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ENERGY DIVISION

ENVIRONMENTAL ANALYSIS OF THE OPERATION OF OAK RIDGE NATIONAL LABORATORY (X-10 SITE)

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FOREWORD

This report was prepared in response to a U.S. Department of Energy, Oak Ridge Operations Office, request to provide an environmental evaluation of those activities of Oak Ridge National Laboratory (ORNL) which affect or have the potential for affecting the human environment. Its issuance represents the culmination of a program of data acquisition that has covered the past several years. The analysis is specific to the current operation of ORNL at the X-10 site and does not cover divisions located at the Y-12 site.

SUMMARY

Located on the Oak Ridge Reservation near the city of Oak Ridge in East Tennessee, Oak Ridge National Laboratory (ORNL) is a government-owned facility operated by the Union Carbide Corporation, Nuclear Division, for the Oak Ridge Operations Office of the U.S. Department of Energy (DOE). This report describes the ORNL physical plant, characterizes the existing environment, cites ORNL environmental management policies, discusses accident safety policy, and presents an environmental analysis of the operation of the ORNL facilities in Bethel and Melton valleys. It does not cover site-specific impacts related to ORNL facilities located at the Y-12 site.

Environmental effects caused by the operation of a major technical complex such as ORNL may vary widely—from those that are associated primarily with process effluents to those that are associated with socioeconomic impacts. At ORNL the primary operational product is new scientific and technological information of national importance. In arriving at this product, the predominant effects on the human environment are socioeconomic and result from research and development (R&D) programs devoted to advancements in science and technology. In order of significance, these are (1) ultimate effects of R&D results on society, (2) continuing major socioeconomic effects on the regional communities and on the rest of the United States, and (3) effects associated with the dispersion of small amounts of materials which are released to the area environment. The R&D impacts on society are not within the scope of the current analysis and are not considered further; this report is devoted rather to the socioeconomic effects on the region and on the nation and to the assessment of operational releases.

SOCIOECONOMIC IMPACTS

In 1981 ORNL employed about 4900 and had a payroll of $128 million; its R&D subcontracting and materials procurement outlay was $120 million. Payroll and procurement disbursements create significant direct impacts on the local economy as well as indirect and induced impacts.

The local region selected for evaluation was the Knoxville Bureau of Economic Analysis (BEA) economic area. Comprising 24 counties, this area includes the Knoxville Standard Metropolitan Statistical Area (SMSA) and the counties tied to the SMSA based on journey-to-work patterns. The direct effects of ORNL payroll and procurement expenditures on the Knoxville BEA area during 1981 was the support of 5600 local jobs (4900 ORNL employees plus 700 jobs from local procurement) and the creation of about $139 million of local income ($128 million in ORNL payroll plus $10.9 million in local procurement). The indirect plus induced effects supported an additional 4800 local jobs and created $74 million in local income.

Thus the total impact of ORNL operations on the Knoxville BEA region was the creation of 10,400 jobs and $213 million in income. The total effect of ORNL employment and procurement on the Knoxville BEA region shows that each ORNL employee supports an additional 0.75 unit of employment in the local economy through consumer expenditures. Each dollar of ORNL payroll spent locally creates an additional 45¢ of local income, and each dollar of ORNL procurement secured locally creates $1.50 in income.

The total economic impact of ORNL operation is considerably larger than the local impact just described. A large proportion (73%) of ORNL equipment and supplies is procured from outside the local area. Also, an estimated 10% of personal consumption by ORNL employees occurs outside the Knoxville BEA area. When added to the local employment and income impact, the total economic

impact of ORNL payroll and procurement throughout the United States in 1981 was the support of 16,000 jobs and $301 million of personal income. About 36% of these jobs and 30% of this income occurred outside the local region. The total employment and income multipliers associated with combined ORNL payroll and procurement activity are estimated to be 2.87 (employment) and 2.17 (income). The distribution of total employment and income impacts from combined payroll and procurement is about 65% inside and 35% outside the region.

IMPACTS ON THE PHYSICAL ENVIRONMENT

The impacts associated with the release of materials to the environment result from releases to the atmosphere and from releases to both White Oak Creek (WOC) and Melton Branch, a tributary to WOC. White Oak Creek flows through the ORNL central site and through White Oak Lake into the Clinch River.

Nonradiological releases to the air include gases and particulate emissions from the coal-fired steam plant, chemical vapors from a large number of hoods and other building exhausts, exhaust and dust from vehicular traffic, and cooling tower drift. Calculations based on nonradiological releases show that national ambient air quality standards are not exceeded for any of the criteria pollutants. Cooling tower drift does not degrade air quality except possibly near the towers. Ambient air concentrations of chemicals from hoods and building exhausts are not environmentally significant.

Radiological discharges to the atmosphere amounted to 1.87 PBq (50,000 Ci) of radioactivity in 1981. About 77% of this activity consisted of the noble gases [^{133}Xe ($t_{1/2}$ = 5.3 d) and ^{85}Kr ($t_{1/2}$ = 10 years)], and about 23% consisted of tritium ($t_{1/2}$ = 12 years). Also included in the total was about 18 GBq (0.5 Ci) of ^{131}I ($t_{1/2}$ = 8 d) and 2.8 kBq (75 nCi) of particulates. For worst-case assessment purposes the particulates were assumed to be ^{239}Pu ($t_{1/2}$ = 24,000 years) and to be respirable (diameter <0.3 μm) and soluble. In assessing radiological impacts to the public, conservative assumptions that maximize absorbed dose have been used. The maximum exposed offsite individual is assumed to be at the Clinch River southwest of ORNL. It is assumed that the individual resides at this location 100% of the year and that all food (vegetables, beef, milk, and fish) consumed by this individual is raised at this same location. Such an individual will receive a total-body, 50-year dose commitment of 3.8 μSv (0.38 mrem), 95% of which results from the tritium released. The maximum organ dose is to the thyroid from the ^{131}I released and amounts to 22 μSv (2.2 mrems).

The allowable standards (50-year dose commitment) for a member of the public are 5 mSv (0.5 rem) to the total body, gonads, and bone marrow and 15 mSv (1.5 rems) to other organs. Thus the maximum exposed individual, as defined above, receives doses equal to only 0.076% (total body) and 0.15% (critical organ) of the allowable standards.

The population within an 80-km (50-mile) radius of ORNL is calculated to receive a 50-year dose commitment of 0.1 person-Sv (10 person-rems) to the total body, primarily from the tritium released, and 0.28 person-Sv (28 person-rems) to the thyroid from the ^{131}I released. The total-body, background, 50-year dose commitment to this same population is 1100 person-Sv (110,000 person-rems). Therefore, ORNL releases are equivalent to an 0.01% increase in background radiation. The total-body population, 50-year dose commitment to the remainder of the U.S. population outside of the 80-km (50-mile) radius is only 0.03 person-Sv (3 person-rems).

Postulated health effects from ORNL releases will result in 0.002 excess cancer deaths annually within the 80-km (50-mile) radius of ORNL, 0.001 excess cancer deaths annually for the rest of the United States, and 0.001 excess cancer deaths annually for the world outside of the United States. The number of excess cases of thyroid disease to the population within 80 km (50 miles) of ORNL is 0.001 per year from the ^{131}I release. Because of dispersion and because of the short half-life of ^{131}I, the number of excess cases of thyroid disease to the rest of the United States and to the world is insignificant.

Six solid waste disposal areas (SWDAs) contain more than 170,000 m^3 (6 million ft^3) of buried radioactive solid waste. SWDAs Nos. 1–3 are located in Bethel Valley and have been closed;

Nos. 4–6 are located in Melton Valley (No. 4 has been closed); No. 5 is presently reserved for retrievable storage of transuranic waste; and No. 6 is currently active. Chemicals and radioactive liquid wastes have also been disposed in pits and trenches in Melton Valley in past years, but this is no longer done. In 1981, about 4.3 PBq (120,000 Ci) of radioactive waste was buried or stored in SWDAs Nos. 5 and 6.

Monitoring data from streams within the WOC basin and from nearly 300 observation wells throughout the SWDAs, together with data from independent studies, have shown that the groundwater is contaminated beneath the SWDAs and at least part of the central site and that these areas are contributing to the radioactivity and chemical loading in WOC and in Melton Branch. For example, in November 1981 (a typical month) an inventory in WOC showed that 64% of the ^{90}Sr going over White Oak Dam originated in SWDAs Nos. 1, 3, 4, and 5 and ground disposal areas and floodplains. The most significant radionuclide discharged over White Oak Dam is by far ^{90}Sr. Although the inventory analysis was done only for ^{90}Sr, these same areas are probably also releasing other radionuclides. Studies also show that the concentrations of dissolved solids in tributary streams that receive seepage from the SWDAs and ground disposal areas are increased from 60 to 320% above background levels. (However, the total flow in these tributary streams is small compared with the flow in WOC.) Some chemical species such as nitrate, sulfate, nickel, iron, and mercury are high in tributary streams and are attributable to the burial grounds, pits, and trenches used in the past for disposal of nonradioactive wastes. No evidence exists that offsite release of contaminated water is occurring anywhere other than White Oak Dam. Water quality is discussed below and is within concentration guidelines at White Oak Dam.

To mitigate the ground disposal impacts, several remedial actions have been implemented and others are planned. Each measure that is tried needs to be evaluated to select the best actions for broader application. Three such mitigating measures are (1) bentonite seals over some of the filled trenches in the SWDAs to prevent downward percolation of rainwater through the buried materials (implemented), (2) groundwater diversion channels at the perimeter of the SWDA trench areas to prevent lateral flow beneath the bentonite caps (planned), and (3) surface diversion channels to direct surface water away from floodplains of the small tributaries downslope of the SWDA No. 4 to minimize flushing the contaminants in the floodplains into WOC during storm events (planned).

Sources other than the SWDAs also contribute to the water quality of WOC. Two monitoring stations, located at the Sanitary Treatment Plant discharge and at the Flume, have detected significant quantities of radioactivity. Discharged through the Flume is a natural stream that gathers runoff from a large area of the ORNL central site together with some nonradioactive once-through cooling water. Because no radioactive waste is discharged intentionally into the sewer system or into the Flume, the observed radioactivity apparently results from contaminated groundwater inflow into these effluent streams. Broken and corroded (out-of-service) process pipelines are thought to be the source of most of the radioactivity in the groundwater beneath the central site. Broken (in-service) sanitary lines permit inflow of contaminated groundwater into the sanitary system. If the radioactivity in the Sanitary Treatment Plant and Flume discharges are added to the SWDA discharges, it is evident that the majority of the radioactivity discharged over White Oak Dam comes from nonpoint sources.

After all inputs discussed above are diluted by the flows in WOC and in Melton Branch, the radioactivity in the water that passes over White Oak Dam causes no significant water quality problems in the Clinch River. The water discharged over White Oak Dam for the last 5 years has averaged less than the concentration guide for water in uncontrolled areas (CG_w), a limit established for the protection of human health. Measurements at the mouth of WOC [0.5 km (0.3 mile) below White Oak Dam] have averaged less than 30% CG_w for each of the past 5 years. After dilution by flow in the Clinch River is taken into account, the values have ranged from 0.2 to 0.6% of CG_w during the past 5 years.

From the foregoing discussion, it is apparent that the water quality within portions of the WOC basin lying within the restricted areas above White Oak Dam is degraded. The extent of the most significant biotic degradation is limited to the 1- to 2-km (0.6- to 1.2-mile) stream reach located between ORNL discharges and White Oak Lake. Ammonia, mercury, copper, and cadmium are the contaminants most probably responsible for the observed effects on aquatic biota. Unplanned events (e.g. large variations in pH) may also contribute to the depauperate condition in this stream reach. The average mercury level observed in fishes from White Oak Lake is 70% of the Food and Drug Administration action level. Between ORNL and White Oak Dam polychlorinated biphenyls (PCBs) concentrations in sediments are above background, although the concentration in the water is below the limits of detection. This suggests an earlier release of PCBs and prior accumulation in the sediments. The public does not have access to White Oak Lake or to WOC between ORNL and White Oak Lake. The first public access to WOC discharges is immediately below White Oak Dam where the water quality is at or below CG_w. Analyses of sediments and trace elements in fishes in the Clinch River have not shown significant adverse impacts.

The radiological impact of liquid effluents from ORNL was assessed by calculating the radiological dose to individuals from various uses of the Clinch River and to populations taking their drinking water from the Clinch and Tennessee rivers downstream from ORNL. In 1981 the total radioactivity discharged to the Clinch River over White Oak Dam consisted of 0.11 PBq (3000 Ci) of tritium and 95 GBq (2.6 Ci) of other radionuclides, 93% of which consisted of ^{60}Co, ^{90}Sr, and ^{137}Cs. The total-body, 50-year dose commitment to the maximally exposed individual from all aquatic pathways was 60 μSv (6 mrems); this is only 1.2% of the allowable standard (DOE) for the public. The maximum 50-year organ-dose commitment (bone) was 82 μSv (8.2 mrems); this is only 0.6% of the allowable standard.

The population 50-year dose commitment from drinking water from the Clinch and Tennessee rivers was 0.038 person-Sv (3.8 person-rems); this is only about 0.01% of the dose to the similar population of 0.39 person-Sv (39 person-rems) from natural background radiation.

Intermediate-level waste is now pumped to the Melton Valley Hydrofracture Facility for disposal by injection as a cement grout into the Pumpkin Valley member of the Conasauga shale [over 200 m (650 ft) below the surface]. The grout sets in a few hours after injection, thereby permanently fixing the radioactive wastes in the shale formation. Over 5400 m^3 (1.4 million gal) of waste containing over 1.4 PBq (38,000 Ci) of ^{90}Sr and 25 PBq (680,000 Ci) of ^{137}Cs, together with much smaller quantities of other radionuclides, have been injected. Radiological surface water and groundwater studies indicate that no migration of radionuclides has occurred.

No employee received a total-body dose that exceeded the standards (DOE) for radiation exposure during 1981, the latest year on record. The maximum total-body dose sustained by an employee was about 38 mSv (3.8 rems), or 76% of the applicable standard of 50 mSv (5 rems) per year. The greatest cumulative dose to the skin received by an employee in 1981 was about 39% of the applicable standard of 150 mSv (15 rems) per year. The maximum cumulative hand dose recorded was about 20% of the applicable standard of 750 mSv (75 rems) per year. The greatest cumulative total-body dose received by an employee was about 1.15 Sv (115 rems) accrued over 38 years of employment. This represents about 60% of the applicable standard.

