting regulatory requirements; implementation should, however, help ORNL to reduce effluents below levels that would be present otherwise.

Site selection criteria for screening low-level waste disposal sites have not been systematically used in the past at ORNL. Unfortunately, the seven DOE site selection criteria (Lee et al., 1983) are too general to specify favorable or unfavorable characteristics of particular sites on the reservation. A restudy of site selection methodology and a reevaluation of sites on the reservation are needed. The U.S. NRC has, in 10 CFR Part 61, set forth criteria for the selection of suitable sites for the disposal of low-level radioactive waste.

Improved Waste Packages

Improvements in burial methods have been attempted at ORNL for a long time. Much of the material presented in Chapters 3, 5, 6, and 8 of this report deals with site conditions and with attempts to cope with them, such as better placement of trenches or auger holes or attempts to divert water away from the trenches. Burial of waste in concrete boxes may retard the rate at which radionuclides would be leached, but still water will intrude and leach the waste, unless the package is made impervious. ORNL should consider using 300-year, high-integrity plastic containers as now used in the nuclear power industry.

The panel was not able to find any comprehensive cost analyses of low-level radioactive solid waste disposal at ORNL. One major study of the costs of future disposal options has been published (Chandler et al., 1982). For all options, it assumed that new capital facilities would be required, for example, for compaction or incineration. Compared to the costs of treating the waste, which are dominated by the capital facility costs (discounted at 10 percent over a 20-year life), the cost differences attributable to "storage/disposal" options were quite small--often differing by only $35 to $70 per cubic meter ($1 to $2 per cubic foot) and never more than $500 per cubic meter ($14 per cubic foot). The storage/disposal options considered varied from burial of concrete boxes or carbon-steel drums in unlined trenches to disposal in hydrofracture. The small size of these differences suggests that the more expensive storage/disposal options are probably worthwhile if they can achieve any significant reduction in releases.

As an illustration of the possible costs of one option for improved shallow land burial, Table 10-2 shows the costs (ignoring the value of the land itself) for burying all waste types in concrete boxes (waste volume and activity were set forth in Table 10-1). The treatment costs for Type I waste would be just over $2 million per year. Storage and disposal costs would range from $250 to $700 thousand per year. For Type II waste (except sources), treatment costs would be almost $3 million per year, and storage/disposal costs would run from $50 to $150 thousand per year. To the extent that existing facilities could continue to be used, the costs would be lower.

Waste Preparation for Hydrofracture Disposal

For the reasons discussed in Chapter 9, the panel believes that the hydrofracture technique is promising for disposal of higher-activity waste and that analyses should be conducted on the preparation of various wastes, including some solid waste, for emplacement by hydrofracture. Possible approaches include conversion to hydrofracture grout of such products as incinerator ash and anaerobic-digestion sludge from combustible solid waste, crushed glass, and liquids from decontamination of metals. Except for crushed glass (a current option), these have all been described by the Planning Committee as likely to be available within the next 10 years (Ad Hoc Committee, 1983). Although the Planning Committee report calls for increased reliance on hydrofracture as a key element, it contains no specific plans to implement its increased use.

The chief current option for treating the biogenically degradable waste is incineration, although a prospective method now being tested in a pilot plant is anaerobic digestion. Both methods apply only to the combustible waste--less than half of the Type II waste; both produce residues that could be disposed by hydrofracture; and both have the potential to cause radioactive releases to the atmosphere.

Aside from possible air pollution problems--which do not appear to have been well evaluated by ORNL--the major drawback of incineration is claimed by ORNL to be cost. If only high-activity combustible waste were incinerated (about 70 m^3 or 2500 ft^3), the cost has been estimated at approximately $35,000 per cubic meter ($975 per cubic

TABLE 10-2 Annualized Costs of Disposal of Wastes at ORNL in Concrete Boxes

Type I Waste	
Cost of shared facilities	$486,000
Treatment costs	
Combustible	490,000
Metal	561,000
Glass	96,000
Rubble	579,000
	$1,726,000
Storage and disposal costs (range)	
Combustible	$1,500-2,500
Metal	2,000-4,000
Glass	80,000-220,000
Rubble	168,000-462,000
	251,500-688,500
	Total $2,463,500-2,900,500
Type II Waste	
Cost of shared facilities	$1,104,000
Treatment costs	
Combustible	696,000
Noncombustible	1,115,000
	$1,811,000
Storage and disposal costs (range)	
Combustible	$10,000-25,000
Noncombustible	42,000-120,000
	52,000-145,000
	Total $2,967,000-3,060,000

SOURCE: Chandler et al., 1982.

foot) (Chandler et al., 1982). The ORNL cost estimates for incineration, both for capital construction and for operations, are much greater than estimates prepared for incineration of both types of waste by nuclear power plant operators. Total incineration costs for nuclear power plants would be \$2 to \$5.50 per kilogram (\$1 to \$2.50 per pound), depending on the specific system selected (Kupp, 1984), while associated operations (shredding, crushing, and grinding) add another \$10,000 per cubic meter (\$300 per cubic foot).

The unit cost of incineration could be reduced if distributed over a larger waste volume by including Type I combustible waste in the same system. An incinerator capable of handling this waste stream is under construction at ORGDP; consideration should have been given to ORNL requirements in sizing this unit. However, the Chandler study assumes that a different type of incinerator would be needed for each waste type. This assumption may be unduly conservative in view of the successful experience at facilities in the Federal Republic of Germany and in Japan in using a single incinerator for incineration of both low- and intermediate-level waste, and in view of the aforementioned plans for U.S. nuclear power plants. According to the Chandler study, the incinerator for the Type I waste would cost about \$14 million compared to \$20 million for a Type II incinerator. The process of incineration and burial of Type I waste via hydrofracture would cost about \$5300 per cubic meter or \$150 per cubic foot (\$2.3 million for the 425 m^3, or 15,000 ft^3, each year) more than the cheapest alternative considered in that study--tenfold compaction, packaging in fiber boxes, and trench burial. Considering that this \$2.3 million expenditure would divert only 7 Ci/yr from shallow land burial and reduce shallow land burial volume by only 42 m^3 (1500 ft^3/year) (about 2.5 percent of the annual volume), incineration of this waste could be difficult to justify.

The only cost figures available for anaerobic digestion (J.D. Sease, ORNL, personal communications, April 20 and 22, 1983) indicate that this method would cost roughly one-tenth that of incineration, and one-third that of compaction for Type I combustible waste, although, as indicated above, ORNL's estimates for incineration appear high. If air pollution problems associated with the process are not significant, it may be a useful alternative for preparing appropriate solid waste for shallow land burial or hydrofracture disposal. If anaerobic digestion can also be applied to preparing the Type II combustible waste for hydrofracture, its development might deserve a very high priority.

Incineration offers an advantage over digestion in that it can help solve one of the most critical problems at ORNL--disposal of liquid scintillation fluids; it is not clear that digestion can reduce the toxicity of the scintillation fluids.

Near-Surface and Above-Ground Disposal

The uncertainty as to whether shallow land burial at ORNL can dependably protect waste from water infiltration and leaching requires that other options be considered. One approach to keep water from intruding would be to use storage buildings or above-ground concrete modules, a second would be to use concrete monoliths and soil mounds (tumuli).

Modules. Alternative methods considered for burial ground 6 (Clancy et al., 1980) included concrete modules that could be placed above ground. This method was endorsed for further study by the Planning Committee, which recommended converting a current small-scale program investigating the use of concrete boxes for below-ground waste burial into a research and demonstration project for above-ground disposal.

Although it may be argued that above-ground disposal is only a temporary storage method, it may be the most effective way at ORNL to prevent excessive releases from the high-activity waste. It should be noted that burial has not guaranteed permanence; not only has some waste at ORNL had to be dug up and reburied, but some of the burial practices have also led to releases that, if the monetary and worker exposure costs were not so great and population dosages so low, might make limited exhumation desirable.

Tumuli. This approach appears especially attractive for a disposal site like that at ORNL; it has been used for nearly 15 years in France (Lavie and Marque, 1983) (Figure 10-1). Type II and higher-activity Type I waste could be emplaced in asphalt-coated near-surface concrete monoliths. Type I waste could be packaged in concrete modules or steel drums for emplacement on top of the monolith as above-ground soil-covered mounds called tumuli. Each monolith and tumulus has a collection and treatment system should any seepage occur. Emplacement costs (at the 1982 exchange rate) are approximately \$880 to \$1400 per cubic meter (\$25 to \$40 per cubic foot) for waste in tumuli and \$1800 to \$5300 per cubic meter (\$50 to \$150 per cubic foot) for those in monoliths (Lavie and Marque, 1983).