In 1981, construction projects affected relatively small areas of land and wildlife habitat, which was usually adjacent to existing buildings. Only minor transitory degradation of the local environment resulted from this construction. No plant or animal species on the federal or state endangered species lists were affected by the construction activities.

1. INTRODUCTION

An environmental analysis of the operation of the Oak Ridge National Laboratory (ORNL) facilities in Bethel Valley and Melton Valley has been conducted to present to the public information concerning the extent to which recognizable effects, or potential effects, on the environment may occur. The analysis addresses current operations of the ORNL X-10 site and completed operations that may continue to have residual effects. The work place of 18–19% of ORNL personnel is at facilities located at the Y-12 site, where liquid and gaseous waste streams from both ORNL and Y-12 Plant operations feed into common collection (and treatment) systems. Environmental issues related to these Y-12-used facilities are not addressed in this report. On the other hand, solid wastes from ORNL operations at the Y-12 site which are transported to the X-10 site for burial (e.g., Biology Division animal wastes) are included as part of X-10 site operation. Socioeconomic effects are associated primarily with the communities where employees live and with the Knoxville Bureau of Economic Analysis economic area as a whole. Therefore, ORNL employees at both Y-12 and X-10 sites are included in the ORNL socioeconomic impact analysis. Such impacts are not directly associated with the respective sites.

The document does not conform to the format prescribed by the Council on Environmental Quality (45 CFR Pts. 1500–1508, Nov. 29, 1978) for environmental impact statements, required by the National Environmental Policy Act (NEPA) for "major federal action" significantly affecting the quality of the human environment. However, the document can function as a major reference and publicly available baseline for future NEPA documents as may be required for additions to, or modifications of, existing ORNL facilities. In addition, the document itself could be converted readily into an NEPA environmental assessment or environmental impact statement.

An extensive base of environmental data has been accumulated for this report. Over 80 reports related to ORNL facilities and/or operations are cited as well as many open-literature citations.

Environmental effects of the operation of ORNL result from operational discharges from the onsite facilities; construction and/or modification of facilities; transportation to and from the site of persons, goods and services; socioeconomic impacts to the local, regional, and general population; and accidental discharges if they should occur. Operational discharges to the environment are constrained by federal, state, and local regulations and by criteria established by the U.S. Department of Energy to minimize adverse impacts.

Numerous transfers of materials occur within facilities bounded by ORNL site limits and do not result in releases to the adjacent area. It is the purpose of this document to evaluate the operation of the ORNL insofar as impacts beyond the site boundary may occur or have the potential for occurrence.

Monitoring activities and data acquisition continue as ongoing activities of ORNL. Accordingly, although many of the analyses presented in this document are complete and adequate for this evaluation, continuation of monitoring and data acquisition is justified to refine the data base and/or to detect any unforeseen adverse environmental impacts that might require mitigation.

2. DESCRIPTION OF OAK RIDGE NATIONAL LABORATORY (X-10 SITE)

2.1 LABORATORY MISSION AND PROGRAM ACTIVITIES

2.1.1 Historical Background

The Oak Ridge National Laboratory (ORNL) was built in 1943 as a pilot plant for demonstrating production and separation of plutonium. Since that time it has evolved from a laboratory almost wholly dedicated to nuclear technology research and development to one of the largest national laboratories in the United States and now includes extensive multidisciplinary efforts in nonnuclear technologies and sciences. Employment has grown from initial cadre of about 1200 to about 4900 at present.

2.1.2 Present Role

ORNL is a government-owned facility managed by the Union Carbide Corporation, Nuclear Division (UCC-ND) for the U.S. Department of Energy (DOE). A staff of wide-ranging technical expertise and varied and unique research facilities are maintained to support the extensive and diverse ORNL programs.

In the last decade ORNL, reflecting changes in the mission of DOE, has made a transition from primarily nuclear fission energy/physical sciences work to a broader research and development base (Fig. 2.1). Although nuclear fission energy programs continue to receive the greatest funding, important work is carried out in many other areas, as is shown in the apportionment of operating funds during 1981 (Fig. 2.1).

Emphasis, however, is on long-term, high-risk, high-payoff technology development that is of national importance. Because of the long-term payoff and/or high monetary risk, the private sector and universities choose not to undertake the programs.

Another important function of ORNL is to identify and provide solutions to generic problems in energy-base technologies such as materials development, separation techniques, chemical processes, biological screening, and biotechnology. In carrying out this role, ORNL conducts basic research in physical and life sciences to provide a solid basis on which to make decisions about the various energy technology options. ORNL also serves as a technical program manager for DOE in specialized areas of technology development in which it has special competence.

ORNL produces and sells radioactive and stable isotopes (when not available elsewhere) to the medical, industrial, and research communities. Private industry also provides this service but does not provide any of the same isotopes. Laboratory sales do not compete with private industry.

ORNL also does work for other federal agencies such as the U.S. Nuclear Regulatory Commission, the U.S. Department of Health and Human Services, the U.S. Department of Housing and Urban Development, the U.S. Department of Defense, and the U.S. Environmental Protection Agency (EPA) in areas where DOE has a program interest. This work for others amounts to about 20% of ORNL's program.

ORNL expends special effort to transfer technology to the private sector; to involve industry, where appropriate, in ORNL programs; and to encourage cooperative uses of facilities, both formally in users' groups and informally through professional contacts and participation. Similarly, ORNL provides universities with ready access to major research facilities and programs. At ORNL, users have access to state-of-the-art research capabilities, training facilities for faculty and students, and an opportunity for collaborative research in areas in which these facilities and techniques are not available to universities.

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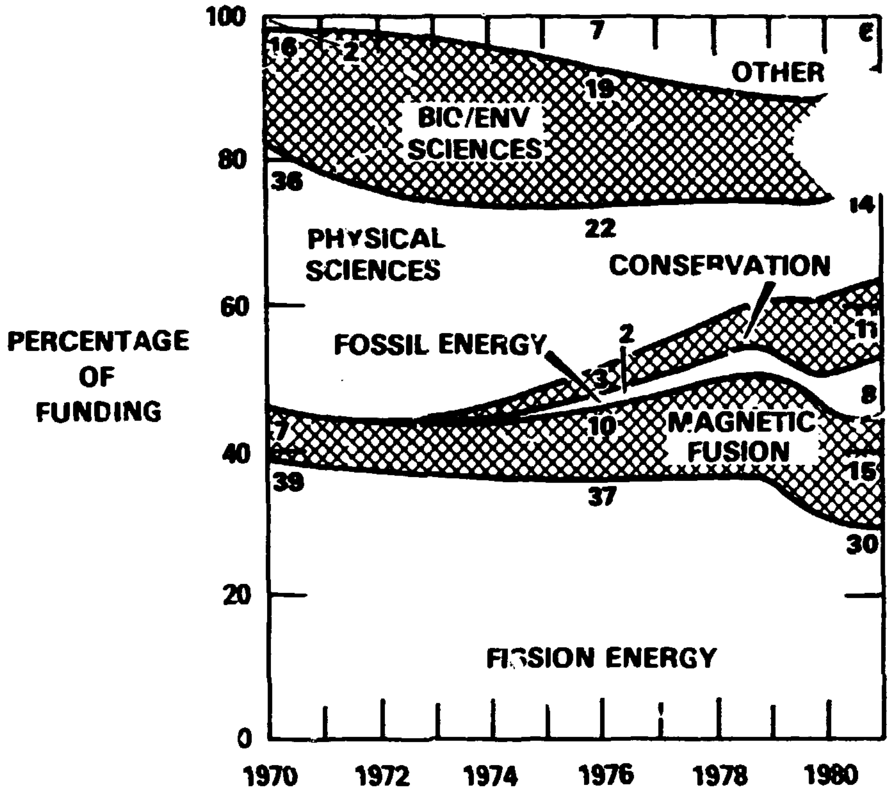

Fig. 2.1. Programmatic funding at ORNL, 1970–1981. Source: *Oak Ridge National Laboratory Institutional Plan FY 1982–1987*, ORNL/PPA-81/8, Oak Ridge National Laboratory, Oak Ridge, Tenn., p. 7.

ORNL plays a special regional role for energy-related studies by providing universities in the Southeast access to its facilities which enables them to investigate energy technologies that are of particular interest to the Southeast. ORNL has a long-standing tradition of participation by university and industrial personnel in its research and development (R&D) programs. The number of guest assignees, representing university, industry, and foreign institutions, has steadily increased and currently accounts for a major portion of some research programs—for example, transuranium chemistry research. About 1300 university guests from 500 colleges and universities participated in DOE-sponsored programs in 1981. Some 90 research proposals for experiments at the Holifield Heavy Ion Research Facility (HHIRF) have been accepted for implementation. Special programs have been established to facilitate university research cooperation in small-angle scattering, both neutron (SANS) and x-ray (SAXS); materials research (SHaRE); synchrotron studies of materials properties (NSLS) separation and investigation of short-lived isotopes (UNISOR); determination of properties of transuranium elements (TRL); environmental studies [Oak Ridge National Environmental Research Park (NERP)]; and several more.

Industrial participation in the use of specialized facilities and staff talents may proceed through either contractual or collaborative arrangements. Some examples of current or recent industrial participation are studies of polymer structures by SANS (Du Pont), coal structure studies by specialized electron spin resonance apparatus (Exxon), studies of low-level alpha emitters in high-purity silicon (International Business Machines), and radionuclide measurements in solving problems with the cleanup operation at Three Mile Island (General Public Utilities).

One of the two major extramural expenditures is subcontracting; the other is procurement. Figure 2.2 shows that a very substantial growth in extramural expenditure has occurred since DOE

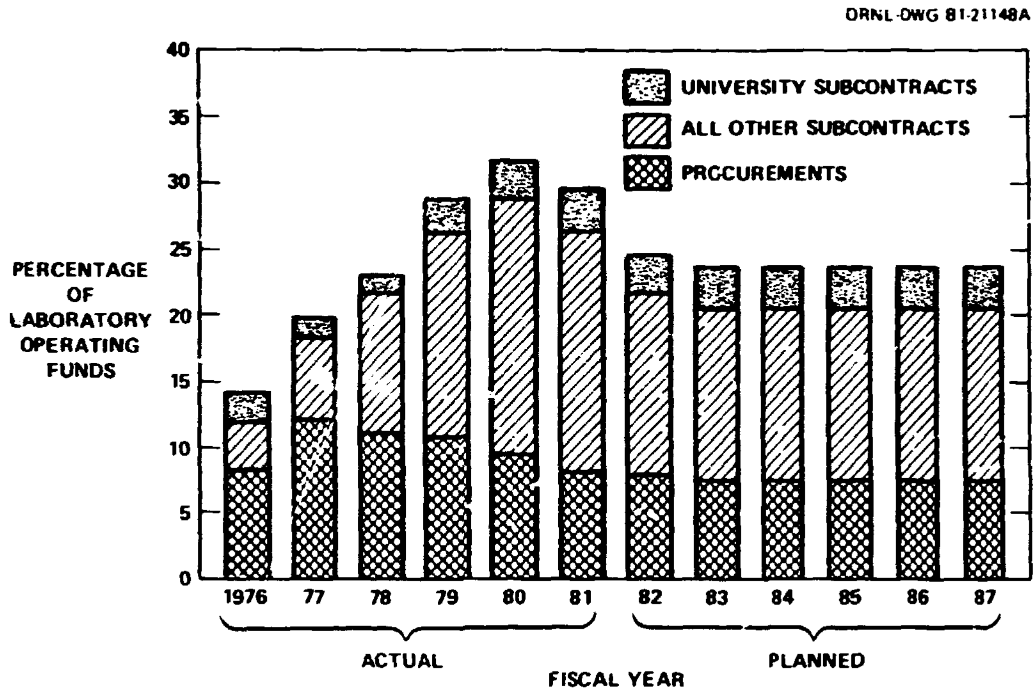

Fig. 2.2. Percentages of ORNL operating funds used for subcontracting and procurement. Source: *Oak Ridge National Laboratory Institutional Plan FY 1982-1987,* ORNL/PPA-81/8, Oak Ridge National Laboratory, Oak Ridge, Tenn., p. 9.

authorized ORNL to increase subcontracting in 1974. However, future expenditures are expected to remain at near the current level.

ORNL supports and collaborates with other institutions, such as state and local governments and the Tennessee Valley Authority (TVA), that are primary R&D influences in the area. In addition, ORNL is linked to other DOE-sponsored development activities in the Oak Ridge area, such as the Clinch River Breeder Reactor and the uranium enrichment programs, and it provides support to the DOE Oak Ridge Operations Office.

2.1.3 Organization

The operating structure of ORNL is a decentralized matrix organization in which management duties are split between functional and program lines (Fig. 2.3). In this system, four associate directors and an executive director are responsible for specific ORNL divisions; this constitutes the functional line. The associate directors also administer ORNL's technical work programs through interaction with both divisions and programs; this constitutes the program line. Programmatic money is provided by DOE and other sponsors through the administration of the Oak Ridge Operations Office.

The total number of employees at ORNL is 4900 plus about 900 guests. The number of personnel has remained close to this level since FY 1978 but is expected to be reduced gradually over the next couple of years, thus paralleling expected funding drops by DOE and other agencies. The composition of the professional staff is both varied and substantial. Engineering programs account for the employment of 590 chemical, electrical, mechanical, and nuclear engineers; physical science research, some 670 scientists; life sciences, 300 biomedical and environmental scientists; and social sciences, 40. Approximately 40% of the personnel hold degrees from universities or colleges (some 870 of this group hold Ph.D. degrees).