The French system of disposal, while providing for greater protection against the release of effluents offsite, is not without drawbacks. Radiation exposures to individual workers are in the range of 1 to 2 rem/yr due to the greater care exercised in emplacement (Sousselier et al., 1983). Also, prevention of cover degradation requires maximal compaction and treatment (Sousselier and Van Kote, 1983), such that combustible waste must be incinerated or otherwise degraded before it is accepted for disposal. Thus the incineration of even degradable Type I waste may be required at ORNL. If anaerobic digestion were to be used, conversion of liquids and sludges to solids would require additional work and cost.

DOE has already considered the use of tumuli as the method of choice for disposal at ORNL of waste generated by its FUSRAP program (U.S. DOE, 1984). Their study looked in detail at the stability of the tumuli against erosion, and found them to be more than sufficient for disposal for at least 1000 years. Disposal costs were estimated to be \$190 per cubic meter (\$5.50 per cubic foot). Since this waste is only soils or soil-like residues, pretreatment was not necessary.

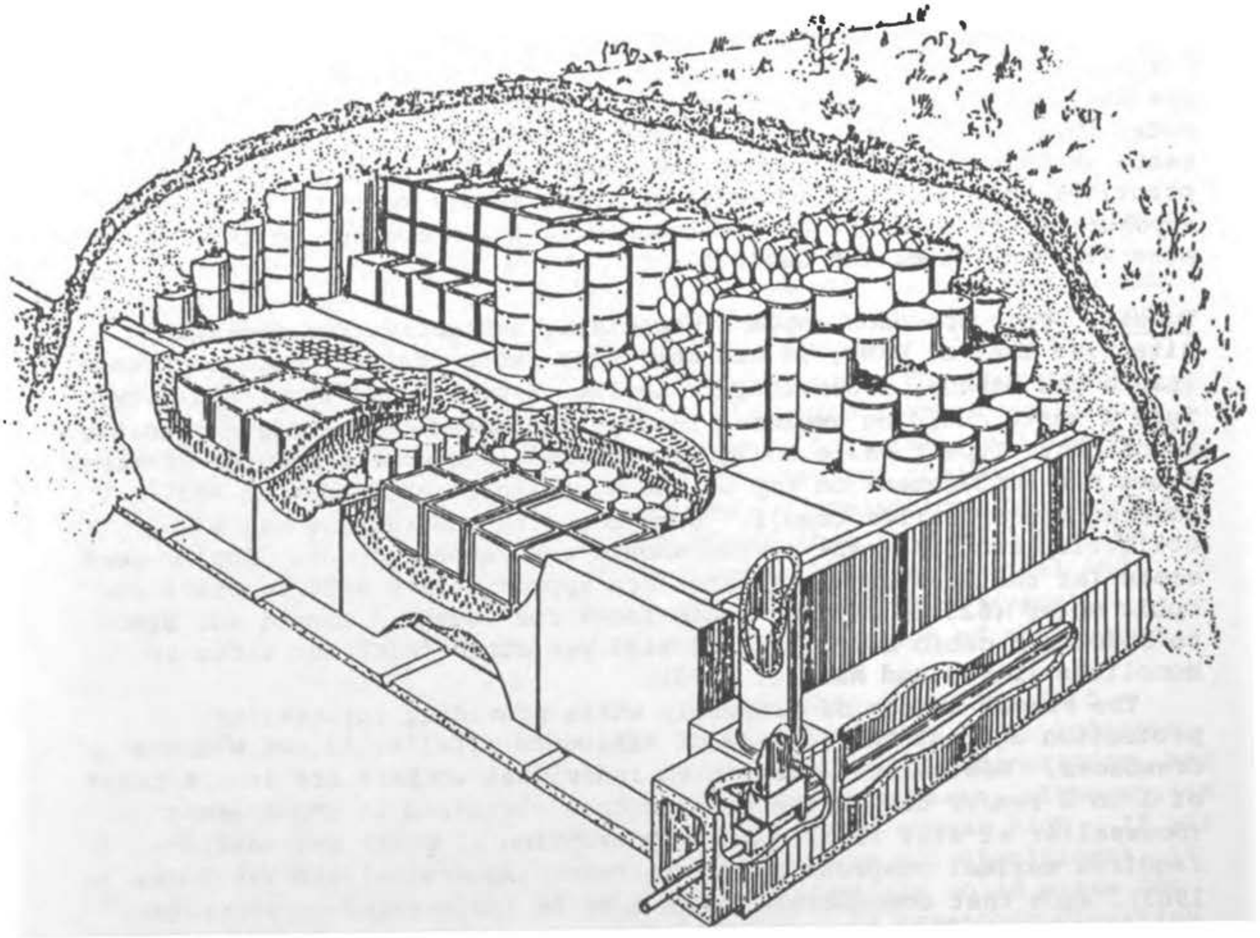

FIGURE 10-1 French disposal method.

Shipment Offsite

According to ORNL officials, the DOE currently rules out the option of shipping radioactive waste off the Oak Ridge Reservation. In contrast, ORNL does ship toxic chemical waste to offsite dumps. Some other DOE national laboratories (e.g., Lawrence Berkeley, Lawrence Livermore, Brookhaven, and Argonne) also ship small volumes of solidified, packaged radioactive waste offsite. Shipment of future waste offsite raises questions about risks from transportation accidents and occupational exposures, but the main issue--aside from public acceptance--appears to be one of cost. The panel has found no estimates by ORNL of the costs of shipping offsite; however, commercial nuclear facilities and nuclear power stations routinely ship their low-level waste offsite, and cost figures for such shipments are available from the Electric Power Research Institute (EPRI) and the National Low-Level Radioactive Waste Management Program (NLLRWMP).

Table 10-3 presents data from EPRI estimates of the costs for transporting low-level radioactive waste 1300 km (800 mi) from a boiling water reactor site to the commercial burial site at Barnwell, South Carolina. The EPRI figures do not include the capital costs of the facilities used to prepare the waste for shipment (e.g., buildings and compactors). To develop an estimate for the circumstances at ORNL, the capital costs from Chandler et al. (1982) were used for the least expensive method of treatment for each type of waste. Transportation cost estimates were based on data from the NLLRWMP publication "Directions in Low-Level Waste Management" (U.S. DOE, 1983a). Rates for unshielded shipments as of January 1, 1983, were $3.46 per cubic foot for a 3200-km (2000 mi) trip (one-way) and $4.17 for a 4000-km (2500 mi) trip. For shielded waste, the same costs (except for round trips in order to return the casks) were $51.53 and $63.98. Hanford is within that distance range. Assuming some inflation since 1983, the panel has used figures of $4.50 for unshielded shipments and $70 for shielded. Shipments to Savannah River would be approximately one-fourth those values.

In Table 10-3, burial costs seem to be the single most important factor for disposal of commercially generated waste. Commercial waste sites now have a basic charge of approximately $880 per cubic meter ($25 per cubic foot) along with surcharges for high-curie-content waste or others requiring special handling. In the EPRI data, the burial costs range from about $565 per cubic meter ($16 per cubic foot) for the low- activity waste to almost $2500 per cubic meter ($70 per cubic foot) for the highest activity waste. These costs have increased sharply in recent years due to the closure of some burial sites and host state attempts to limit the waste buried while increasing the revenues gained from operations. Burial charges as great as $18,000 per cubic meter ($500 per cubic foot), though rare, have been imposed at the commercial sites.