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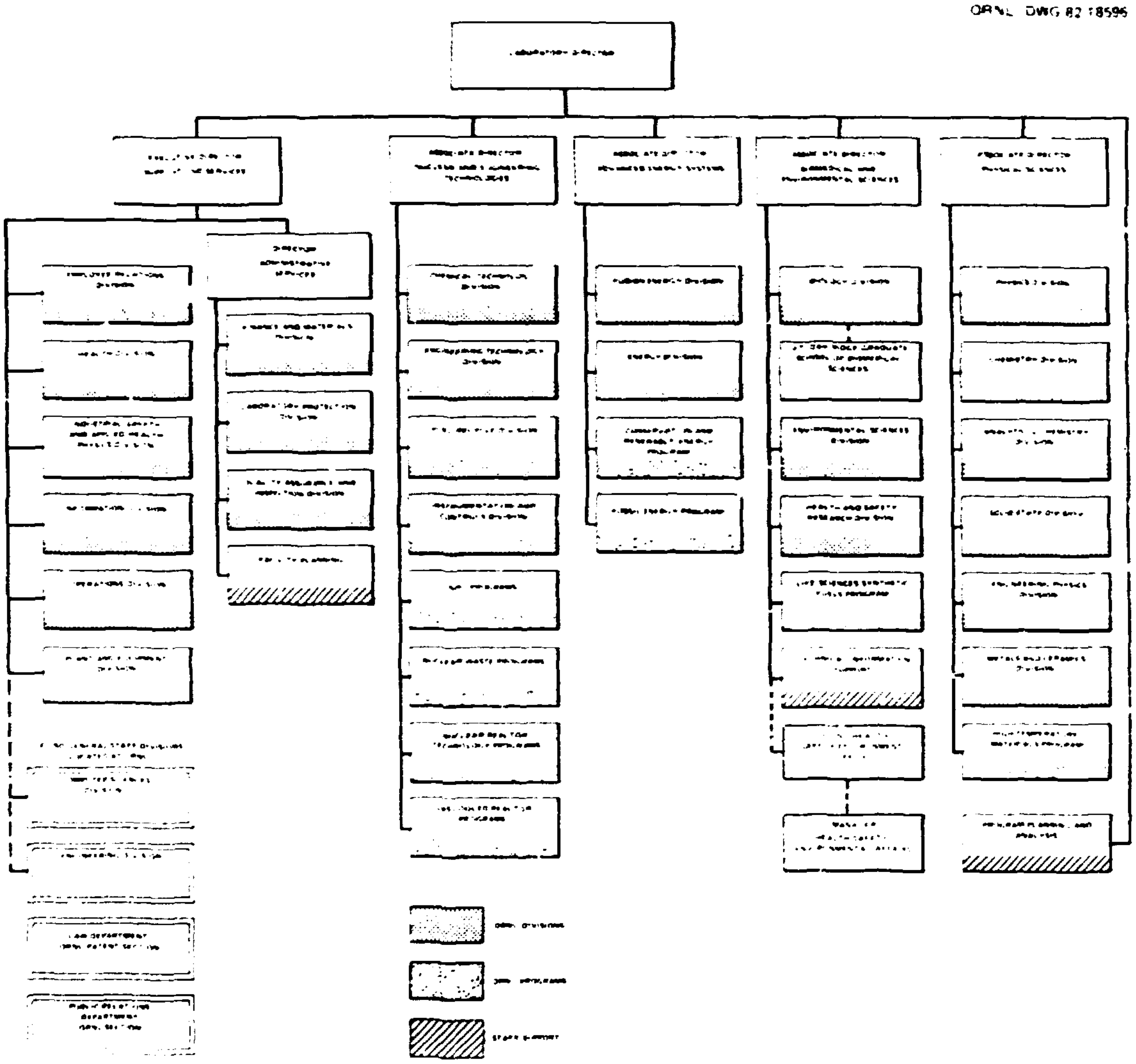

Fig. 2.3. ORNL functional and programmatic administrative structure. Source: *Trends and Balances ORNL 1982 1987*, ORNL/PPA-82/1, Oak Ridge National Laboratory, Oak Ridge, Tenn., p. 6 (updated).

2.1.4 Mission Direction

Appropriate roles for the national laboratories, identified in the Congress, include weapons R&D and stewardship of large and expensive research facilities (user facilities). As one of the major federal research laboratories, ORNL is expected to adopt mission directions that fulfill its sponsors' needs. An important responsibility of ORNL is the maintenance and safeguarding of special facilities that are nationally or internationally unique or rare. These include accelerators, reactors, scattering facilities, and large animal populations, among others.

The specialized collection of equipment and unique facilities that exists at ORNL continues to make possible some research and service activities that are not carried out elsewhere in the nation. Some examples are (1) the HHIRF for studies of heavy-ion nuclear reactions; (2) the High Flux Isotope Reactor (HFIR) and the transuranium-processing facilities for transuranium element processing, production, and research; (3) large-scale facilities for stable isotopes production; (4) a laboratory for producing and studying surface modifications of solids; and (5) an environmental research park.

The Institutional Plan for FY 1982–1987 identifies five new initiatives: an engineering science center, strategic materials for energy, environmental control technology, hazardous waste technology, and global environmental concerns. It is by identification and planning such initiatives that mission directions of common interest to ORNL, its sponsors, and the nation are embarked upon and that the course of ORNL programs is set.

2.2 LOCATION

ORNL is located on a federal reservation approximately 13 km (8 miles) southwest of the city of Oak Ridge. The area is one of hills and valleys in the eastern part of Tennessee. Figure 2.4 shows the location of ORNL in the state and its relation to surrounding communities. The DOE reservation is in a rural setting and is bounded by the Clinch River on its eastern, southern, and western borders.

Within the reservation, there are three DOE plant complexes in addition to ORNL: the Y-12 Production Plant, the Oak Ridge Gaseous Diffusion Plant (ORGDP), and the Comparative Animal Research Laboratory (CARL). The Y-12 Plant functions mainly in the design and production of nuclear weapon components. The ORGDP functions primarily as a facility for the enrichment of uranium for use in commercial light-water reactors. CARL (operated by the Oak Ridge Associated Universities for DOE) uses several areas of the DOE reservation for research on mammalian metabolism and the toxic effects of energy-related activities on mammals.

Three prominent TVA facilities—two coal-fired steam plants (Kingston and Bull Run) and a hydroelectric generating station (Melton Hill Dam)—are operating in the area.

2.3 PHYSICAL PLANT DESCRIPTION

2.3.1 Laboratory Site

ORNL is centrally located on the southern border of the federal reservation (Fig. 2.5). Its principal R&D facilities consist of nuclear research reactors, particle accelerators, hot cells, engineering process development facilities, radioisotope production facilities, and research facilities in physics, chemistry, and the environmental sciences (Sect. 2.3.2). Other major facilities are located in satellite areas in proximity to the X-10 central site (Sect. 2.3.3) and at the Y-12 site. Support facilities and systems are described in Sect. 2.5. ORNL facilities in the X-10 central site area and satellite areas are shown in Fig. 2.6. A list designating the ORNL facilities (shown in Fig. 2.6) is given in Appendix A. Although several of the major programmatic activities of ORNL are conducted by personnel located in facilities in the Y-12 area, the environmental effects of those facilities are not considered in the current environmental analysis.

The central site area lies in Bethel Valley, which runs approximately in a northeast-southwest direction. Although the valley floor is highly developed within the central site area, the surrounding terrain is wooded. White Oak Creek (WOC) passes to the south of the developed area and leaves the valley through a gap in Haw Ridge into Melton Valley. All the satellite facilities are located in Melton Valley except the Tower Shielding Facility, which is on Copper Ridge south of Melton Valley.

ORNL facilities cover a broad area and are somewhat dispersed. This dispersal permits the accommodation of a variety of experimental programs that require isolation. The natural areas beyond the central area are also used for research programs of ecology and forestry.

2.3.2 Central Site—Major Facilities

2.3.2.1 Reactors

Three reactors are currently operating in the central site area: the Oak Ridge Research Reactor, the Bulk Shielding Reactor (BSR), and the Pool Critical Assembly (PCA). The three reactors have a common water purification system (ion exchange columns) and a common heat dissipation system.

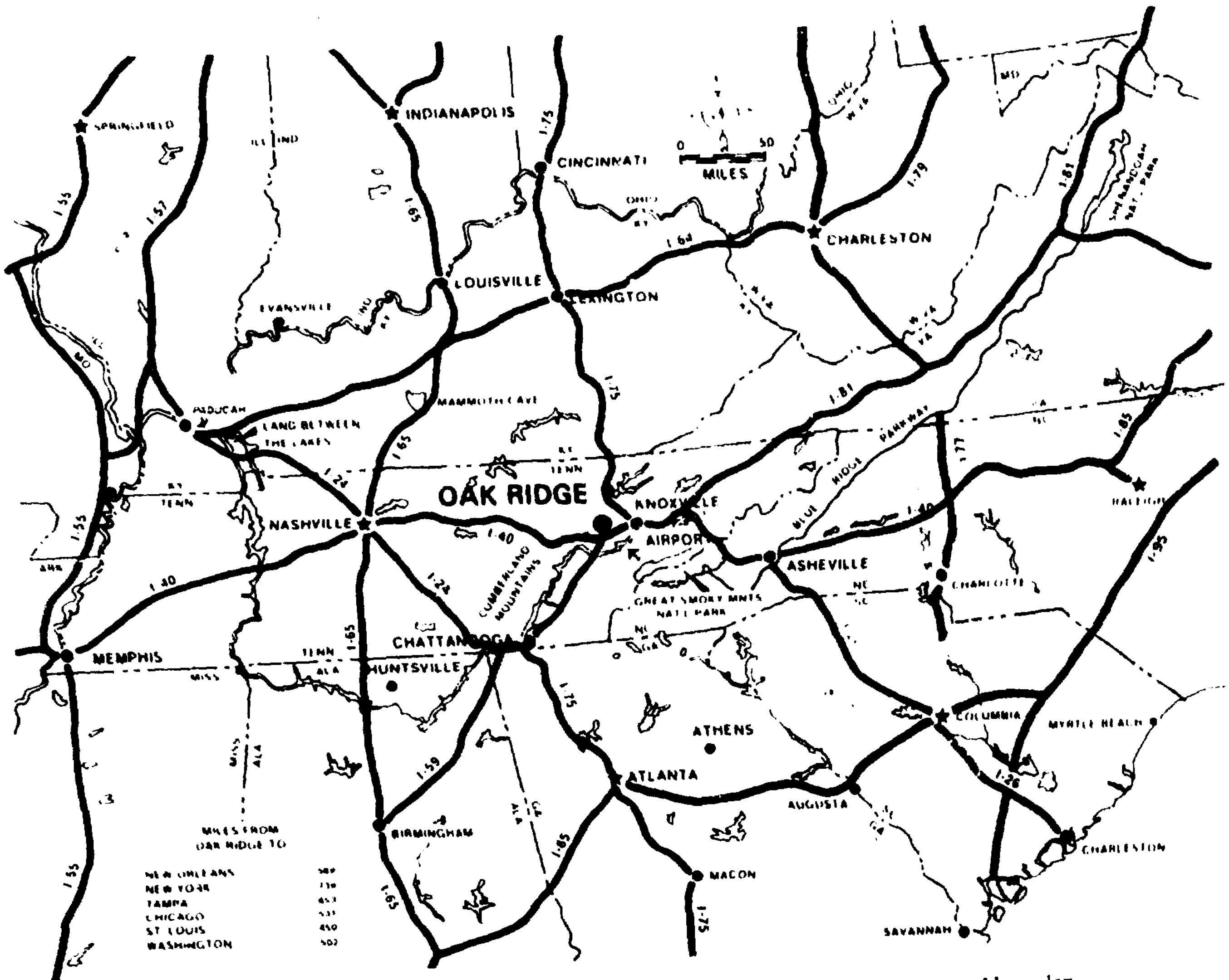

Fig. 2.4. Map showing location of Oak Ridge in Tennessee and relationship to geographic region.

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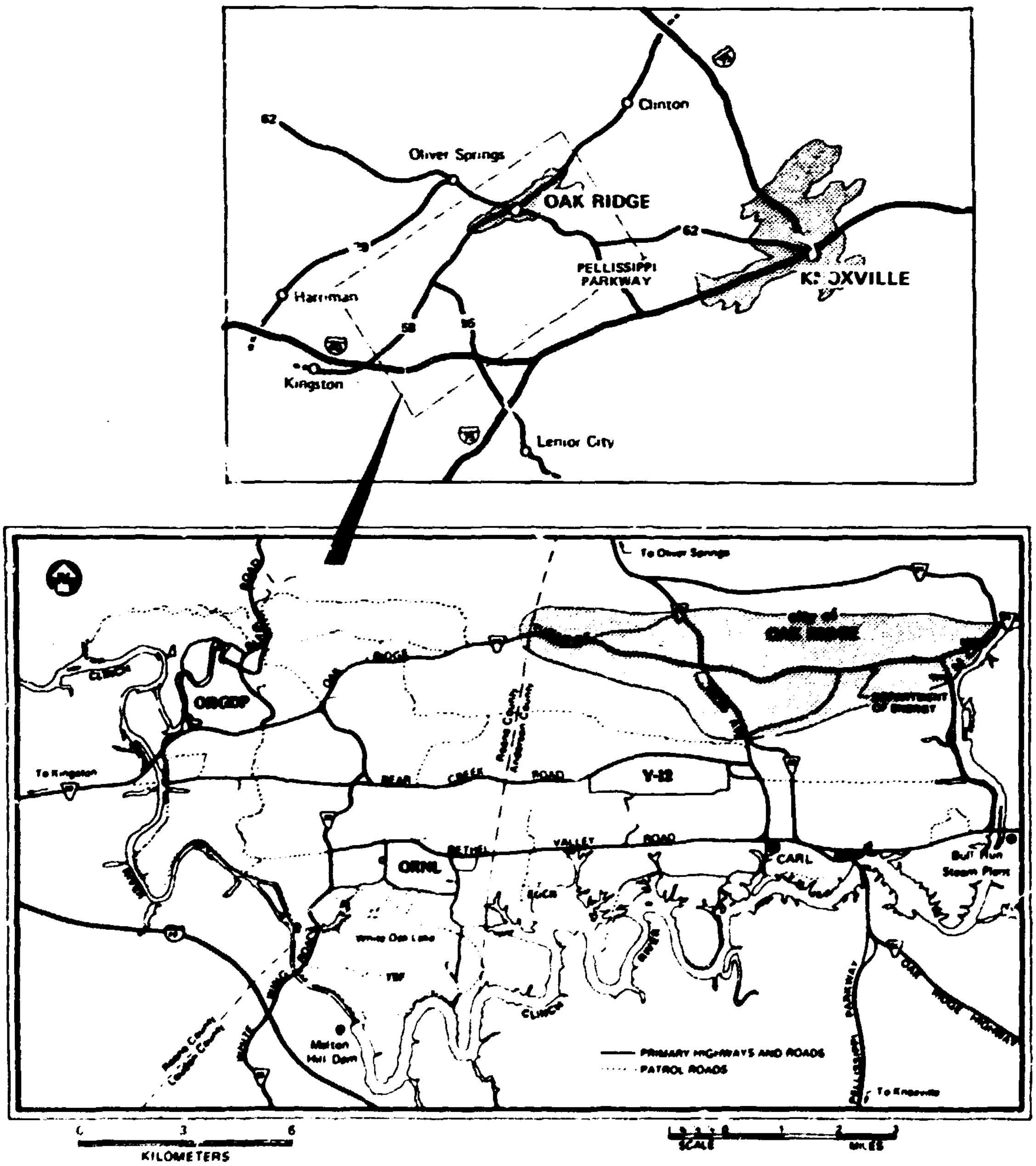

Fig. 2.5. Map showing location of ORNL on the Oak Ridge Reservation and the relationship to surrounding communities.