Determining the true costs to society of waste burial is a difficult enterprise. Although the actual resources employed in burial are known, no one knows what future remedial actions may be required. One cannot be sure whether the prices charged by commercial burial

TABLE 10-3 EPRI Estimates of 1983 Disposal Costs for LLW

		Itemized Costs, in thousands of dollars					
Waste Type	Volume in m^3 Shipped (ft^3)	Consumables	Labor	Transportation	Burial	Total	Total Cost per m^3 (ft^3)
Compactible	405 (14,300)	67	48	28	232	375	919 (26)
Noncompactible	228 (8,050)	38	27	16	131	212	919 (26)
Filters	1.4 (50)	0.4	0.25	0.1	1.9	3	2120 (60)
Resins	59 (2,100)	21	12	106	134	273	4590 (130)
Sludges	157 (5,550)	56	32	280	383	751	4810 (136)
Concentrates (in concrete)	130 (4,600)	46	27	37	222	332	2540 (72)
					Total	1946	

SOURCE: Michael Naughton, EPRI, personal communication, 1984.

sites are above or below their optimal level (i.e., the price that equals the marginal cost to society). However, the likely alternative to burial at ORNL would be burial at another DOE facility. Most of these, like Hanford, have hydrologic conditions for shallow land burial that are superior to those at ORNL. Less expensive burial methods could be employed at such facilities without risk of additional releases, although the overall expense might not be much less than that of shallow land burial at ORNL. Further, it must be clear that transportation to and operation of the offsite disposal facility will not result in population doses greater than those that would be incurred in the absence of such action.

Another factor leading to lower costs at other DOE sites is the significant economies projected for burial sites where large volumes of waste are disposed. NLLRWMP, in "Understanding Low-Level Radioactive Waste" (U.S. DOE, 1983b), estimates that burial costs vary nearly linearly with volume, while Rogers (Rogers et al., 1983) estimates that burial costs vary as the square root of the volume. Because the Hanford, Nevada, and Savannah River sites, respectively, generate 9, 12, and 16 times more volume of low-level solid waste than does ORNL, appropriate savings are likely for this reason as well.

Table 10-4 provides estimates of the cost of burying all of ORNL's radioactive waste at Hanford--using EPRI figures on power reactors for burial costs, the NLLRWMP figures for transportation costs, and ORNL figures on treatment and preparation costs. For both Type I and Type II waste the midpoints of the ranges of costs for offsite shipment are 79 to 93 percent of those for onsite burial using concrete boxes (see Table 10-2), one of the less costly onsite options. Perhaps this conclusion is incorrect; however, it seems very unlikely that offsite shipment of future waste would be substantially more expensive than projected onsite options. However, it is recognized that transportation, in itself, raises a number of difficult and contentious issues.

Limitation Policies

Radioactive waste management at ORNL could be facilitated by policies that limit the radioactive waste that must be disposed at ORNL. These include (1) a policy to place projects that generate large amounts of radioactive waste (particularly wastes containing ^{90}Sr) at other DOE sites; (2) a policy to provide incentives to project managers to reduce the amounts of radioactive waste (particularly wastes containing ^{90}Sr) that they generate or to put the waste in more manageable forms; and (3) a policy to prevent radioactive waste from other sites from being sent to ORNL.

Integrated Assessment of Alternatives

If DOE decides to place a high priority on preventing any increase in nuclide releases and wishes to reduce uncertainty about the effects of future disposal, it should cancel ORNL's current plans for burial

TABLE 10-4 Annual Costs[a] of Treating ORNL Type I and Type II Waste, of Shipping It Off Site, and of Burying It

TYPE I Waste

Description	Volume in m^3 (ft^3) Before Treatment	Selected Treatment	Volume in m^3 (ft^3) After Treatment	Treatment Cost, $K
Combustible	425 (15,000)	Compaction to fiber boxes	42 (1,500)	302
Metal	566 (20,000)	Size reduction + compaction to CSD	141 (5,000)	435
Glass	57 (2,000)	Grinding to SSD	6 (200)	114
Rubble	594 (21,000)	Size reduction to CSD	283 (10,000)	348
				1199
Shared treatment facility total annual cost, $K				450
Total annual treatment cost, $K				1649
Range of total annual cost (treating + shipping + burial)				1649
				1649

TYPE II Waste

Description	Volume in m^3 (ft^3) Before Treatment	Selected Treatment	Volume in m^3 (ft^3) After Treatment	Treatment Cost, $K
Combustible	71 (2,500)	Compaction to SSD	7 (250)	645
Noncombustible	170 (6,000)	?	34 (1,200)	925
				1570
Shared treatment facility total annual cost, $K				1050
Total annual treatment cost, $K				2620
Range of total annual cost (treating + shipping + burial)				2620
				2620

NOTE: Transportation and burial costs are explained in the text.

[a] Treatment costs are from Chandler et al. (1982) and were calculated in English units.

TABLE 10-4 (continued)

Transportation Cost @ \$160/m^3 (\$4.50/ft^3)	Burial Cost Range			Range of Total Annual Cost, \$K
	Lower Cost @ \$350/m^3 (\$10/ft^3), \$K	Higher Cost @ \$1400/m^3 (\$40/ft^3), \$K		
6.8	15	60		
22.5	50.	200.		
0.9	2.	8.		
45.0	100.	400.		
75.2	167	668		
+75.2	+167		=	1891 (lower end)
+75.2		+668	=	2392 (higher end)

Shielded Transport Cos @ \$2500/m^3 (\$70/ft^3)	Burial Cost Range			Range of Total Annual Cost \$K
	Lower Cost @ \$1060/m^3 (\$30/ft^3) \$K	Higher Cost @ \$2500/m^3 (\$70/ft^3) \$K		
17.5	7.5	17.5		
84.0	36.0	84.0		
101.5	43.5	101.5		
+101.5	+43.5		=	2765 (lower end)
+101.5		101.5	=	2823 (higher end)

ground 7 and perhaps those for burial ground 6 after the opening of the CWDF. Instead, DOE should consider disposal of solid waste in concrete monoliths and above-ground tumuli, conversion of the high-activity waste for disposal in hydrofracture, or shipping the waste offsite. Shipping higher-activity waste offsite appears to be cheaper than converting the waste to hydrofracture disposal at Oak Ridge. This appraisal might change if the volume of combustible higher-activity waste is at least a factor of 5 greater than that now being generated. In any event, incineration does not appear as a part of any solution for the noncombustible Type II waste, which has approximately the same curie content but nearly 3 times the volume.

The appropriate strategy for ORNL depends upon possible future regulatory requirements and the weights DOE assigns to the different criteria that have been reviewed above. The panel realizes that shipment offsite poses political problems for the DOE. However, it believes that this alternative should be considered in a comprehensive review of options for solid waste management.

The lack of a comprehensive review of all options is a troubling weakness in ORNL planning. Hundreds of millions of dollars will be spent on waste management at ORNL over the coming decade. Studies have been performed on pieces of the overall decision problem: the costs of one set of options, the possible burial methods of another, or site planning for burial of one type of waste. However, these studies have not been designed in a systems context. ORNL has not developed a comprehensive perspective. Indeed, ORNL has failed to evaluate the impact that even such a limited action as opening the CWDF will have on the other burial grounds. An example of a much better analysis of options is the Final Environmental Impact Statement on hydrofracture (U.S. ERDA, 1977). A thorough evaluation of at least those options that the panel has described here seems appropriate.

DECONTAMINATION AND DECOMMISSIONING

Inasmuch as they represent a substantial inventory of potential solid waste that will eventually have to be disposed, no discussion of waste management planning at ORNL would be complete without addressing the status and anticipated handling of the principal contaminated facilities located at the laboratory.

Most of the ORNL facilities are in use, but 46 have been declared surplus and are included in the ORNL Surplus Facilities Management Program (SFMP) (Myrick and Coobs, 1983). The ORNL SFMP is a part of an overall DOE SFMP that is administered by the Richland Operations Office of DOE. Active direction of the ORNL program is by a small group within the Operations Division. This group has recently completed and issued a maintenance and surveillance plan (Coobs and Myrick, 1983) and has issued a long-range plan (Myrick, 1984). Priorities and "long-term management strategy" for the decommissioning of the remaining surplus facilities are included in the long-range plan.

The ORNL SFMP defines its ultimate objective as accomplishing facility disposition in a safe, cost-effective, and timely manner, stressing the reuse of valuable materials, equipment, and property.

Status

The administration of SFMP at Oak Ridge to date has necessarily been in the context of an operating facility with no identifiable termination date. The criteria for the plan have been consistent with this context. At such time as a date for close-out of operations is set, criteria may have to be changed to put ultimate safety on the site ahead of long-term efficient operation of facilities. At such time, decontamination and decommissioning (D&D) will have to be reevaluated. For the present, the D&D that has been done provides useful background with regard to the varied problems that must be considered.