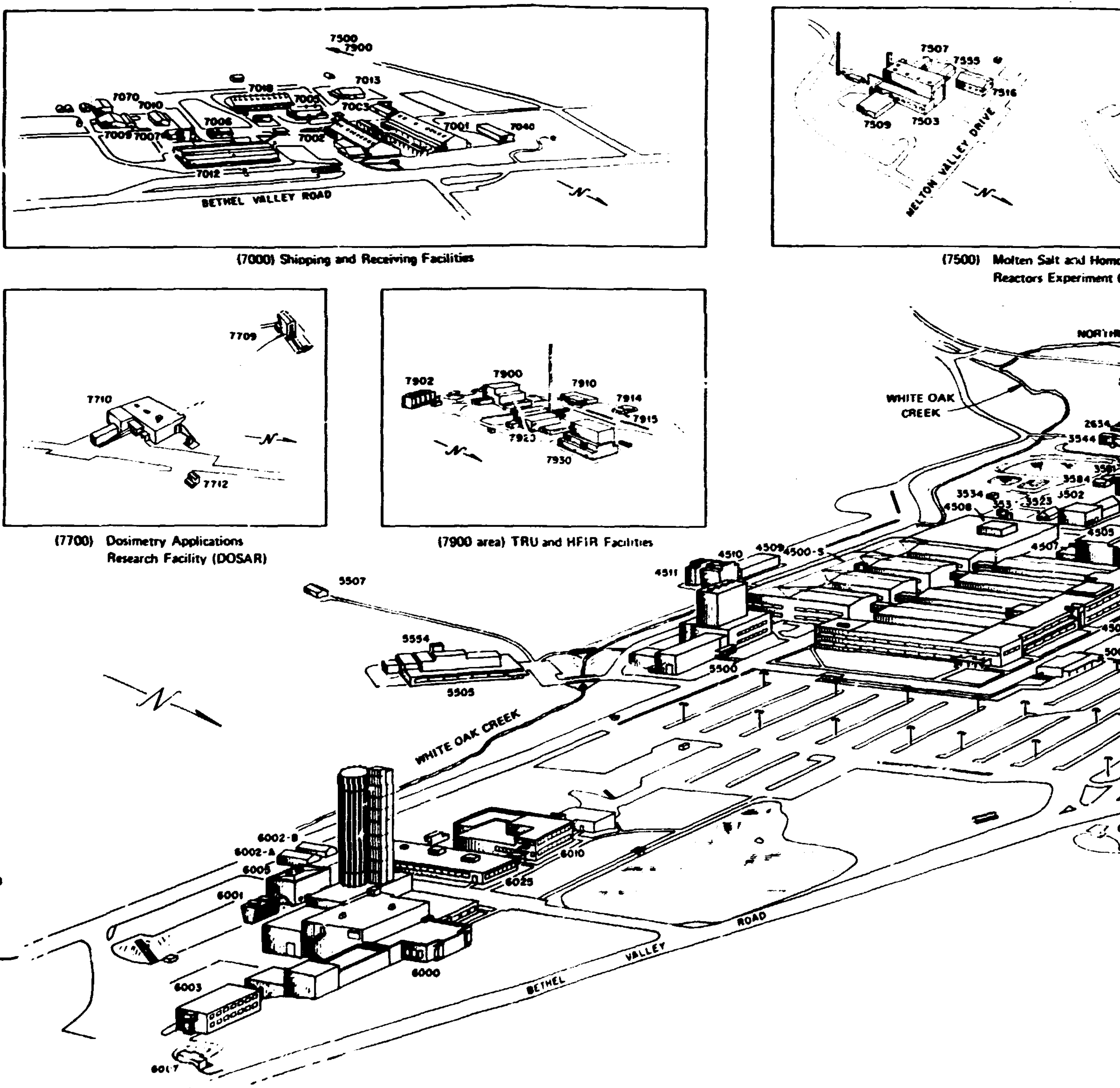

Fig. 2.6 Facilities of the Oak Ridge National Laboratory at the X-10 central site and outlying sites (Y-12, N

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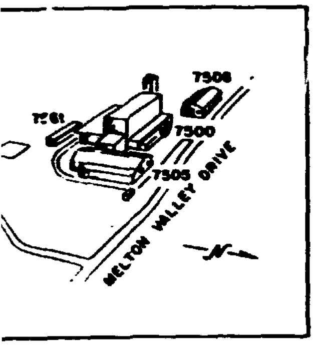

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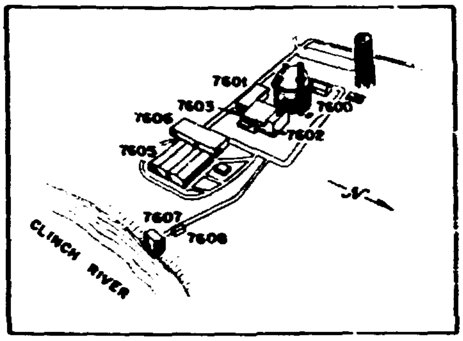
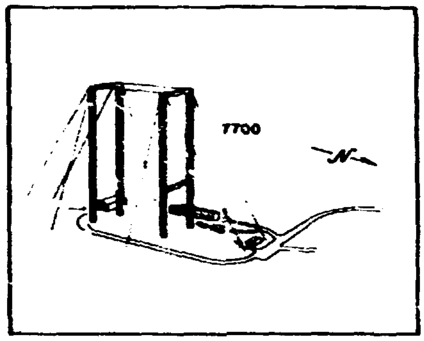
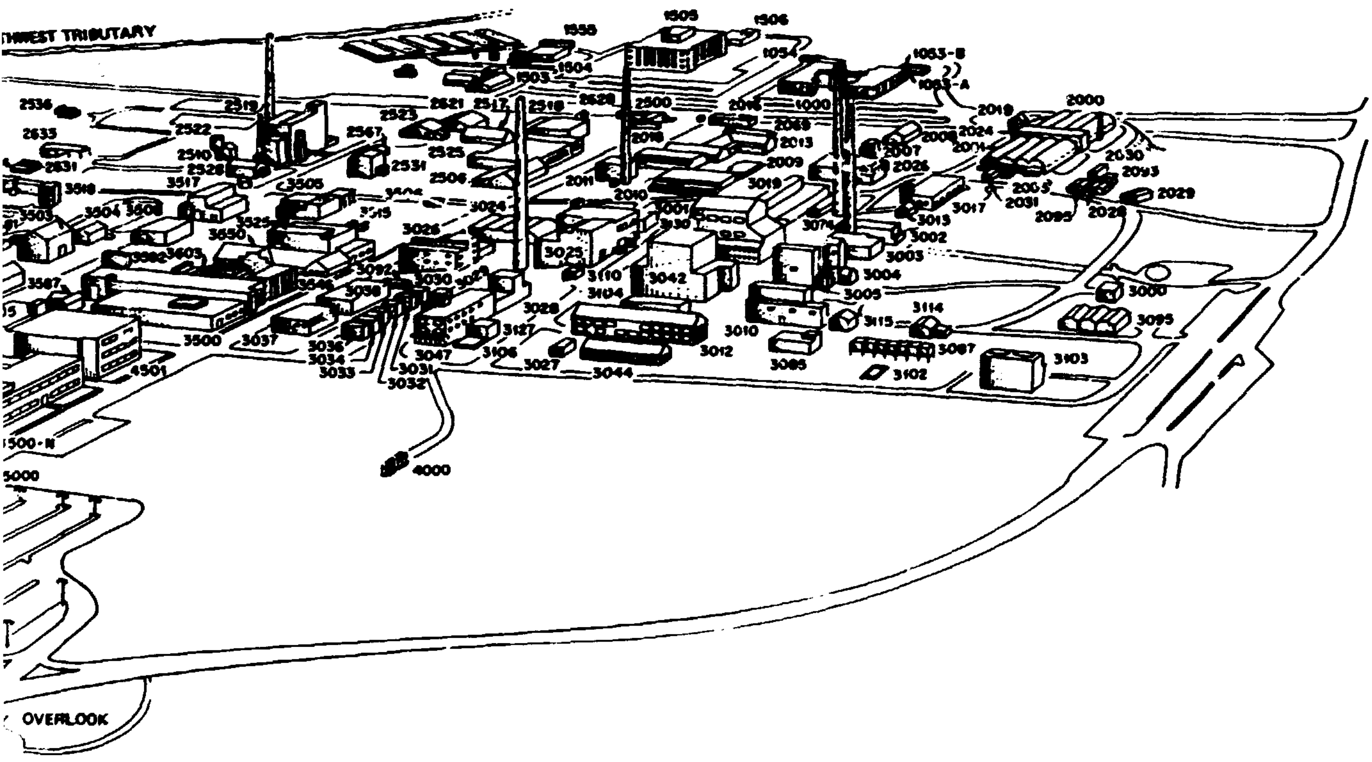


(7600 area) Consolidated Fuel Reprocessing Facility



(7700) Tower Shielding Facility



National Environmental Research Park, and the solid waste disposal area not shown).

Oak Ridge Research Reactor. This reactor (Bldg. 3042) operates at 30 MWt using enriched uranium fuel in the form of aluminum-uranium alloy fuel plates; it is light-water moderated and cooled, beryllium- and water-reflected. Refueling the reactor requires 12 kg (26 lb) of uranium annually.

Reactor core cooling is effected by using degassed demineralized water as the primary coolant. The water flows through the reactor tank at about 1100 L/s (18,000 gpm) and through four stainless steel heat exchangers, where heat is transferred to the secondary coolant [treated process water flowing at about 3700 L/s (58,000 gpm)] and then to the atmosphere through cooling towers. A second cooling system is provided to remove about 0.7 MW of heat from the reactor pool and reject it to the atmosphere through a cooling tower, if necessary.

Approximately 480 PBq (13 million Ci) of mixed fission products (100-d decay period) and 11 PBq (300,000 Ci) of ^{65}Zn and ^{115}Cd from shim rods and end boxes are generated annually. Insignificant amounts of this radioactivity are released to the environment.

Bulk Shielding Reactor and Pool Critical Assembly. The BSR and the PCA are contained in a water-filled pool housed in Bldg. 3010. The operating power levels of the two reactors are 2 MWt and 100 Wt respectively. Water serves as the fuel coolant, moderator, shield, and reflector for each. Pool water quality is maintained by circulating it at a rate of about 13 L/s (200 gpm) through a filter bed and at about 2 L/s (30 gpm) through a bypass demineralizer. Fission heat is removed by pulling pool water downward through the core into a plenum box below the reactor at a rate of 63 L/s (1000 gpm) and passing through a syphon break, decay tank, and stainless steel shell-and-tube heat exchanger. The secondary coolant is circulated through a two-cell 5-MW cooling tower that dissipates heat to the atmosphere.

Approximately 0.1 kg (0.22 lb) of ^{235}U is consumed annually by the BSR, thus generating approximately 4.8 PBq (130,000 Ci) per year of mixed fission products (estimated after a year's decay). These fission products, contained in the spent fuel elements, are placed in long-term storage in the solid waste disposal area (SWDA).

2.3.2.2 Particle accelerators

Several particle accelerator facilities are operated as sources of subatomic particles for basic research experiments in atomic nuclear physics and materials studies. Operation of the particle accelerators may produce high levels of radiation in target areas, but such radiation occurs only during beam operation and is confined entirely within shielded rooms. Only the HHIRF in Bldg. 6000 and a neutron generator in Bldg. 2011 release small quantities of toxic materials during normal operation.

The HHIRF consists of two subunits: the Oak Ridge Isochronous Cyclotron (ORIC) and the Heavy Ion Facility. The ORIC may be operated independently or in conjunction with the Heavy Ion Facility; in conjunction, the two operate as the HHIRF. The ORIC is an experimental particle accelerator that provides intense beams of a wide variety of ions at various energies suitable for nuclear reaction research; it can be used as an intermediate-energy booster for the 25-MeV heavy ion tandem accelerator. Some of the heavy ions accelerated by ORIC are produced by introducing certain gases into the cyclotron ion source. Some of these gases are toxic, and precautions are taken to prevent the release to the environment of hazardous quantities. The toxic gases used are carbon monoxide, sulfur dioxide, chlorine, hydrogen sulfide, and boron trifluoride. Of these, only carbon monoxide is used for more than a few days per year, and even carbon monoxide is used only a few weeks per year. The gases are purchased in lecture bottles rather than in large cylinders so that accidential loss of the entire inventory would produce only a local hazard. During use, the rate of consumption is less than 5 cm^3/min at standard temperature and pressure. The gas, after leaving the ion source, goes through the cyclotron vacuum pumps where it becomes diluted and is exhausted to the atmosphere through a vent on the roof of the building. If the calculated concentration in the vent stack exceeds the tolerance level for respirable air, additional air is pumped into the vent stack so that the effluent never reaches a hazardous level at the point of discharge.

The Oak Ridge Electron Linear Accelerator is used primarily to obtain neutron cross-section data. The radioactivities induced in the targets and surrounding materials by the intense electron beam and secondary neutrons are disposed of in the SWDAs as low-level waste (LLW). Monitoring of the exhausted air shows that insignificant amounts of radioactivity are released.

A Kaman Model 1250 neutron generator in Bldg. 2011 produces 2 × 10^{11} 14-MeV neutrons/s. The generator is operated in conjunction with mechanical properties testing equipment. It is estimated that approximately 370 MBq (0.01 Ci) of tritium may be released annually from this facility.

2.3.2.3 Hot cells

Hot cell facilities are employed at ORNL for postirradiation mechanical disassembly of experiments and for physical and metallurgical examination of nuclear fuel elements. The hot cells are operated in support of the reactor development program and fundamental research in metallurgy, chemistry, and solid state physics. Major hot cell facilities are located in Bldgs. 2026, 3019 (see separate heading below), 3025, 3026-D, 3517, 3525, and 4501.

Although different operational experiments and different levels of radioactivity are handled in different buildings, the approach to safe operation is the same for each facility. In each of the facilities, protection from direct radiation is provided by concrete walls and shielding windows around the cells; the cell walls vary in thickness and are adequate in each case for the levels of radioactivity handled in the facility. Provisions are made for double containment of any airborne radioactive gas or particles. The primary containment consists of the hot cell structure; the cells are maintained at a negative pressure relative to the surrounding areas so that any air flow is inward, thus decreasing the potential for escape of radioactive material. Secondary containment is provided by the building around the hot cell structure. In the High Radiation Level Examination Laboratory (Bldg. 3525), where the most hazardous materials are handled, the secondary containment area is automatically isolated and brought under negative pressure on detection of airborne radioactivity by constant air monitors in the area. Waste gas systems are discussed in Sect. 2.5.6.

All liquid wastes from hot cells are considered to be radioactive and are processed as intermediate-level waste (ILW) (see Sect. 2.5.7.1). Solid waste disposal systems are discussed in Sect. 2.5.8.

Consolidated Edison Uranium Solidification Program (Bldg. 3019). This program will convert 1047 kg (2308 lbs) of uranium (75 wt % ^{235}U, 10 wt % ^{233}U and 120 ppm ^{232}U) from a nitrate solution to an inert solid for safe, long-term storage in an existing seismic-proof facility. This uranium, originially recovered by processing the Consolidated Edison Indian Point Core "A" in 1968 at the Nuclear Fuels Services Plant (West Valley, New York), has been stored in a tank in the form of a uranyl nitrate solution at ORNL for 13 years. In its present form, the material is a potential hazard because of its fissile content and its near-equilibrium content of high-energy ^{232}U daughters.

Prior to the conversion to solid, which is currently scheduled to be performed during FY 1985 and FY 1986, the design, fabrication, purchase, and installation of special equipment needed for the task must be completed.

The chemical processing is conceptually simple but is complicated by space restrictions in the available hot cell and requirements for massive shielding [50 cm (20 in.) of steel equivalent]. The liquid material will be filtered, concentrated by evaporation, then denitrated to UO_3 in the storage cans. Highly reliable processing equipment and dedicated machines that can be operated remotely are required to move the cans through a series of steps required for sealing, handling, and weighing. The solidification process will be accomplished inside Cell 3 of Bldg. 3019. Long-term storage will be in dedicated wells provided for this job in Cell 4.

2.3.2.4 Engineering process development facilities

Engineering process development facilities (pilot plants) are housed in nine ORNL buildings that are used primarily in the investigations of nuclear materials. The buildings differ greatly in size, construction, and content. Estimates of the amounts of radioactive and chemical waste discharged from each building are included in ORNL total presented in Sects. 2.5.6, 2.5.7, and 2.5.8. The amounts are extremely variable because the amounts of materials used and discharged may change with program changes.

Where special provisions are required for safety, multiple containment is provided. In most instances, the process equipment itself provides the primary containment. Secondary containment may consist of either partially shielded glove boxes or a completely shielded hot-cell structure. Tertiary containment consists of the building in which the glove boxes or hot cells are located. Glove boxes, hot cells, and building areas are maintained at reduced pressures relative to the surrounding areas so that the flow of air is always inward toward the most contaminated areas; thus the possibility for release of radioactive materials is decreased.

2.3.2.5 Radioisotope and special materials production facilities

For many years ORNL was the principal U.S. producer and supplier of radioisotopes. Although much of the demand is now fulfilled by industry, ORNL continues to furnish special materials where the unique need cannot be met otherwise. Thirteen buildings comprise the radioisotope production, storage, and shipping facilities. These are located primarily in the 3000 area of ORNL. Not all the facilities are in current use; some building space has been converted to other uses. The Fission Product Development Laboratory (Bldg. 3517) is used to recover long-lived fission products from aqueous waste for beneficial uses and to test new procedures for fission product source fabrication.

2.3.2.6 Research and development facilities

In recent years the scope of R&D efforts at ORNL has broadened to give increased emphasis on environmental, nonnuclear energy, and social science research. Many programs do not result in any discharges to the environment. In other programs, the types of materials that are utilized are similar to those utilized in university and industrial R&D. All activities are performed under careful surveillance and approved safety procedures, and discharges are controlled.

Laboratory activities that result in the discharge of significant quantities of materials to the gaseous and liquid waste treatment systems are performed by the Analytical Chemistry, Chemistry, Chemical Technology, Environmental Sciences, Metals and Ceramics, and Solid State divisions. Disposal of these wastes is discussed in Sects. 2.5.6, 2.5.7, and 2.5.8.

2.3.3 Outlying Sites—Major Facilities

2.3.3.1 Reactors

High Flux Isotope Reactor. The HFIR, located in Bldg. 7900, is a 100-MWt pressurized light-water reactor that uses enriched uranium (93%) fuel. Reject heat is transferred from the core through the primary and secondary cooling systems to the atmosphere via mechanical draft cooling towers (Sect. 2.5.5). The HFIR's main purpose is the production of research quantities of transplutonium elements. Several beam tubes permit neutrons to be transmitted to satellite experimental areas. The lifetime of a fuel assembly is about 23 d; both the inner and outer fuel assemblies are replaced after that time. More than 220 fuel cycles have been completed at the HFIR.

Gaseous releases are discharged through the Bldg. 7911 stack; these releases are discussed in Sect. 2.5.6. Liquid effluents containing radionuclides are piped to the radioactive waste treatment facilities in Bethel Valley (Sect. 2.5.7).

Tower Shielding Facility. The Tower Shielding Facility is located within a large exclusion area on Copper Ridge 3.8 km (2.4 miles) SSE of the ORNL central site. The operating reactor, the Tower Shielding Reactor II, is a radiation source located in a region free from ground or structure scattering; it is positioned in the air within an area bounded by four 96-m (315-ft) towers. It is a 1-MWt-enriched, ^{235}U, light-water-moderated and -cooled, shielded reactor, spherical in shape, from which radiation is emitted symmetrically as collimated beams from shield ports. Operation poses no hazard to the public. The reactor-handling pool provides shielding during the removal and temporary storage of fuel elements and the changing of reactor shields. Clarity of the water is maintained by circulating the water through a series of filters. The reactor-handling pool water is not contaminated and is discarded infrequently (every 2 to 5 years).

Fission heat is removed from the reactor by circulation of demineralized water at a rate in excess of 50 L/s (800 gpm) through a 5-MW forced-draft air cooler.

No gaseous wastes, radioactive or chemical, are released from the reactor system or from any process at the Tower Shielding Facility. Water that is drained from the reactor cooling system and rinse residues from the demineralizer are collected in a 19,000-L (5000-gal) holding tank, held for a short decay period, and then shipped to the ILW-handling facility. The sanitary waste system drains to a septic tank and drainage field. The remaining potable wastewater is discharged as surface runoff to Watts Bar Lake.

Health Physics Research Reactor. The Health Physics Research Reactor is a small reactor that is fueled with enriched uranium and operable in the pulsed or steady-state mode. The reactor is an integral part of the Dosimetry Applications Research facility, which is located in an exclusion area approximately 3.4 km (2.1 mile) ESE of the ORNL central site.

Radioactive material, mostly paper, cloth, glass, metal, etc., that is slightly contaminated as a result of experimental activities, is deposited in the SWDA (Sect 2.5.8). Sanitary wastes are sent to a septic tank. No gases are released from the facility.

2.3.3.2 Consolidated Fuel Reprocessing Facility

The Consolidated Fuel Reprocessing Facility (CFRF), located 3.5 km (2.2 miles) ENE of the ORNL central site in the 7600 area (EGCR site, Fig. 2.5), is used for nuclear reactor fuel reprocessing development. Radionuclides are not handled in the normal operation of the CFRF at this time. Sanitary wastes are discharged through a septic tank and drain field system. Administrative controls are applied to prevent discharge of chemicals into this system. Some of the chemical wastes are collected in tanks and transferred to the neutralization facility for treatment and discharge to WOC; other waste chemicals are transferred to the Department of Environmental Management (DEM) for offsite disposal.

2.3.3.3 The Oak Ridge National Environmental Research Park

Several land areas totaling 5500 ha (13,600 acres) on the DOE Oak Ridge Reservation (ORR) were designated by DOE in 1980 as the Oak Ridge NERP (Fig 2.7). Four other DOE NERPs are located in various areas of the United States. The NERPs are outdoor areas, most of which are relatively undisturbed by human activities. Although their permanence is not ensured by DOE, the NERPs provide scientists throughout the United States with research areas for at least short-term study of the impacts of energy-producing technologies on environmental quality. Any scientist may apply to DOE for permission to conduct research on the NERPs.

The Oak Ridge NERP consists of two types of designated areas: (1) natural areas that are habitats for regionally unique, rare, or endangered plant and animal species and (2) control-program natural areas that are representative of the vegetation communities of the southern Appalachian region. Research at the Oak Ridge NERP is conducted on pollutant transport, environmental toxicology, and population and community dynamics. In addition, environmental scientists conduct assessments of the impacts of forest management, solid waste disposal, cooling-tower drift deposition, and emissions from coal-fired power plants and facilities involving the nuclear fuel cycle.

In addition to the outdoor areas, various research facilities at ORNL are available to scientists. These facilities include laboratories, growth chambers, greenhouses, artificial ponds, and fish tanks.

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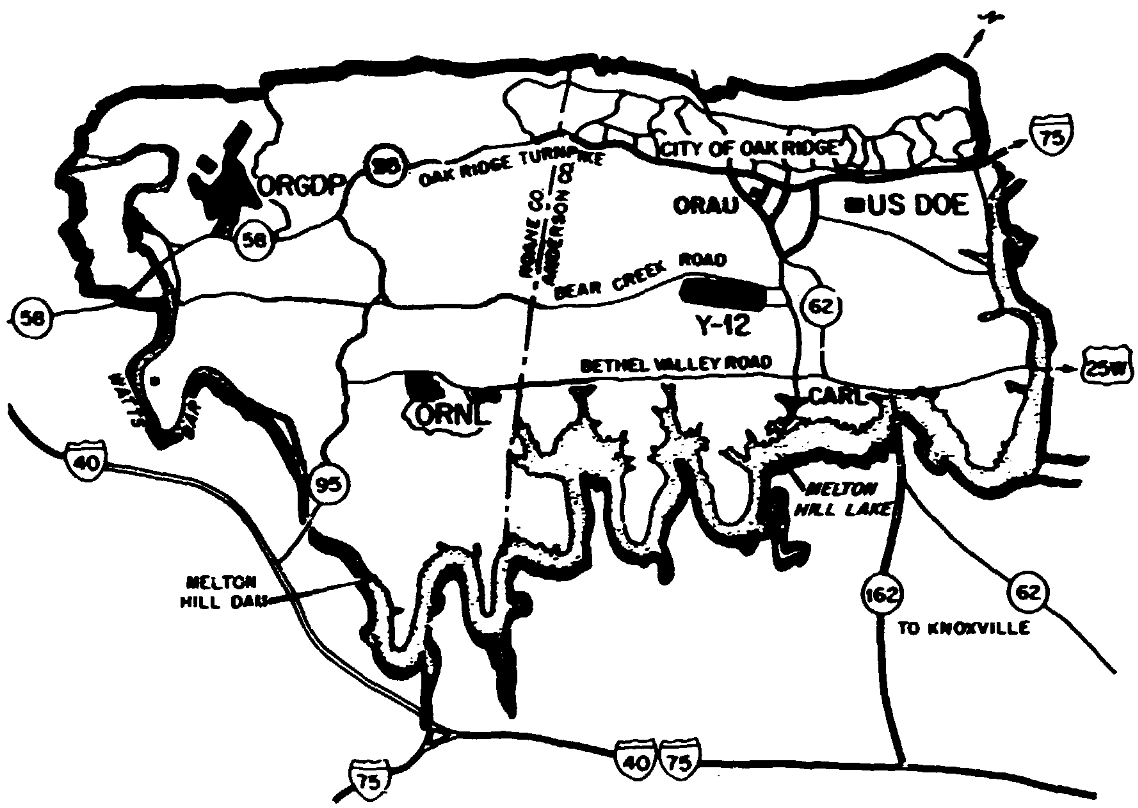

Oak Ridge National Environmental Research Park

Fig. 2.7. Map of the Oak Ridge National Environmental Research Park.

2.3.4 Deactivated and Decommissioned Facilities

Fifteen facilities at ORNL have been designated in the national Surplus Facilities Management Plan as candidates for decontamination and decommissioning because they are no longer needed for their intended purposes and could be either decommissioned or returned to service in another capacity. Operations that are ongoing and/or planned for deactivating these facilities are described in Sect. 4.7.

2.4 ENVIRONMENTAL MANAGEMENT POLICIES

2.4.1 Past Practices

Since ORNL's beginning in 1943, potential operational hazards have been associated with dispersion of radioactivity in the environment. From the start, disposal of radioactive gaseous, liquid, and solid wastes has been conducted in a manner intended to present the least hazard to the environment outside the controlled zone and to the operating personnel within the controlled zone. However, 40 years ago regulations and accepted disposal practices were much different from what they are today. Because regulations have proliferated and have become much more restrictive, some of the procedures used in prior years have proven to be unsatisfactory and are unacceptable today.

Historically, nearly all waste gases containing radioactivity have been discharged through stacks constructed primarily for that purpose. Primarily because of the lack of availability of suitable filters, radioactive particulate matter was a major component in gaseous effluent streams in the early days. Filters and techniques have evolved over the past 40 years so that today entrainment of particulate matter in the gaseous effluent streams has reached very low levels. Methods of iodine removal from gas streams have improved greatly also so that today the inert rare gases constitute the vast majority of radionuclides released to the atmosphere.

When ORNL was built, an extensive underground piping system was installed to collect ILW [this may be roughly defined as liquid waste containing up to approximately 200 GBq/L (20 Ci/gal) of radioactive material corresponding to a heat generation rate of about 15 mW/L (0.2 Btu/h/gal)] from the various ORNL facilities and transport it for storage to a central group of six "gunite" storage tanks [volume about 640 m^3 (170,000 gal) each] located in the South Tank Farm.[1] As ORNL grew, the storage tanks became inadequate to handle the volume of radioactive waste generated. The problem was solved temporarily by precipitating the wastes in the storage tanks with caustic and allowing them to settle. The supernatant, which contained only a small fraction of the original activity, was decanted to a large pond for further settling and finally was discharged to WOC and eventually to the Clinch River.

This process was abandoned in 1949, and from June 1949 to June 1954 the ILW was concentrated in a pot-type evaporator. The concentrate was returned to one of the storage tanks and the condensate discharged to WOC. During this period, the underground piping system was expanded by adding collection tanks near the various ILW sources.

From 1954 until 1965 the waste was stored in open pits where it was concentrated by solar evaporation and ion exchange on Conasauga shale. Also in the past, chemical wastes have been disposed of in pits and in trenches. In March 1965 a new waste evaporator, which has been in service since then, was put into operation. In the following year the practice of disposing of the concentrated waste by hydrofracture was inaugurated. This method of disposal is still the method used at ORNL.