- The ORNL Graphite Reactor was decommissioned nearly two decades ago. It was suitably decontaminated and protected, and established as a National Historical Landmark, with free access by the public. Some of the ancillary components of the reactor complex are still radioactive and require continuing surveillance.
- An Intermediate Level Waste Transfer Line (underground) was successfully decontaminated and decommissioned. Other, albeit probably less highly contaminated, underground lines remain as potential risks. Other lines should be evaluated in due course as candidates for D&D. Further work on such lines should be done only after flow tests and exploratory excavations have defined the needs for corrective action.
- The Fission Product Pilot Plant was entombed in place in a thick concrete shell; it no longer requires maintenance, only minimal surveillance.
- The "Gunite" Intermediate-Level Liquid Waste Storage Tanks are now being emptied, and their contents are being permanently disposed in shale by hydrofracture. After the initial transfer, however, the tanks will still contain radioactive materials with activities at about 5 to 10 percent of their original levels; these materials will continue to constitute one of the larger sources on the site. ORNL has begun a new sluicing operation that is designed to break up and remove most of the remaining contaminated "cementitious" chunks of sludge and crystalline precipitates. When this new effort has been completed, the tanks will be evaluated to determine whether the small quantity of residual activity is "fixed" on the gunite or is associated with rubble and trash that has found its way into the tanks and is not removable by sluicing. Any decisions toward dismantlement or entombment must await completion of the new sluicing program and subsequent evaluations of the nature of the residue.
- The Fission Product Development Laboratory (FPDL) is now being decontaminated and decommissioned and will be reused for new purposes. The project will cost $2.8 million, create 260,000 L (70,000 gal) of liquid waste and 230 m^3 (8000 ft^3) of solid waste, and require about 5 years. The recovered facility is expected to be usable for 15 to 20 years and to be the equivalent of a new $15 million building.

- Five shielded transfer tanks containing inorganic ion-exchange medium on which is held about 4000 Ci of ^{137}Cs are stored outdoors in a fenced area. The tanks are stainless-steel lined, lead shielded, and carbon-steel clad and are in good condition. The ion-exchange medium, along with the ^{137}Cs, could be blended into grout for disposal by hydrofracture. To ensure that the ^{137}Cs has not caused degradation of the medium and thus become mobile, samples could be taken and tested.
- The Metal Recovery Facility (MRF) building has been the subject of a feasibility study. The building has potential for reuse. Utility systems have been upgraded, and decontamination has been under way for one year. Decommissioning is expected to be complete in 1988, at a total cost of $6 million.
- The Molten Salt Reactor Experiment and storage vessels still contain the inventory of fissionable materials, their decay products, and fission products in a solid mass of water-soluble, corrosive salts. Radiolytic decomposition of the fluorides, which liberates fluorine gas, makes it necessary to remelt the salt annually to permit recombination. The facility is a continuing operation and is not ready for decommissioning. Failure of the storage vessels, as the result of corrosion or rupture or accidents during the annual recombination, could permit available water to disperse the radionuclides over the site and into local streams. A preliminary decommissioning study for the MSRE was issued in 1977 (Cagle and Pugh, 1977); a feasibility study on the disposal of the salts was conducted (Ebasco Services, 1980). Further progress awaits government decisions on methods and site for ultimate disposal of the radioactive materials.

The projects included in the program are listed in Table 10-5, and their locations are shown in Figures 10-2 and 10-3.

Table 10-6 provides a rough comparison of the total radioactive material (Ci) at various ORNL surplus and waste storage facilities. Inasmuch as there are some inconsistencies among the data from which the table was prepared, the information presented should be used for general comparisons only.

Long-Range Plan and Schedule

Present criteria for the ultimate closure of nuclear sites require that institutional control be assured for 100 years following closure and, afterward, that the condition of the site be such that no user or casual intruder will be harmed by residues or conditions that remain. Predicting and planning for closure of ORNL will be difficult. It is a major government site for scientific research, process development, and the production of nuclear materials. It is in a state of vigorous operation with no clearly recognizable factors that would define a date after which it would no longer be used. Its location within the Oak Ridge Reservation, with adjacent defense production facilities, makes a date of closing still less predictable.

TABLE 10-5 ORNL Surplus Facilities Management Program

Project[a]	Facility/Location
1. ILW Transfer Line	ILW pipeline in White Oak Creek Floodplain
2. Curium Source Fabrication Facility	Bldg. 3028
3. Metal Recovery Facility	Bldg. 3505
4. Fission Product Development Laboratory	Bldg. 3517
5. Waste Holding Basin	Basin Site 3513
6. Old Hydrofracture Facility	Shale Fracturing Batch Plant, Site 7852
7. Gunite Storage Tanks	Tanks W-5 to W-10, Site 3507
8. Waste Storage Tanks	Tanks WC-1 (SW of 3037), WC-15, WC-17 (SE of 3587), W-1, W-2, W-3, W-4, W-13, W-14, W-15 (3023), W-11 (S of 3536), TH-1, TH-2, TH-3 (S of 3503), TH-4 (SW of 3500)
9. ORNL Graphite Reactor	Bldg. 3001
10. Molten Salt Reactor Experiment	Bldg. 7503
11. Low-Intensity Test Reactor	Bldg. 3005
12. ORR Experimental Facilities	ORR-GCR A9-B9 Exp. Fac. (3042) ORR Molten Salt Loop (3042) ORR Maritime Ship Reactor Loop (3042) Pneumatic Tube Irradiation Facility (3042) ORR-GCR Loops I and II (3042) ORR Water-Air Heat Exchanger (3087)
13. Radioisotope Process Facilities	Storage Garden 3033 (Rear of 3033) Storage Garden 3026-D (E of 3026-D) Carbon-14 Process System (3033-A) Waste Evaporator Facility (3506) Fission Product Pilot Plant (3515) Shielded Transfer Tanks (Burial Ground 5)
14. Homogeneous Reactor Experiment	Bldg. 7500

[a] Projects included in the SFMP. Listing is not in any particular order.

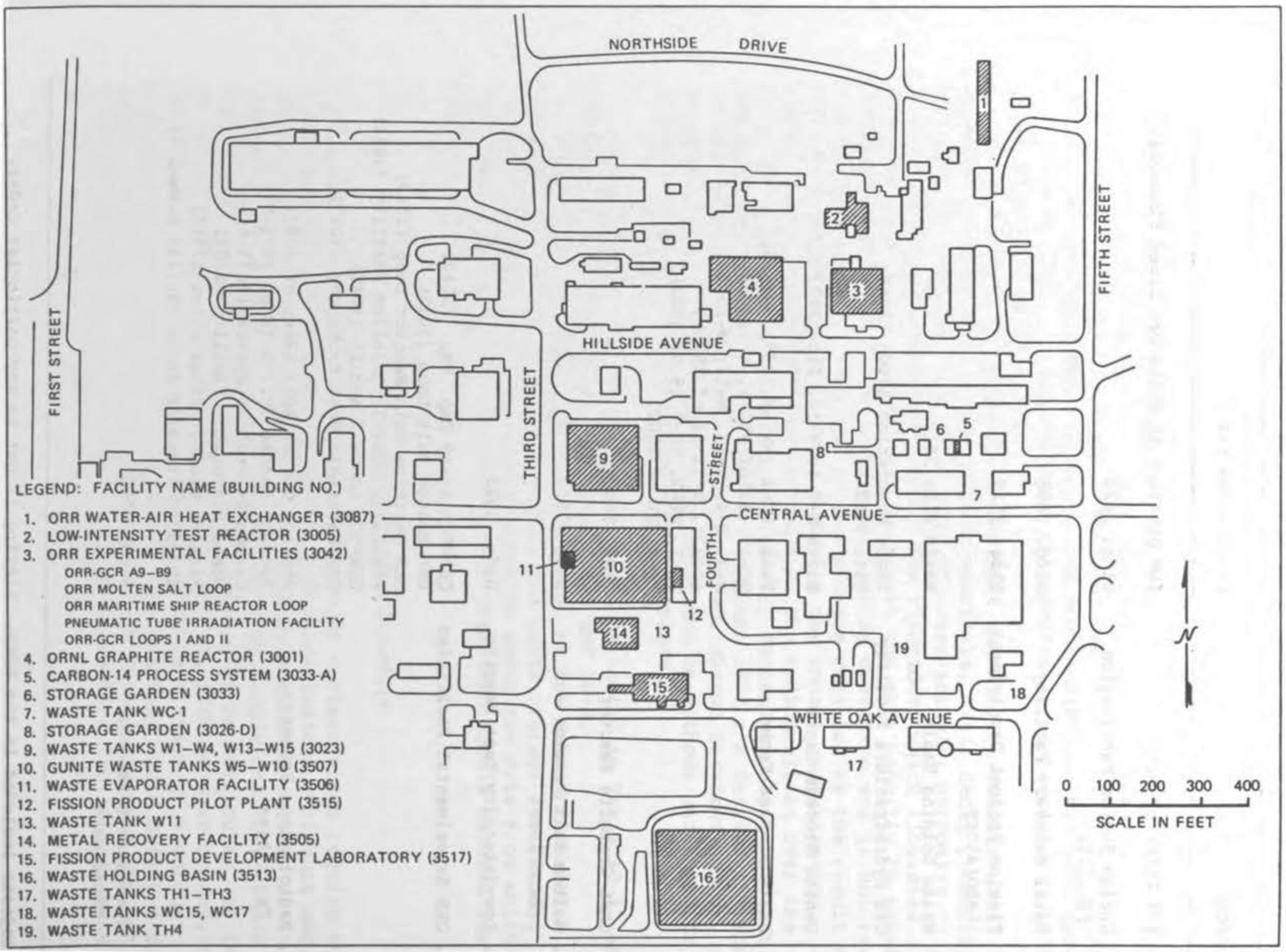

FIGURE 10-2 Projects in the ORNL surplus facilities program--Bethel Valley.