Prior to late summer 1981, liquid LLW (this is an aqueous stream that may be slightly contaminated, consisting of floor drainage, steam and cooling water, leakage, flush drains, etc.) were processed using a scavenging precipitation–ion exchange process.[2] The scavenging precipitation–ion exchange process consists of (1) a scavenging precipitation step in which dissolved magnesium and calcium salts are precipitated with sodium hydroxide, along with iron hydroxide, and removed by the sludge blanket in a clarifier, (2) a waste stream filtration step using anthracite filters, (3) an ion exchange process step using columns loaded with Duolite CS-100 ion exchange resin (CS-100 is a weak acid carboxylic-phenolic action exchange resin manufactured by Diamond Shamrock Company, Redwood City, California), and (4) an ion exchange resin regeneration step using nitric acid followed with a sodium hydroxide conditioning step. This process has operated essentially trouble free since 1976 and has consistently discharged effluents to WOC with radionuclide concentrations well below stream concentration guidelines[3]; but the accumulation since 1976 of about 1 million L (260,000 gal) of sludge from the first step in the process has, because of environmental considerations, made it necessary to test a substitute flowsheet that eliminated the sludge formation. The sludge is stored in an 830-m^3 (29,000-ft^3) basin at SWDA No. 5. See Sect. 2.5.7.1 for a description of the current low-level process.

Radioactive solid wastes have been and continue to be disposed of by land burial or retrievable storage (see Sect. 2.5.8). The main advances over the years have been refinement of technique and better choice of disposal areas. Of the six SWDAs at ORNL, SWDAs Nos. 1, 2, and 3 were chosen more for convenience of location and ease of digging rather than for long-term isolation of the materials buried. Present burial areas have been carefully chosen so that (1) wastes will remain above the water table at all times, (2) the geologic material surrounding the buried waste is Conasauga shale (a material with desirable ion exchange properties), and (3) infiltration of rainwater is minimized.

Little is known about the physical and radiological characteristics for much of the waste buried before 1971. Included in this period (1955–1963), ORNL served as the Southern Regional Burial Ground for southern regional LLW. Since 1971, detailed records have been kept of both the volume and the activity content of all waste packages stored in the SWDAs. These records are kept in a computerized Solid Waste Information Management System for ease of retrieval, updating, trend studies, etc.

Past and current nonradioactive, nonhazardous solid wastes have been sent to the Bear Creek Valley landfill at Y-12. A site selection process is under way to locate a new landfill site that will provide better isolation of the wastes than does the landfill in Bear Creek Valley.

Some of the waste disposal practices of the past have proven to be unsatisfactory and are causing radioactivity dispersal problems at the present time (see Sect. 4.2). Ways to minimize further dispersal are being tried, and current disposal methods are constantly being improved so that future problems will be minimized.

2.4.2 Current Procedures

The DOE now places greater emphasis on radioactive waste management practices that utilize available acceptable waste disposal technologies; waste management practices at ORNL currently reflect this policy. ORNL now has a DEM, a part of the Industrial Safety and Applied Health Physics Division, whose mandate is to monitor environmental effects of ORNL operations and to ensure that ORNL complies with all environmental regulations. To enlist the help of all employees in complying with regulations, the DEM keeps employees informed about regulations pertaining to the environment and has prepared and distributed various manuals on environmental protection.[4–6]

Some of the main functions of the DEM include (1) environmental surveillance, (2) environmental protection, (3) environmental assessment, (4) management of hazardous materials, and (5) serving in an advisory capacity to employees and ORNL management in environmental matters.

The environmental surveillance group provides (1) a monitoring program for effluent releases (gas and liquid) and (2) a monitoring program to satisfy regulations and to ascertain if ORNL's impact on the environment is reasonable within the principles of as low as reasonably achievable and/or as low as practical. The monitoring program (see Sect 2.6) includes an air-monitoring network made up of local air-monitoring (LAM) stations, perimeter air-monitoring (PAM) stations, and remote air-monitoring (RAM) stations at which concentrations of both radioactive and nonradioactive airborne pollutants are measured. There are a total of 39 stations covering the areas adjacent to point sources and extending out to distances of 120 km (75 miles). In addition to the air samples, aquatic (five sampling stations), terrestrial, and biological samples, as well as foodstuff samples, are routinely taken. The sampling frequencies may be daily, weekly, monthly, quarterly, or yearly, depending on the environmental media and the major paramcters. Details of the program are given in ref. 6.

All major construction projects at ORNL are reviewed by the DEM to determine possible environmental impacts, to assess the equipment and processes to determine if a reduction in release of hazardous materials is feasible, and to ensure that proper permit forms are filled out. The DEM prepares environmental impact statements and environmental assessments as may be required by the National Environmental Policy Act. The DEM must ensure that ORNL operations and all new projects comply with regulations resulting from approximately ten federal laws such as the Clean Air Act, the Toxic Substances Control Act, and the Clean Water Act, all DOE directives, and with about eight Tennessee regulations, criteria, or standards.

A large number of chemicals used at ORNL are hazardous on the basis of flammability, corrosivity, ignitability, reactivity, or toxicity. Guidelines for the procurement, use, storage, transportation, and disposal of hazardous materials are contained in a manual that is available to all ORNL personnel.[5] To ensure proper and safe handling of these chemicals, the DEM monitors their status from the time they are ordered until they are disposed at a hazardous waste facility.[7,8] Before being transported to a centralized temporary storage facility at ORNL, hazardous wastes are identified at their place of generation. Here or at the storage facility, they are packaged according to U.S.

Department of Transportation (DOT) regulations. Virtually all of the wastes remain in storage only a short time before being transported to a disposal facility. A small amount of material which includes radioactive hazardous waste must be stored indefinitely because of a current lack of availability of a proper treatment method and/or disposal site.

The storage and transportation of hazardous materials at ORNL is in accordance with EPA and DOT guidelines and regulations mandated by the Resource Conservation and Recovery Act of 1976 (RCRA), the Hazardous Materials Transportation Act of 1974, and standard practice procedures mandated by UCC-ND management. ORNL is permitted, under RCRA interim status, as a hazardous waste generator and hazardous storage facility.

With the implementation of the procedures discussed above, it is believed that the environment, both on and off the site, will be better protected than in the past. The radionuclides and elevated concentrations of some trace elements in the sediments of WOC, Melton Branch, and the Clinch River (Sect. 3.2.4) are the result of past waste disposal practices, and it is known that some migration of radionuclides from SWDAs is occurring (Sect. 3.2.3.5). Therefore, past practices for liquid and solid waste disposal will continue to have adverse effects on WOC and on the Clinch River for some years to come.

2.5 SUPPORT SYSTEMS OF OPERATIONAL ACTIVITIES

2.5.1 Water Supply and Treatment System

The current average water consumption rate of ORNL is approximately 0.22 m^3/s (5 Mgd). Water from the Oak Ridge water treatment plant located atop Pine Ridge near Y-12 is delivered to the ORNL reservoirs through a 60-cm (24-in.) main. One 11,400-m^3 (3-million-gal) reservoir is located on Chestnut Ridge, and two 5,700-m^3 (1.5-million-gal) reservoirs are located on Haw Ridge. Representative analyses of the water, determined at various periods in the past, are listed in Table 2.1.

Water is distributed to ORNL facilities through two separate water systems: one is for potable water; the other, process water. Process water is water that could become contaminated and unfit for human consumption. The potable water system supplies the process system and is protected from back contamination by reduced pressure-backflow preventer valves. Cooling water is obtained from the process water system.

The major part of the water used at ORNL is discharged through various liquid waste systems. The waste streams that are considered to have the potential for radioactivity contamination are monitored before release to WOC and the Clinch River.

2.5.2 Steam-Generating Plant

The ORNL five-boiler steam plant, located in Bldg. 2519, has a rated maximum steam capacity of 138,000 kg/h (305,000 lb/h) and transmits the steam to onsite facilities through 0.86-MPa (125-psig) and 1.7-MPa (250-psig) lines. In cold weather, most of the steam is used for space heating in the central site area (including the 7000 area) and the 7900 area. Steam is also used for processing radioactive wastes, laundry operations, and other processes. The plant must be available at all times to ensure the operability of steam turbines used for backup emergency operation of gaseous exhaust systems for reactors and fume hoods. Four of the five boilers operate on coal (2–3 wt % sulfur) mined in the region. The fifth boiler, operating at a maximum rate of 45,000 kg/h (100,000 lb/h), is fired by oil (containing typically 1.5% sulfur) or natural gas. Generally during extremely cold weather, all units are operated simultaneously so that the fifth unit can provide a continued supply of steam if an outage occurs in the coal-fired units.

Maximum coal consumption is 29,000 tonnes/year (32,000 tons/year) with a daily maximum of 180 tonnes (200 tons). The corresponding ash production rates are 2320 tonnes/year (2500 tons/year) or 14 tonnes/d (15.4 tons/d). Ash is discharged to a storage silo (20-d capacity), trucked to a waste disposal site located on the reservation 1.5 km (1 mile) west of the central site,

Table 2.1. Results of analyses of ORNL water supply, 1960–1981

Determination	Concentration (mg/L)				
	March 1960	May 1968	July 1971	February 1973	January 1981
Aluminum	<0.05	0.04	<0.02	0.05	<0.001
Calcium	23	30	33	31	28
Chloride	4	4.5	5.5	4.1	5.7
Chromium	<0.05	<0.02	<0.02	<0.005	0.001
Copper	<0.05	0.02	0.02	0.006	0.017
Fluoride	0.92	0.85	0.55	0.88	1.0
Iron	<0.05	0.02	0.02	0.014	0.003
Magnesium	3	6	8	8	9.5
Nickel	<0.05	<0.02	<0.02	<0.02	<0.001
Nitrate	<0.05	3.5	0.11	0.72	0.18
Phosphate	<0.05	0.04	0.07	0.02	0.2
Silicon	1.5	0.03	2.1	2.4	1.5
Sodium	6	6	10	9	4
Sulfate	10	5	40	24	18
Uranium	<0.1	<0.005	<0.005	<0.005	<0.005
CO_3^{2-} as $CaCO_3$	6	0	0	0	0
HCO_3^- as $CaCO_3$	19	80	100	88	93
Total alkalinity	28	80	100	88	93
CO_2, dissolved	<1	<1	<1	5	2
Ca hardness	60	80	80	78	75
Total hardness	95	105	115	112	113
Total solids		120	160	140	137
Specific resistance, S	(5270)	(4700)	(4300)	(3900)	(4167)
pH, standard units	(8.30)	(7.70)	(7.84)	(7.26)	(7.70)

Source: W. R. Laing and R. R. Rickard, Analytical Chemistry Division of the Oak Ridge National Laboratory.

and deposited above the water table. Electrostatic precipitators are used to prevent discharge of particulates at rates exceeding 0.043 kg/GJ (0.1 lb/million Btu). In tests conducted during 1981, the average particulate emission rate through the precipitator outlet ducts was 0.012 kg/GJ (0.027 lb/million Btu) heat input with an average efficiency of 98.99%.[9] Above the tripper room is a dust collector, where coal dust from the coal feed is drawn into fabric filters and transferred into the coal hoppers.

Operation of the plant at full rated capacity requires an air volume throughput and discharge of 54 m^3/s (115,000 cfm) through the 53-m (175-ft) stack (2.7 m or 8.8 ft ID). At average coal consumption rates, SO_2 and NO_x discharge rates are 44 g/s (250,000 lb/month) and 6.9 g/s (40,000 lb/month) respectively.

Coal is brought in by truck and stored in a 1-ha (2.5-acre) coal yard. Storage capacity is approximately 20,000 tonnes (22,000 tons) of coal. Coal pile runoff is collected in an impoundment having a total capacity of 1135 m^3 (40,000 ft^3). Currently runoff is discharged from the impoundment at rates that may amount to as much as 18,000 m^3/year (635,000 ft^3/year). Funds have been requested to construct and equip a facility to ensure compliance with the 1977 Clean Water Act amendments that call for "best available treatment economically achievable" for neutralizing the coal yard runoff and removal of heavy metals from the discharge. The equipment will consist of a mixing tank and associated controls for adjusting the pH of the pond effluent so that it is maintained in the range from 6 to 9.

2.5.3 Electrical Distribution System

Electricity is distributed to ORNL from a two-transformer, 161/13.8-kV primary substation that is fed by two 161-kV lines—one from ORGDP and one from the Elza substation. Eight voltage-regulated, 13.8-kV feeder circuits of varying lengths and configurations make up approximately 25 km (15 miles) of overhead lines and 1.6 km (1 mile) of underground cable. Within ORNL, the distribution system is divided into a 13.8-kV system and a 2.4-kV system. Each system consists of overhead lines, underground cables, transformers, breakers, and miscellaneous equipment. Three substations comprise the interface between the 13.8-kV and 2.4-kV systems. In 1981, ORNL required a peak load of 36 MVA. The monthly average (seasonal) load ranged from 17 MVA to 25 MVA (July).

Twenty-five transformers at ORNL contain polychlorinated biphenyl (PCB) dielectric material or oil contaminated (>50 ppm) with PCBs. The cumulative PCB inventory is about 36 Mg (79,000 lb). The largest transformers contain 4936 kg (10,900 lb) each. In the final rule on the use of PCB transformers, the EPA authorizes the use of PCB transformers for the remainder of their useful lives and specifies the requirements pertaining to inspection, maintenance, and records keeping on the transformers.[10] The regulations do not require that PCB transformers be diked, although a less frequent inspection schedule is permitted if the transformers are diked to contain 100% of the contents. ORNL is in compliance with the regulations. The DEM keeps a log on each transformer including its location, the PCB content, and whether or not it is diked. At present only six of these transformers are diked. The DEM is currently reviewing all regulations concerning PCB transformers and is preparing a procedure on the proper diking of transformers for inclusion in the ORNL *Environmental Protection Manual.*[4] The procedure is expected to be completed in 2 to 3 months. Following this, the DEM will work with the Operations Division to implement the diking of transformers in a schedule yet to be determined. It is expected that it will be a minimum of 1 to 2 years before diking of all transformers is completed.

Emergency power is provided at individual facilities within ORNL by 26 diesel and 7 gasoline generators.

2.5.4 Natural Gas Supply System

Natural gas is distributed to ORNL facilities from the East Tennessee Natural Gas Metering Station B, which is located northwest of the 7000 area. Gas is transmitted through a 15-cm (6-in.)

line at 1.7 MPa (250 psi) to the No. 3 PRV (pressure-reducing valve) station west of the 7000 area and the No. 2 PRV station at the northeast corner of the steam plant. The PRV station No. 3 reduces gas pressure to 690 kPa (100 psi) before distribution is made. The gas is then routed via a 15-cm (6-in.) line to the steam plant, where the pressure is reduced to 138 kPa (20 psi). The gas pressure to the central site area is reduced to 34 kPa (5 psi) for the low-pressure-system transmission and further reduced at the points of use to pressures varying from 1.7 to 3.5 kPa (7 to 14 in. of water).

The distribution system consists of approximately 7000 m (23,000 ft) of piping and 320 major valves. Maximum consumption of gas in the past has been 2 m^3/s (4200 cfm); however, current use of the No. 5 boiler in the steam plant, much less frequent than in the past, is intermittent and unscheduled and depends on availability. On occasion when the boiler is used in its normal operating mode (50% capacity), gas consumption is 40,000 m^3/d (1.4 million ft^3/d). ORNL consumption, other than by the steam plant, is 3.4–4.0 m^3/d (120–140 ft^3/d).

2.5.5 Heat Dissipation Systems

Operation of various plant facilities generates sufficient heat to require its rejection (in part) to the environment. This heat comes from reactors, particle accelerators, evaporators, environmental control systems, process systems, research laboratories, engineering-scale development facilities, and space-heating condensates. Most of the reject heat is transferred to once-through cooling water or dissipated to the atmosphere using wet-evaporative, mechanical-draft cooling towers.

The heated discharge from once-through cooling is directed to the storm sewer system and thence to WOC. Water quality is unaffected except by elevated temperature. Because of the distance traversed by the effluent, only an insignificant amount of residual excess heat from these sources is transmitted beyond White Oak Dam.

Seven mechanical draft cooling towers, ranging in capacity from 1.1 to 38 MWt (3.9 to 130 million Btu/h) discharge the principal heat burden generated by the operation of ORNL facilities. About 20 smaller towers, operating for the most part in the intermittent mode, serve lesser demands. The total peak heat rejection capacity of the entire group of cooling towers is 93.2 MWt (318 million Btu/h).

Blowdown from all cooling towers is discharged to the storm sewer systems; except for the tower operating at the CFRF, which is outside the WOC watershed, the effluents reach the Clinch River by way of WOC. Blowdown from the CFRF cooling tower enters Melton Hill Lake between Bearden Creek and Walker Branch. The amounts of chemicals required annually for treatment of the cooling towers and discharged (except for small losses through evaporation and drift) are listed in Table 2.2.

2.5.6 Gaseous Waste Systems

Most gaseous wastes are released to the atmosphere either through roof exhaust systems or through stacks constructed specifically for the discharge of gaseous wastes. Radioactivity may be present in waste gas streams as a solid (particulates), an absorbable gas (such as iodine), or as a nonabsorbable species (noble gas). All gaseous wastes that may contain radioactivity are processed to reduce the radioactivity to acceptable levels before being discharged. The form of the radioactivity determines the type of cleanup procedure used.

Only insignificant amounts of radioactivity are discharged through roof exhaust systems. These systems will not be discussed except to point out that any operation that involves radioactivity and utilizes these systems is scrutinized very carefully to ensure its safety and to ensure that all of the exhausted air is filtered through absolute filters. (Absolute filters remove 99.95% of particles of 0.3-μm diam or larger.)

2.5.6.1 Radioactive gases

ORNL policy requires that individuals in charge of operations that generate gaseous radioactive wastes must clean up most of the radioactivity present before the gases are released into the

Table 2.2. ORNL cooling tower data

Area served	Amount of chemicals used annually			Water usage			
	Phosphate treatment[a] (kg)	H_2SO_4 (L)	Biocide (L)	Makeup (L/s)	Blowdown (L/s)	Drift (L/s)	Evaporation (L/s)
HFIR (Bldg. 7901)	11,800	75,700	9,400	37.9	8.5	1.0	28.4
ORR (Bldg. 3103)	2,550	20,500	1,190	15.8	2.6	1.7	11.6
ORR (Bldg. 3086)	230	630	160	0.6	0.2	0.1	0.3
ORR (Bldg. 3089)	110	0	160	0.8	0.2	0.2	0.3
BSR (Bldg. 3117)	240	950	810	1.2	0.3	0.2	0.7
4500 Area	2,360	0	3,000	12.6	1.7	1.3	9.7
ORIC (Bldg. 6001)	1,180	0	1,500	6.3	0.8	0.6	4.9
Miscellaneous - 20	320	0	850	2.5	0.8	0.5	1.3
Total	18,790	97,780	17,070	77.7	15.1	5.6	57.2

[a]Phosphate treatment includes organic phosphates and other organic corrosion inhibitors and is used continuously.

Source: Gary Coleman and K. H. Poteet, Operations Division-ORNL, Dick Peden, Plant and Equipment Division-ORNL, August 1981.

gaseous waste systems. Radioactive gaseous waste systems therefore normally serve both as secondary cleanup facilities and emergency backup systems for many of the primary cleanup systems at reactors, hot cells, engineering development laboratories, etc. The two systems for handling waste gases that may contain radioactivity are the cell-ventilation system and the process off-gas system.

Cell ventilation systems, sometimes called the "high-volume, low-level" systems, collect and clean the air from processing equipment cells and laboratory analytical hoods. Negative pressure for the central laboratory system (3039 stack area) is produced by three electrically driven fans (two steam-driven auxiliary fans) capable of moving approximately 92 m^3/s (195,000 cfm). All major cell ventilation ducts in both the central laboratory system and in the HFIR system are monitored by tape monitors and are provided with flow-measuring devices. Important ducts in the 3039 stack area also have sampling ports where collection samplers employing filter-charcoal cartridges may be attached. Discharge points for the cell-ventilation systems are the 3039 stack in Bethel Valley and the 7911 stack in Melton Valley.

Off-gas is a stream of gaseous waste of much smaller volume than cell-ventilation waste, but it contains much more activity. Off-gas lines are connected directly to operating equipment for venting purposes or where reduced pressure is required. In addition to radioactive emissions, off-gas systems must also dispose of organic vapors and acid and caustic fumes. A central system, terminating at the 3039 stack, serves the Bethel Valley area of ORNL. The treatment facility includes a caustic scrubber for the removal of reactive gases and a high-efficiency filter unit (roughing filters followed by absolute filters) to remove particulate matter. An electric blower with steam-powered auxiliary provides a capacity of 2 m^3/s (4000 cfm).

The gaseous waste system was installed 20 to 30 years ago and has undergone periodic modifications since then. It is presently in need of repair and upgrading to the current state of the art. A capital improvement project (cost approximately $13 million) is currently under way to replace and upgrade the 3039 stack area off-gas and cell-ventilation system.

Air exhausted from the facilities in Melton Valley is passed through absolute filters, a silver-plated copper mesh, and two charcoal beds before being discharged to the atmosphere, mostly via the 7911 stack.

The quantities of radioactivity discharged from ORNL stacks from 1976 through 1981 are listed in Table 2.3 through Table 2.7.

2.5.6.2 Nonradioactive gases

Nonradioactive gaseous wastes are released to the atmosphere by numerous laboratory operations and support activities. Typically some 36 organic chemical compounds that have various volatilities are purchased in quantity each year (Table 2.8). Typical quantities of gases purchased and released each year are given in Table 2.9. Combustion products of the steam plant account for the major fraction of nonradioactive gas release (see Sect. 2.5.2).

Vehicles used for transportation consume approximately 7.2×10^5 L (190,000 gal) of fuel annually. The sulfur content of the fuel is about 0.5 g/L.

2.5.7 Liquid Waste Process Systems

2.5.7.1 Radioactive wastes[2]

ORNL routinely handles relatively large amounts of liquid radioactive waste in terms of both volume and activity. The wastes are classified as low-level waste (LLW), intermediate-level waste (ILW), high-level waste (HLW), and transuranic (TRU) waste. Currently no HLW is produced routinely. However, an HLW system does exist if the need arises. It consists of two internally and externally cooled 190-m^3 (50,000-gal) stainless steel tanks located in an underground, reinforced concrete vault adjacent to the evaporator building. The system has been used only on a very limited basis. The TRU wastes are administratively segregated; a new, doubly contained, 39-m^3 (10,000-gal) collection tank was recently placed in service. Efforts are made to minimize the amount and concentration of liquid TRU waste by converting as much as possible to a solid form.

Table 2.3. Annual rates of discharge of radionuclides in air effluents from the Building 3039 stack, 1976–1981

Year	Radionuclide release rate (Bq/year)[a]					
	^{3}H	^{85}Kr	^{131}I	^{133}Xe	^{134}Cs	^{137}Cs
1976	2.2E14	3.4E14	4.0E10	1.7E15		
1977	9.3E13	2.5E14	4.4E10	1.2E15		
1978	9.3E13	3.8E14	5.7E10	1.9E15		
1979	1.9E14	3.2E14	6.7E9	1.6E15		
1980	5.4E14	2.8E14	4.2E9	1.4E15	1.4E8	8.1E7
1981	3.6E14	1.9E14	4.4E9	9.1E14		

[a]To convert becquerels to curies, multiply by 2.7E-11.

Source: W. F. Ohnesorge, Industrial Safety and Applied Health Physics Division of the Oak Ridge National Laboratory.

Table 2.4. Annual rate of discharge of ^{239}Pu[a] in the air effluents of Buildings 5505 and 4508, 1976-1981

Year	^{239}Pu release rate (Bq/year)[b]	
	Bldg. 5505	Bldg. 4508
1976	5.8E2	1.6E2
1977	5.8E2	1.6E2
1978	5.8E2	1.6E2
1979	1.2E4	6.9E2
1980	2.8E3	1.5E3
1981	1.4E3	1.4E3

[a]Measured as unidentified alpha; all activity assumed to be due to ^{239}Pu, the most hazardous alpha emitting radionuclide present in the effluent.

[b]To convert becquerels to curies, multiply by 2.7E-11.

Source: W. F. Ohnesorge, Industrial Safety and Applied Health Physics Division of the Oak Ridge National Laboratory.

Table 2.5. Annual rate of discharge of tritium in air effluents from Building 7025, 1977 - 1981

Year	^{3}H release rate (Bq/year)[a]
1977	8.9E11
1978	9.3E11
1979	4.0E13
1980	1.1E13
1981	5.6E13

[a]To convert becquerels to curies, multiply by 2.7E-11.

Source: W. F. Ohnesorge, Industrial Safety and Applied Health Physics Division of the Oak Ridge National Laboratory.

Table 2.6. Annual rate of discharge of ^{131}I in air effluents from Buildings 3020 and 2026 stacks, 1981[a]

Bldg. stack	^{131}I release rate (Bq/year)[b]
2026	4.4E9
3020	4.4E9

[a]Data is available only for 1981.

[b]To convert becquerels to curies, multiply by 2.7E-11.

Source: W. F. Ohnesorge, Industrial Safety and Applied Health Physics Division of the Oak Ridge National Laboratory.

Table 2.7. Annual rates of discharge of radionuclides in air effluents from Building 7911 stack, 1976 - 1981

Year	Release rate (Bq/year)[a]		
	^{85}Kr	^{131}I	^{133}Xe
1976	8.1E13	6.3E9	4.1E14
1977	6.6E13	6.7E9	3.2E14
1978	6.4E13	5.2E9	3.1E14
1979	6.7E13	<4.4E9	3.3E14
1980	4.5E13	<4.4E9	2.2E14
1981	5.9E13	<4.4E9	2.9E14

[a]To convert becquerels to curies, multiply by 2.7E-11.

Source: W. F. Ohnesorge, Industrial Safety and Applied Health Physics Division of the Oak Ridge National Laboratory.

Table 2.8. Representative list of organic chemicals purchased annually[a]

Chemical	Amount (kg)	Chemical	Amount (kg)
Ethylene glycol	8,200	Petroleum ether	100
Acetone	3,900	Glycerin	84
Ethanol	2,900	Cyclohexane	72
Methanol	2,100	Versene	57
Propanol	1,700	Xylene	56
Tetrachloro ethylene	1,700	Acetonitrile	43
Methylethyl ketone	850	Dextrose	36
Oxalic acid	780	Tetrahydro furan	35
Trichloro ethylene	570	Carbon disulfide	29
Benzene	460	Ethyl acetate	29
Ethyl ether	420	Dioxane	26
Chloroform	400	Dodecane	26
Hexane	360	Citric acid	25
2-ethyl hexanol	290	Dimethyl sulfoxide	25
Acetic acid	280	Butyl acetate	25
Toluene	270	Amyl acetate	24
Methylene chloride	220	Heptane	22
Carbon tetrachloride	120	Formaldehyde	20

[a]Materials were not included when the quantity purchased from chemical stores was less than 20 kg/year.

Source: Record of materials purchased from ORNL-Stores, FY-1980.

Only two streams, therefore, are treated routinely: the LLW and the ILW. Figure 2.8 is a schematic representation of the liquid waste transport and treatment systems. Detailed descriptions of these systems are available.[11] Table 2.10 is a record of the radioactivity discharged to the Clinch River between 1949 through 1981 from the liquid waste treatment systems.

Low-level waste system. A complex system of underground piping is provided to collect LLW. The system consists of over 30 km (18 miles) of pipe that is 10.2–76.2 cm (4–30 in.) in diameter, most of which is constructed of vitrified clay. The wastewater flows through this piping system by gravity from the source generators to open collection ponds. At various points along the way, the flow rate and activity level in major branches of this collection system are automatically measured and read out in the Waste Operations Control Center. The process waste from the Bldg. 4500 complex flows alternately into two surge ponds (facilities 3539 and 3540) of equal capacity, approximately 570 m^3 (20,000 ft^3) each. After collecting in the ponds, the wastewater is sampled

Table 2.9. Representative amounts of emissions of gaseous chemicals released annually by research and support facilities[a]

Chemical	Amount (kg)	Chemical	Amount (kg)
Acetylene	1.3E3	Hydrogen	3.5E5
Ammonia	3.8E2	Hydrogen fluoride	5.1E0
Argon	1.6E5	Hydrogen sulfide	1.2E1
Mixed gases[b]	4.6E3	Methane	2.5E1
Carbon monoxide	5.1E1	Nitrogen (gas)	1.9E4
Carbon dioxide (gas)	1.5E3	Nigrogen (liquid)	1.5E9
Carbon dioxide (solid)	1.3E5	Oxygen (gas)	8.4E3
Chlorine	1.4E3	Oxygen (liquid)	6.1E4
Fluorocarbons	1.2E4	Propane	2.5E3
Helium	2.3E3	Sulfur hexafluoride	4.7E3

[a]Materials were not included when the quantity purchased was less than 12 kg/year.