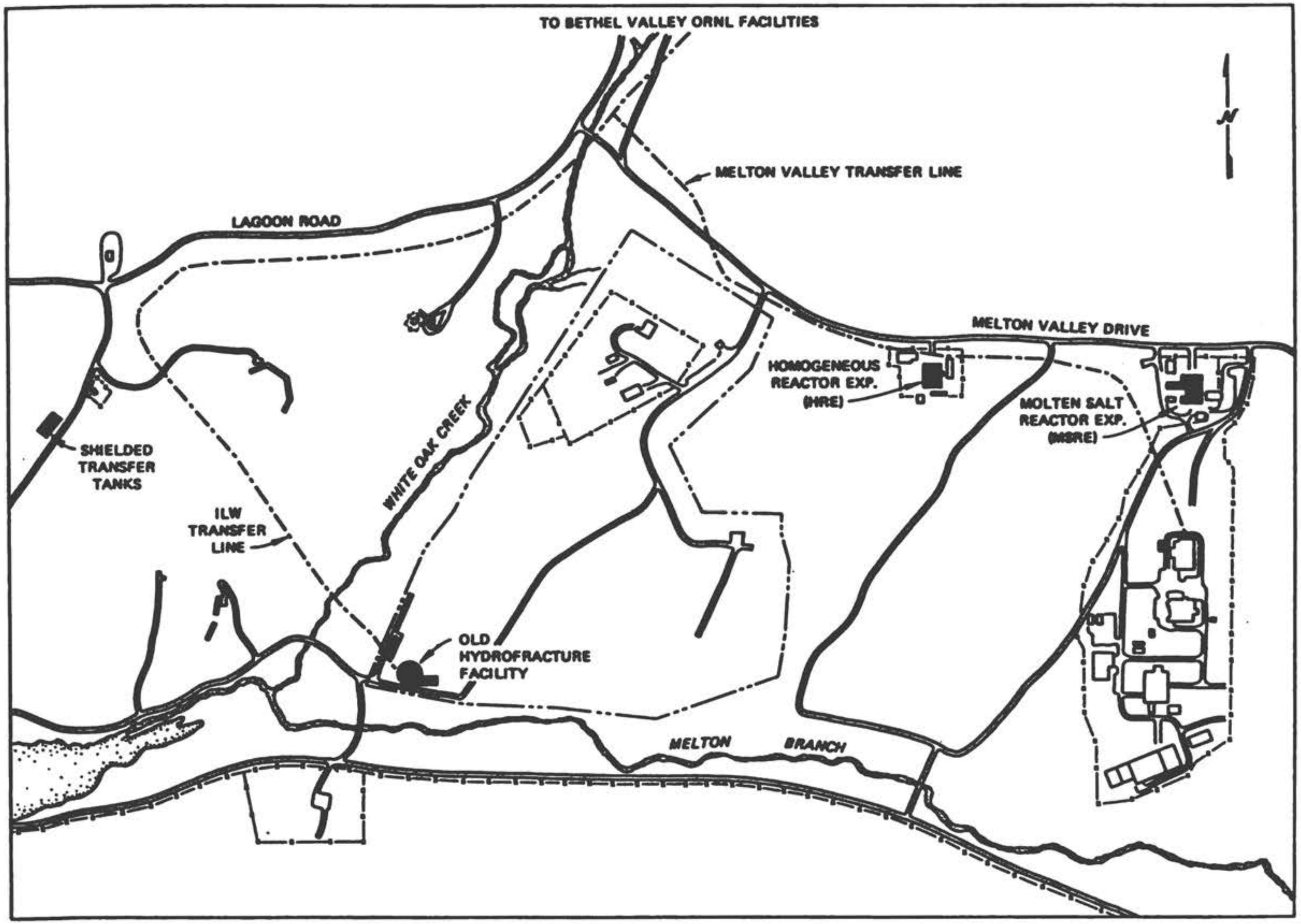

FIGURE 10-3 Projects in the ORNL surplus facilities program--Melton Valley.

TABLE 10-6 Radionuclides in Surplus and Waste Storage Facilities at Oak Ridge National Laboratory (Ci)

Location	^{60}Co	^{90}Sr	^{137}Cs	Actinides
Irretrievable waste				
Shale--old hydrofracture		40,000	600,000	
Liquid waste disposal pits		80,000	170,000	
Burial grounds	30,000	50,000	20,000	1
Retrievable waste--in buildings, tanks, etc.				
Gunite tanks (sludge)		800,000	90,000	12,000
Gunite tanks, after transfer of sludge		150,000		
Shielded transfer tanks			4,000	
Molten Salt Reactor Experiment		4,000	8,000	10^7
Homogeneous Reactor Experiment		100	200	
Fission Product Pilot Plant (Entombed)			100	
Liquid waste tanks				
Th 4				?
Th 1-3				?
W 1-15	50	50	100	
Metal Recovery Facility				?
Fission Product Development Laboratory		100	100	
White Oak Lake--sediment	30	20	600	1
Clinch River--sediment	20	3	150	
Basins and ponds				
3513		34	200	5
3524	2	30	100	10
7852	1	3	400	
Others	Each less than 10 Ci total activity			

SOURCES: Carrigan, 1969; Committee on ORNL Waste Handling Practices, 1972; J. Coobs, ORNL, personal communications, 1983, 1985; Coobs and Myrick, 1983; Evaluation Research Corporation, 1982; Oakes et al., 1982; Tamura et al., 1977; and U.S. ERDA, 1977.

Almost all of the surplus buildings at ORNL are in some use, being partially occupied as offices or service facilities, and many are potentially convertible to new uses.

In addition to the several buildings and facilities addressed previously in this chapter, a number of other decontamination and decommissioning projects have been proposed in the Five-Year Plan (ORNL, 1984). Some of these have little justification for early action; others offer little, if any, improvement as long as decontamination and decommissioning is conducted under present conditions. Study will be needed to determine the costs and benefits associated with these projects. Before implementing them, a determination must be made of their priorities, relative to those of other corrective measures.

Stabilization of White Oak Lake Sediments

Foremost among the expensive proposed actions with high public visibility is that of decontamination and/or stabilization of White Oak Lake sediments. While the sediments do pose some small risks, the small inventory of radionuclides (mainly ^{137}Cs and ^{60}Co) in White Oak Lake sediments (Table 10-6) provides little justification for the expensive ($49.7 million) remedial action proposed for the fiscal years 1985-1989.

Sediment Movement. As described in Chapter 8, ORNL estimated the effects of a catastrophic washout of the White Oak Lake sediments. The predicted radiation exposures resulting to the maximally exposed individual(s) are so small that this pathway does not justify the expenditure of funds of this magnitude at any time.

The need for other near-term actions appears to be more pressing, especially when some of those near-term decisions will have a continuing effect on the radionuclide content of White Oak Lake sediments. For example, remedial actions on existing burial grounds and the pits and trenches area, the radionuclide content and packaging of solid waste going to burial ground 6 or a new burial ground 7, or diversion of LLW to hydrofracture or offsite may increase or decrease the rate at which certain radionuclides are deposited in White Oak Lake sediments. However, sediments of low radionuclide concentration continue to accumulate behind White Oak Dam (siltation), and some time in the reasonably near future, planning will have to start for removal of at least some of the less radioactive upper sediments to preserve White Oak Lake and maintain a channel for White Oak Creek.

Site Closure. On the other hand, surface radiation exposures from the sediments seem to preclude abandoning the White Oak Lake sediments without some remedial action to protect the unknowing intruder (e.g., someone who builds on or near the sediments and uses them for farming). Thus these sediments may eventually require removal or some sort of stabilization and cover. While the total costs for cleanup will be greater if performed at a later date, total discounted costs may not be appreciably greater.

The remedial action descriptions do not establish where ORNL plans to dispose of any sediments removed from White Oak Lake. Should they be transferred to a burial ground under present conditions, a significant portion of the radionuclides would only leach back into White Oak Creek and the Clinch River. On the other hand, extensive repackaging appears to be prohibitively costly and would provide little benefit in dose saving. Furthermore, commitment of additional areas to solid waste disposal will only exacerbate the already pressing problem of limited available space.

A decision to proceed with this proposed action requires a much better cost-benefit evaluation for the various options that may be considered. Therefore the panel believes that early remedial action is not warranted, although ORNL should proceed with an integrated evaluation of the costs and benefits that would be realized by the several alternative actions that are available.

Stabilization and Cleanup of Ponds

A similar question arises with the proposed cleanup and stabilization of various holding basins and ponds during the fiscal years 1985-1989 (ORNL, 1984). Catastrophic washout of these several basins and ponds does not appear to be an issue, but the potential for groundwater contamination is present. However, the radionuclide inventories of the basins and ponds (Table 10-6) are very small in comparison with the inventories in, and going to, the burial grounds. Therefore groundwater contamination appears to be an inadequate reason to begin early remedial action on the several basins or ponds--the potential for contamination from the burial grounds and pits and trenches area is overwhelmingly greater and is therefore a more pressing regulatory issue.

As with the White Oak Lake sediments, a question arises of what to do with any sediments removed from the ponds. If those sediments are emplaced in one of the burial grounds, the potential for groundwater contamination remains undiminished. If the sediments are disposed in the hydrofracture facility, repackaged in high-integrity containers, or shipped offsite, then the potential for groundwater contamination would indeed be diminished, but the costs may be excessive in view of the limited dose saving that might be realized. Here again the institutional failure to integrate evaluations is apparent and makes the proposed expenditure of $55.6 million one of cosmetic improvement with no apparent technical gain in the near term. As with the White Oak Lake sediments, long-term management may yet require remedial action to protect an unknowing intruder, but the several technical and cost options must be much more fully evaluated and an integrated assessment of potential benefits and risks prepared before a decision can be reached.

Contaminated Floodplains

Although cost estimates for stabilization and cleanup of contaminated floodplains and other parts of the White Oak Creek drainage are included in the Five-Year Project Plan (ORNL, 1984) with those for White Oak Lake, little information is available upon which to evaluate their potential for harm. Estimates of radionuclide inventories do not exist, and data concerning radionuclide concentrations and distributions are so sparse that estimates of inventories have not been made. Therefore neither the potential risk from catastrophic washout nor that from groundwater contamination can be estimated. It would be prudent to define the extent of the problem and its potential for near-term offsite risks or for long-term harm to an unknowing intruder prior to the expenditure of significant funds. As with the White Oak Lake and the holding ponds, an integrated assessment of all impacts and benefits is required.

Disposal of Old Pipe and Surrounding Contaminated Soil

Unlike the pressing operational need for replacing the old and leaking low- and intermediate-level waste water pipes, the issue of what to do with the residues of pipe and soil after replacement is poorly defined at this time. As with the sediments from White Oak Lake and the holding ponds, digging up the contaminated soil and old pipe only to rebury it in an existing burial ground will not diminish the potential for groundwater contamination. Although hydrofracture does not appear to be a useful alternative, the choice of abandoning this material in place may be viable, as might those of burial in sealed containers or shipment offsite. Again, it is apparent that an integrated approach in assessing the problem must be taken.

CONCLUSIONS

1. Planning is greatly complicated by uncertainties in the regulatory environment; i.e., what exposure levels will be acceptable, and where will doses be measured?
2. Reliable predictions of future releases from burial grounds at ORNL have not been made.
3. Little is known about the extent to which planned methods for shallow land burial will reduce the intrusion of water. The effect of a given reduction in water intrusion rate on the quantity or timing of releases is not known.
4. The site that has been chosen for the Central Waste Disposal Facility is a poor one from hydrogeological considerations for burial of radioactive waste; however, prior treatment of already low-activity waste might reduce releases to acceptably low levels.
5. Current plans for shallow land burial at burial ground 7 represent a continuation of recent practices at burial ground 6. The panel believes that water will intrude and that radionuclides will be released. It cannot rule out the possibility that current emissions could increase.
6. The use of hydrofracture to dispose of some solid waste streams to reduce leaching of radionuclides into surface streams may not be

cost effective, especially in the case of the relatively high cost of incineration for so small a waste stream as the combustibles. Alternatives, such as anaerobic digestion, may prove a useful tool for treatment prior to hydrofracture if they can deal with high-activity waste or scintillation fluids.

7. The total costs of treating waste dominate those for its storage and disposal. Offsite shipment appears to be no more expensive than any of the onsite methods considered in the Chandler study.

8. There has been no comprehensive analysis of solid waste management alternatives.

9. The activities of the Planning Committee are appropriate and should be continued.

10. The decontamination and decommissioning objectives appearing in the Oak Ridge Surplus Facilities Management Plan reflect proper priorities; some of those in the Five-Year Project Plan do not.

11. The Molten Salt Reactor Experiment (MSRE) facility, as it now stands, contains an inventory of highly radioactive fluoride salts that are safely contained only through the annual recombination of the radiolytically decomposed salts. The extremely toxic and corrosive nature of this inventory, and its transportability in water, represent a major potential for significant radioactive contamination in the event of accidental release.

12. Insufficient attention has been given by DOE and ORNL to policies that would limit the amounts of radioactive waste (particularly wastes containing ^{90}Sr) that must be disposed by shallow land burial at ORNL.

13. Efforts by ORNL to reduce the amount of radioactive material in the gunite tanks appear appropriate.

14. The need to incur substantial costs to stabilize and/or clean up White Oak Creek sediments or to stabilize and/or clean up sediments in holding basins and ponds has not been established by the analyses provided.

15. No analysis has been provided of the need to clean up and dispose of contaminated floodplains or of contaminated transfer pipes and soils.

16. ORNL's supporting documentation and analyses of proposed waste management programs suffer from a lack of an integrated assessment of impacts and costs.

RECOMMENDATIONS

1. Because of their major impact on ORNL, regulatory uncertainties should be resolved as soon as possible. DOE, not ORNL, should resolve these uncertainties, because of their important policy implications.

2. The data needed to predict burial ground releases should be identified and sought.

3. Alternative CWDF sites should be sought that are not on karst topography--or it should be demonstrated that the potential releases would be insignificant.

4. In view of the inadequacy (to meet projected regulatory requirements) of present burial practices and those now planned, disposal alternatives that promise better confinement of radionuclides should be considered.

5. Solid waste management strategies should be analyzed comprehensively; a systems approach must be used to avoid creating undesirable impacts at one location while solving a problem elsewhere.

6. Waste management planning should be reservation-wide.

7. The panel endorses present criteria for decontamination and decommissioning and recommends continuing case-by-case consideration of surplus facilities to reduce potential for releases, provide additional protection where practical, and make best continuing use of the site and its structures.

8. New approaches should be sought to very long range control of leaching by groundwater of radionuclides from any waste buried in the future. The failure of the geologic medium at ORNL to retain waste predictably implies a clear need to pursue alternative strategies such as greater use of hydrofracture, waste solidification options, disposal in concrete monoliths and/or above-ground tumuli, improved waste packages, or even shipment offsite.

9. ORNL should further evaluate incineration and/or anaerobic digestion as a means of volume reduction, conversion of waste form for disposal as other than untreated solid waste, and disposal of liquid scintillation fluids.

10. DOE and ORNL should consider adopting policies that limit the radioactive waste that must be disposed at ORNL--by placing elsewhere projects that generate large amounts of radioactive waste, by providing incentives to reduce the amounts of radioactive waste generated, and by refusing waste from other sites.

11. ORNL should continue with its plans to reduce further the amount of radioactive material in the gunite tanks.

12. Before substantial funds are expended for the cleanup and stabilization of White Oak Lake sediments, or sediments in the holding ponds and basins, an integrated assessment should be made of the costs and benefits that will be obtained.

13. Projects for the decontamination of floodplains, old transfer pipes, and soil contaminated by leaking pipes require evaluation of the radionuclide inventories before an integrated assessment can be made of the costs and benefits to be realized.

14. The projects in the Five-Year Project Plan to upgrade waste processing and treatment facilities and to improve monitoring systems appear to be mostly in the nature of repair, replacement of depreciated or decadent equipment, or simply "good housekeeping"--these should proceed as funds and priorities permit.

15. DOE should decide what is to be done with the inventory at the MSRE so that firm plans and schedules can be developed promptly for the removal, chemical separation, and final disposal of the actinides, fission products, and corrosive salts that remain in the MSRE.

16. ORNL should analyze the consequences of the collapse of the CWDF into a karst.

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11

Intersite Comparison

Previous NRC panels have reviewed shallow land burial at all DOE sites (National Research Council, 1976) and waste management at the Hanford Reservation (National Research Council, 1978) and at the Savannah River Plant (National Research Council, 1981). Although the regulatory environment has changed since the earlier reviews, this panel was asked, as a part of its review, to compare ORNL with other sites. The comparison was to include characteristics of the sites as they influence waste management practices and to consider whether unique ORNL approaches to waste management problems are applicable to other sites.

The histories of the sites are relevant to this comparison. Hanford and Oak Ridge are two of the original Manhattan District facilities built in the early 1940s to produce materials for the first nuclear weapons. Savannah River was built in the early 1950s and has largely supplanted Hanford for the production, in reactors, of nuclear materials for weapons. The original role of ORNL was to serve as a pilot plant for the operations of the Hanford reactors and for chemical separations facilities. Subsequently, its operations diversified into a wide range of scientific research, process development, and small-scale production of nuclear materials. Hanford, as its production role diminished, shifted toward research and large-scale experimental operations. Savannah River has remained almost entirely a production site, with research restricted principally to support of its own operations.

OVERALL CONCLUSIONS OF THE NRC PANELS

The NRC panels have concluded that the three sites have been operated without unacceptable exposures to the public, specifically:

The Hanford panel concluded ". . . that there has not been in the past, and is not at present, any significant radiation hazard to public health and safety from waste management operations at Hanford."

The Savannah River panel similarly concluded that radiation protection practices have been adequate and effective, that management of low-level, transuranic, and other miscellaneous waste has not created or resulted in radiation hazards to operating personnel or the general public, and that current tank storage (of high-level waste) is adequate as an interim storage method that will function safely for the years needed to select and implement a method of permanent isolation.

This panel concludes that routine offsite effluents from ORNL radioactive waste operations do not present a health hazard.

CONCLUSIONS OF THE NRC PANELS REGARDING ULTIMATE DISPOSAL OF HIGH-LEVEL WASTE

With regard to the most crucial matter of the ultimate disposal of high-level liquid waste, the most pertinent conclusions of the panels were as follows:

At Hanford, ". . . a satisfactory site for a terminal waste repository can probably be developed in the basalt either: (a) several hundred meters below the 200 areas of the Hanford Reservation, or (b) at the end of a tunnel or adit driven into the Rattlesnake Hills."

At Savannah River, "The Panel on Savannah River Wastes concurs completely in the 1972 recommendations of the Panel on Bedrock Disposal and regrets that the recommendations of the earlier panel were not adequately implemented . . . ." (The earlier panel had concluded, ". . . there is a reasonable prospect of achieving adequate protection by storing the waste in vaults in rock underlying the Tuscaloosa Formation beneath the Savannah River Plant Site.") The Savannah River Panel also cited a recommendation by the NRC Panel on Waste Solidification (1979) for, ". . . reexamination of the feasibility of grouting high-level waste (suitably modified as 'supergrout') directly into appropriate geologic formations."

This panel on the management of radioactive waste at ORNL concludes that placement of low- and intermediate-level radioactive wastes by hydrofracture at ORNL has been satisfactory to date; further application of this process at ORNL requires better understanding of the effects of the emplacement on the host rocks and on the groundwater system; and application of the methodology to other waste forms and other sites has potential, but must be supported by appropriate research.

TOPOGRAPHY AND GEOLOGY

Hanford has an arid climate; moderately permeable unconsolidated sediments of sands, clays, and gravels to a depth of about a hundred meters (several hundred feet); permeable basalt below the sediments; a deep water table; and a great distance to a large perennial stream.

Savannah River has a humid climate; nearly flat-lying sand and clay beds to a depth of about 300 m (1000 ft); a water table normally less than 15 m (50 ft) below land surface; several large artesian aquifers below the water table aquifer; moderate distance to a perennial stream; and dense, nearly impermeable bedrock below a depth of 300 m (1000 ft).

Oak Ridge has a humid climate; tilted shale and limestone beds with a thin and erratic residual soil cover; moderately steep ridge and valley surface topography, the limestones chiefly underlying the valleys and the shales, sandstones, and chert beds underlying the ridges; low permeability of soils and shales, permeability decreasing almost exponentially with increasing depth; no aquifer below the shallow near-surface water table system; a water table commonly no deeper than 8 m (25 ft) beneath uplands and within a few feet of land surface beneath lower slopes; wet-weather seeps common on lower slopes; a steep water table gradient; and short routes of groundwater from uplands to the nearest streams (commonly less than 500 m).

Table 11-1 is a comparison of the principal hydrogeological aspects of the three sites.

NEAR-SURFACE DISPOSAL OF LOW-LEVEL WASTE

Radionuclides in waste buried or disposed as liquid near the ground surface can be transported to the environment if rain falls onto the ground, seeps into the disposal zone, and then moves through the ground to a stream or to a well from which water is pumped for domestic or agricultural use. The rate of transport is governed by the amount of rainfall, the existence under the disposal zone of an aquifer that discharges to a stream or from which water is pumped, the depth of the aquifer (water table) below the zone, the lateral distance to the stream or well, the permeability of the aquifer (and for certain radionuclides the ion-exchange properties of the formation), and the hydraulic gradient that moves water through the aquifer. The three sites differ in these inherent characteristics as shown in Table 11-1. The relative suitabilities of the sites for near-surface disposal cannot, however, be ranked by simply counting the pluses and minuses among these factors. The overall transport rate is generally limited by that factor that imposes the greatest resistance to movement. Moreover, each of the sites is relatively large and so varied internally in its characteristics that opportunities exist for choice of the most suitable locations.

At Hanford, the desert climate and very deep water table are nearly ideal. At Savannah River, areas of adequate size are available where the bottoms of burial trenches can be kept 6 m (20 ft) above the water table and, by careful surface grading, percolation of rainwater can be sufficiently suppressed that, although there is some migration of radionuclides, it is small. The concentration of tritium, the most mobile radioactive component, was found to be less than the concentration guide level for drinking water in monitoring wells at the perimeter of the burial ground. Because a number of unfavorable factors coincide at Oak Ridge, however, groundwater flows through many of the burial trenches and seeps from them into White Oak Creek, causing concentration guide levels to be exceeded at White Oak Dam.

Solid waste classified as TRU waste is stored separately and retrievably at all of the sites.

TABLE 11-1 A General Evaluation of Key Hydrogeologic Characteristics at the Three Major DOE Sites (as Related to Shallow Land Burial of Radioactive Waste)

	Oak Ridge	Savannah River Plant	Hanford
Distance to stream	near stream (unfavorable)	moderately near (neutral)	far from (favorable)
Depth to water table	shallow (unfavorable)	moderate to near (unfavorable)	deep (favorable)
Permeability of water table system	low in unfractured zone (favorable) high in fractured zone (unfavorable)	moderate to high (unfavorable)	moderate to high (unfavorable)
Presence of underlying aquifer to contaminate	no (favorable)	yes (unfavorable)	yes (unfavorable)
Hydraulic gradient	steep (unfavorable)	moderate (neutral)	moderate to low (favorable)
Surface topographic slope	steep (unfavorable)	moderately flat (favorable)	moderately flat (favorable)
Rainfall	moderately high (unfavorable)	moderately high (unfavorable)	low (favorable)

UNCONTROLLED DISPOSAL OF LIQUID WASTE TO GROUND

From 1951 through 1965, intermediate-level liquid waste was disposed directly to pits and trenches at ORNL. The strontium and cesium that predominate in the ground in and under these sites are probably irretrievable. Similarly, at Hanford liquids containing varying concentrations of uranium, plutonium, and fission products were percolated into the ground through gravel-filled "cribs" or seeped into the ground below evaporation ponds. During the 1950s the concentrations were high and the quantities were large. There has not been direct disposal of liquid solutions of radionuclides to the ground at Savannah River.

SURPLUS FACILITIES

The earlier reviews did not include evaluation of the management of surplus facilities. In general, however, Hanford and ORNL have many; Savannah River has few. All of the purely production reactors at Hanford are surplus, as are many of the separations facilities. These are massive structures. The many surplus ORNL facilities are generally smaller and structurally lighter. Savannah River has three massive production reactors in operation, one ready for start-up, and one in surplus status. A small experimental reactor and a small tritium processing facility are also surplus.

DISPOSAL OF HIGHLY RADIOACTIVE LIQUID WASTE

All sites are in varying stages of processing stored liquid waste and sludges. The ILW liquids and sludges at Oak Ridge are now being injected into deep shale beds. Radioactive strontium and cesium are being separated from the bulk of the alkaline waste salts at Hanford, and some has been encapsulated. At Savannah River, construction has begun on a facility to incorporate fission products into borosilicate glass cast into steel containers. No decision has been made by federal authorities with regard to the ultimate destiny of the Hanford or Savannah River waste.

ENVIRONMENTAL MONITORING AND REPORTING

All three sites have extensive programs and large organizations for measuring the quantities and concentrations of radioactive materials released and for calculating the resultant doses to offsite populations. Annual reports of the results are prepared and released to the public. The monitoring and reporting began at the outset of the Manhattan Engineering District projects 40 years ago and have continued with increasing detail and comprehensiveness. Savannah River probably has the most comprehensive and thorough monitoring system and reports results in greatest detail.

TABLE 11-2 Comparison of Sites

	Hanford	Oak Ridge	Savannah River
Area of site, km^2	1,500	150	770
Population within 80 km	340,000	840,000	579,000
Calculated population dose from effluents			
man-rem/yr	4	56	67
Percentage of natural	0.01	0.06	0.12
Dose to "hypothetical maximum exposed individual," mrem/yr	0.07	6.2[a]	0.4
Annual releases, Ci			
Aqueous			
Tritium	—	5,400[b]	30,000
^{90}Sr and ^{137}Cs	—	2.7[b]	0.05
Plutonium	—	—	0.009
Gaseous			
Tritium	—	19,000	430,000
Noble gases	100,000	less than 69,000	1,000,000
Waste quantities			
High- and intermediate-level liquid			
^{90}Sr and ^{137}Cs, Ci	8×10^{7} (5×10^{8})[c]	1×10^{6}	2×10^{8} (8×10^{8})[c]
TRU, Ci	1.3×10^{5} (1×10^{6})[c]	1×10^{4}	1×10^{6} (4×10^{5})[c]
Volume in tanks, L (gal)	1.9×10^{8} (5×10^{7})	5.7×10^{6} (1.5×10^{6})	1.1×10^{8} (2.8×10^{7})
Annual generation, L (gal)	5.7×10^{6} (1.5×10^{6})	4.5×10^{5} (1.2×10^{5})	3.8×10^{6} (1×10^{6})[d]
Low-level solid			
Curies	—	1×10^{5}	3.9×10^{6}[e]
Volume, m^3	1.4×10^{5}	greater than 8.7×10^{4}	2.5×10^{5}
Annual generation, m^3	—	—	2×10^{4}
Liquid waste direct to ground, Ci	2×10^{5}	—	2.5×10^{5}

TABLE 11-2 (continued)

	Hanford	Oak Ridge	Savannah River
Environmental Monitoring and Reporting (1982)			
Radiation dosimeters	24	16	165[f]
Air samplers[g]	24	16	29
Rainwater samplers	---	16	29
River samplers			
Continuous	1	2	5
Intermittent	2	3	---
Biological and soil monitoring			
Soil, stations	16	16	7
Milk, stations	9	10	6
Produce, samples/yr	53	---	60
Fish, samples/yr	37	96	300[h]
Wild game, samples/yr	66	48	2252
Annual Environmental Monitoring Report (public)			
Pages	76	63	119
Figures	16	11	19
Tables	54	34	92

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[a] Resulting from all activities on Oak Ridge Reservation (1982).

[b] At White Oak Dam.

[c] U.S. DOE, 1983.

[d] Net after evaporation.

[e] Largely nominal T content of Li-Al alloy.

[f] Plus 12 continuous wide-range gamma monitors at the perimeter.

[g] Filters, activated carbon beds, and desiccant traps at Hanford and Savannah River; no desiccant traps at Oak Ridge.

[h] Plus 12 samples of estuarine invertebrates.

NOTE: Monitoring statistics are for perimeter and offsite stations; onsite monitoring is not included.

Table 11-2 is a numerical comparison of the three sites with regard to important factors that bear on waste management and environmental safety. The principal sources were the three NRC reviews.

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Appendix A

Acronyms and Other Abbreviations Used in This Report

ALARA	As low as reasonably achievable
BG	Burial ground
CG	Concentration guide
CG_a	Concentration guide for air
CG_w	Concentration guide for water
CSD	Carbon-steel drum
CWDF	Central Waste Disposal Facility
D&D	Decontamination and decommissioning
DEIS	Draft environmental impact statement
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
FPDL	Fission Product Development Laboratory
FUSRAP	Formerly Used Sites Remedial Action Program
HEPA	High-efficiency particulate air (filter)
HFIR	High-Flux Irradiation Reactor
HLLW	High-level liquid waste
ICRP	International Commission on Radiological Protection
ILW	Intermediate-level waste
ISAHPD	Industrial Safety and Applied Health Physics Division
LLLW	Low-level liquid waste
MED	Manhattan Engineering District
MRF	Metal Recovery Facility
MSRE	Molten Salt Reactor Experiment
NAS	National Academy of Sciences
NCRP	National Council on Radiation Protection and Measurements
NLLRWMP	National Low-Level Radioactive Waste Management Program
NRC	National Research Council
ORAU	Oak Ridge Associated Universities
ORGDP	Oak Ridge Gaseous Diffusion Plant, also K-25
ORNL	Oak Ridge National Laboratory, also X-10
ORR	Oak Ridge Research Reactor
RCRA	Resource Conservation and Recovery Act
SFMP	Surplus Facilities Management Program
SSD	Stainless-steel drum
STT	Shielded transfer tank
TRU	Transuranic materials

UCC-ND	Union Carbide Corporation--Nuclear Division
USGS	U.S. Geological Survey
U.S. NRC	U.S. Nuclear Regulatory Commission
WIPP	Waste Isolation Pilot Plant
Y-12	Oak Ridge Manufacturing and Developmental Engineering Plant

Appendix B

Glossary

bleed-back	The process of releasing subsurface pressurized fluid after a hydrofracture injection period.
contamination	Radioactive material present in an undesired location.
darcy	A standard unit of permeability, equivalent to the passage of one cubic centimeter of fluid of one centipoise viscosity flowing in one second under a pressure differential of one atmosphere through a porous medium having an area of cross section of one square centimeter and a length of one centimeter.
decontamination factor	The ratio of the radioactivity present before a decontamination process to that present afterward.
discharge area	An area in which subsurface water is discharged to the land surface, to bodies of surface water, or to the atmosphere.
disposed	Permanent disposition of waste in a repository. Use of the word "disposal" implies that no need for later retrieval is expected.
fault block	A crustal unit bounded by faults.
groundwater	Water occupying openings or flowing below the surface (within the zone of saturation).
hydrofracture	A general term for the induced fracturing of rock, by injection of a fluid or gas under high pressure, to produce artificial openings.
ignimbrite	The rock formed by the widespread deposition and consolidation of ash flows.
overthrust	A low-angle fault of large scale, with displacement generally measured in kilometers.

recharge area	An area in which water is absorbed that eventually reaches the zone of saturation in one or more aquifers.
residuum	Residue. An accumulation of rock debris formed by weathering, and remaining essentially in place after
all	
	but the least soluble constituents have been removed.
smectite	The name for the montmorillonite group of clay minerals. The term is in common use to designate dioctahedral and trioctahedral clay minerals.
swallow hole	A closed depression or sinkhole into which all or part of a stream disappears underground.