[b]The major constituent is argon.

Source: Compiled from record of materials purchased from ORNL Stores, FY 1980.

and then either sent to the LLW processing system or discharged directly to WOC, depending upon the activity level found in these samples and/or the radiation readings on the monitors upstream of the ponds. The primary collection pond is the 3800-m^3 (135,000-ft^3), unlined equalization basin which acts as a surge volume to equalize flow to the LLW treatment plant. The liquid LLW system is designed to process wastewater at a rate of about 12.5 L/s (200 gal/min) and to remove 99.9% of the radioactivity in the water.

In the late summer of 1981, a modified clarification–ion exchange process for LLW was implemented.[2] The waste stream is passed directly to anthracite filters and then through ion exchange columns loaded with Dowex HCRS resin (Dowex HCRS is a sulfanated strong acid resin, manufactured by DOW Chemical Company, Midland, Michigan.). Calcium and magnesium ions are trapped on the ion exchange resin bed, along with radioactive contaminants (^{90}Sr and ^{137}Cs), and are removed with the column-regenerating solution and sent to the waste evaporator building for processing in the ILW system. Several months of essentially trouble-free operation has indicated the desirability of incorporating this process as part of the routine operation of the system and to install an additional ion exchange column to take care of the increase in frequency of the ion exchange column regeneration. The engineering design of the new system is essentially complete, and column installation should begin in the summer of 1982.

Intermediate-level waste system.[2] The ILW generated in R&D operations is transported by underground pipes to one of the 23 stainless steel collection tanks. The collection tanks vary in capacity from 1900 to 57,000 liters (500 to 15,000 gal) depending on the requirements of each source. Waste accumulates in each tank to an administrative limit set by the staff of the Operations Division. Underground transfer lines connect the source collection tanks to the collection headers and to the central evaporator storage tanks.

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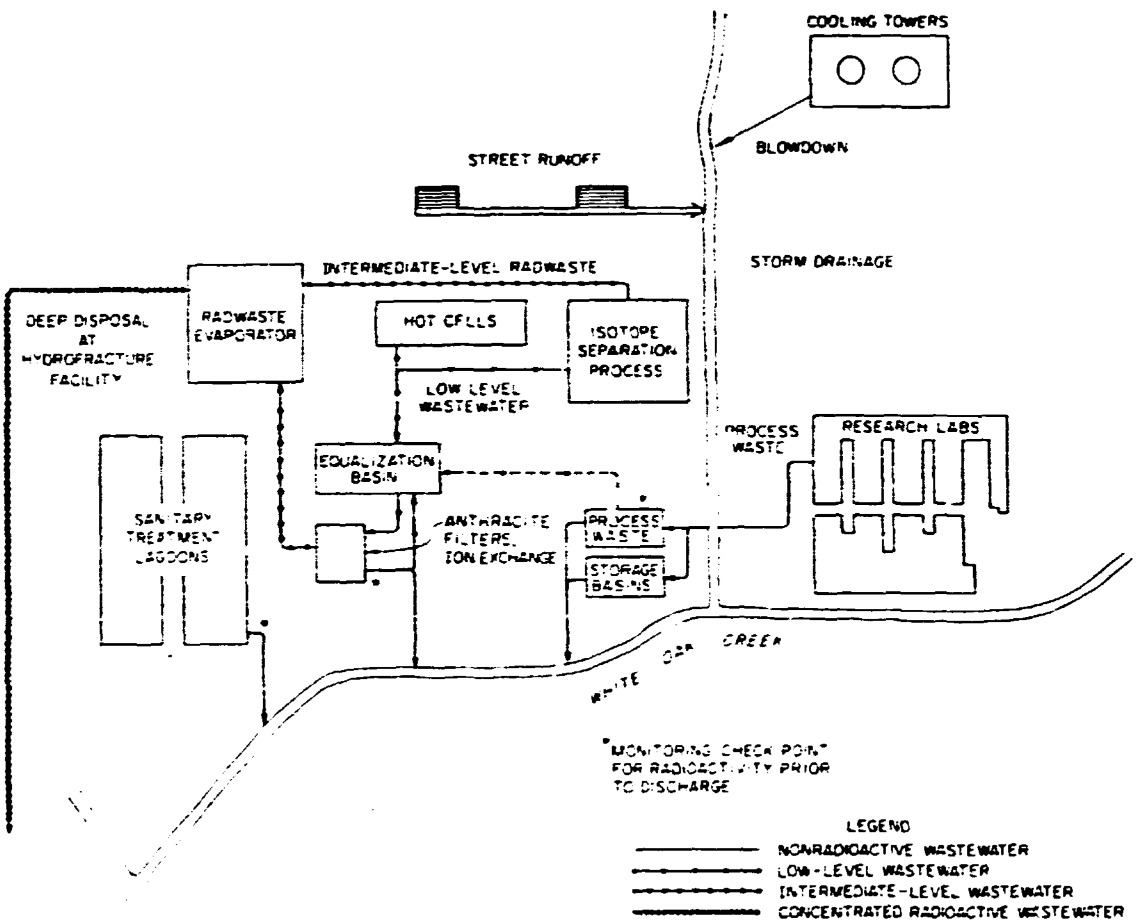

Fig. 2.8. Schematic representation of the liquid waste transport and treatment systems.

The average activity level in the ILW after collection and intermixing is about 0.3 GBq/L (30 mCi/gal). The major radionuclides present in the ILW are ^{90}Sr and ^{137}Cs, with lesser amounts of ^{60}Co, ^{106}Ru, and various rare earths. The ILW contains small amounts of organic material but consists primarily of aqueous waste solutions. As generated, these wastes are usually nitrate solutions; but in the intermediate collection tanks, sodium hydroxide is added to neutralize any acidic conditions. Therefore, when these wastes reach the ILW processing system, they are normally an alkaline mixture of dilute sodium hydroxide and sodium nitrate.

Two stainless steel evaporators with a capacity of about 0.6 L/s (10 gal/min) each are provided for evaporation of ILW. The evaporator is operated on a batch feed system. The vessel is filled with waste, and additional feed is forwarded to the vessel as boil-off occurs. When the vessel operating level is filled with concentrated waste based on a density sample, the evaporation process is terminated, and the waste concentrate is batch-fed to the concentrates surge tank. Concentrates are subsequently pumped about 3 km (1.9 mile) in a new 5-cm-diam (2-in.) stainless steel line to the hydrofracture site storage tanks. The concentrates are periodically disposed of by hydrofracture. The distillates are normally piped to the equalization basin; or if high in activity following radiation monitoring, they are returned to the ILW system.

The volume of ILW treated annually varies from approximately 4900 to 5700 m^3 (175,000 to 200,000 ft^3). The major radionuclides removed are ^{90}Sr, ^{137}Cs, ^{106}Ru, ^{60}Co, and rare earths.

Table 2.10. Annual discharges of radionuclides to the Clinch River, 1949 - 1981

Year	Release rate (Bq/year)[a]											
	^{3}H	^{60}Co	^{89}Sr	^{90}Sr	^{95}Zr	^{95}Nb	^{106}Ru	^{131}I	^{137}Cs	^{144}Ce	TRE[b]	TRU[c]
1949	NA[d]	NA	NA	5.6E12	6.7E12	8.1E11	4.1E12	2.8E12	2.6E12	6.7E11	2.8E12	3.3E08
1950	NA	NA	NA	1.4E12	5.6E11	1.6E12	8.5E11	7.0E11	7.0E11	NA	1.1E12	1.5E09
1951	NA	NA	NA	1.1E12	1.9E11	7.4E10	6.7E11	6.7E11	7.4E11	NA	4.1E11	3.0E09
1952	NA	NA	NA	2.7E12	7.0E11	6.7E11	5.6E11	7.4E11	3.7E11	8.5E11	9.6E11	1.1E09
1953	NA	NA	NA	4.8E12	3.0E11	1.5E11	9.6E11	7.4E10	2.2E11	2.6E11	4.1E12	3.0E09
1954	NA	NA	NA	5.2E12	5.2E11	3.3E11	4.1E11	1.5E11	8.1E11	8.9E11	5.9E12	2.6E09
1955	NA	2.6E11	NA	3.4E12	1.9E11	2.2E11	1.1E12	2.6E11	2.3E12	3.1E12	5.6E12	9.3E09
1956	NA	1.7E12	NA	3.7E12	4.4E11	5.6E11	1.1E12	1.5E11	6.3E12	2.2E12	5.2E12	1.0E10
1957	NA	1.9E11	NA	3.1E12	8.5E11	2.6E11	2.2E12	3.7E10	3.3E12	4.8E11	4.1E12	5.6E09
1958	NA	3.3E11	NA	5.6E12	2.2E11	2.2E11	1.6E12	3.0E11	2.0E12	1.1E12	8.9E12	3.0E09
1959	NA	2.8E12	1.1E10	2.2E12	1.0E11	1.1E12	1.9E13	3.7E10	2.8E12	1.8E12	3.5E12	2.5E10
1960	NA	2.7E12	7.0E10	1.0E12	1.4E12	1.7E12	7.0E13	1.9E11	1.1E12	1.0E12	1.8E12	7.0E09
1961	NA	1.1E12	7.4E10	8.1E11	7.4E11	2.6E12	7.4E13	1.5E11	5.6E11	1.5E11	8.9E11	2.6E09
1962	NA	5.2E11	6.3E10	3.3E11	7.4E10	3.9E11	5.2E13	1.5E10	2.2E11	3.7E10	4.1E11	2.2E09
1963	NA	5.2E11	3.7E10	3.0E11	1.1E10	2.6E10	1.6E12	1.5E10	1.5E11	7.4E10	3.3E11	6.3E09
1964	7.1E13	5.6E11	3.0E10	2.6E11	7.4E09	3.7E09	7.1E12	1.1E10	2.2E11	1.1E10	4.8E11	3.0E09
1965	4.3E13	4.4E11	2.2E10	1.1E11	1.1E10	1.1E10	2.5E12	7.4E09	7.4E10	3.7E09	2.2E11	1.9E10
1966	1.1E14	2.6E11	3.3E10	1.1E11	2.6E10	2.6E10	1.1E12	7.4E09	7.4E10	3.7E09	1.9E11	5.9E09
1967	4.9E14	1.1E11	2.6E10	1.9E11	1.9E10	1.9E10	6.3E11	3.3E10	1.1E11	7.4E09	3.3E11	3.8E10
1968	3.6E14	3.7E10	2.2E10	1.1E11	1.1E10	1.1E10	1.9E11	1.1E10	3.7E10	1.1E09	1.5E11	1.5E09
1969	4.5E14	3.7E10	1.1E10	1.1E11	7.4E09	7.4E09	7.4E10	1.9E10	3.7E10	7.4E08	1.9E11	7.4E09
1970	3.5E14	3.7E10	1.1E10	1.5E11	7.4E08	7.4E08	3.7E10	1.1E10	7.4E10	2.2E09	1.9E11	1.5E10
1971	3.3E14	3.7E10	7.4E09	1.1E11	3.7E08	3.7E08	1.9E10	7.4E09	3.7E10	1.9E09	1.1E11	1.9E09
1972	3.9E14	3.7E10	NA	2.2E11	3.7E08	3.7E08	1.9E10	1.1E10	7.4E10	1.1E09	1.9E11	2.6E09
1973	5.6E14	3.7E10	NA	2.6E11	1.9E09	1.9E09	2.6E10	1.9E10	7.4E10	7.4E08	NA	3.0E09
1974	3.2E14	2.2E10	NA	2.2E11	7.4E08	7.4E08	7.4E09	7.4E09	3.7E10	7.4E08	NA	7.4E08
1975	4.1E14	1.9E10	NA	2.6E11	NA	NA	1.1E10	1.1E10	2.2E10	NA	NA	7.4E08
1976	2.7E14	3.3E10	NA	1.9E11	NA	NA	7.4E09	1.1E09	7.4E09	NA	NA	3.7E08
1977	2.3E14	1.5E10	NA	1.1E11	NA	NA	7.4E09	1.1E09	7.4E09	NA	NA	1.1E09
1978	2.3E14	1.5E10	NA	7.4E10	NA	NA	7.4E09	1.5E09	1.1E10	NA	NA	1.1E09
1979	2.8E14	3.3E10	NA	8.9E10	NA	NA	4.8E09	2.2E09	8.9E09	NA	NA	1.1E09
1980	1.7E14	5.1E10	NA	5.6E10	NA	NA	NA	3.3E09	2.3E10	NA	NA	1.5E09
1981	1.1E14	2.4E10	NA	5.6E10	NA	NA	3.7E09	1.5E09	8.5E09	NA	NA	1.5E09

[a] To convert becquerels to curies multiply by 2.7E-11.

[b] Total rare earths minus cerium.

[c] Transuranic elements.

[d] NA = not analyzed.

Source: T. W. Oakes, et al., White Oak Lake and Dam: A Review and Status Report-1980 Background Report II-Environmental Impact Statement Input, ORNL-5681; update Industrial Safety and Applied Health Physics Division of the Oak Ridge National Laboratory.

Melton Valley Hydrofracture Facility. Intermediate-level wastes are pumped from Bldg. 2531 to the Melton Valley Hydrofracture Facility and stored until injected in the Pumpkin Valley member of the Conasauga shale formation below SWDA No. 5. In the hydrofracturing process, hydraulic pressure is used to initiate the formation of a crack between layers of shale. An alkaline ILW solution is mixed with a solids blend composed of cement and other additives; the mixture is injected under pressure into the crack in the impermeable shale formation at depths between 210 and 300 m (700 and 1000 ft.). As the injection continues, the grout fills the crack and extends it further to form a thin horizontal (approximately) sheet several hundred meters across. The grout sets in a few hours after injection, thereby permanently fixing the radioactive wastes in the shale formation (Fig. 2.9).

The Hydrofracture Facility is designed to inject about 530,000 L (140,000 gal) of grout per injection.[12] One injection per year suffices to dispose of ORNL's accumulation of ILW solution. The design injection rate is about 950 L/min (250 gpm) at an injection pressure of 14 to 28 MPa (2000 to 4000 psi). The system was designed for a maximum pressure of 69 MPa (10,000 psi). The facility consists of the injection well, a network of observation and monitoring wells, storage tanks, and other associated equipment.[13] Initial shakedown tests are under way. The first injection of radioactive wastes in the new facility was completed successfully in June 1982.

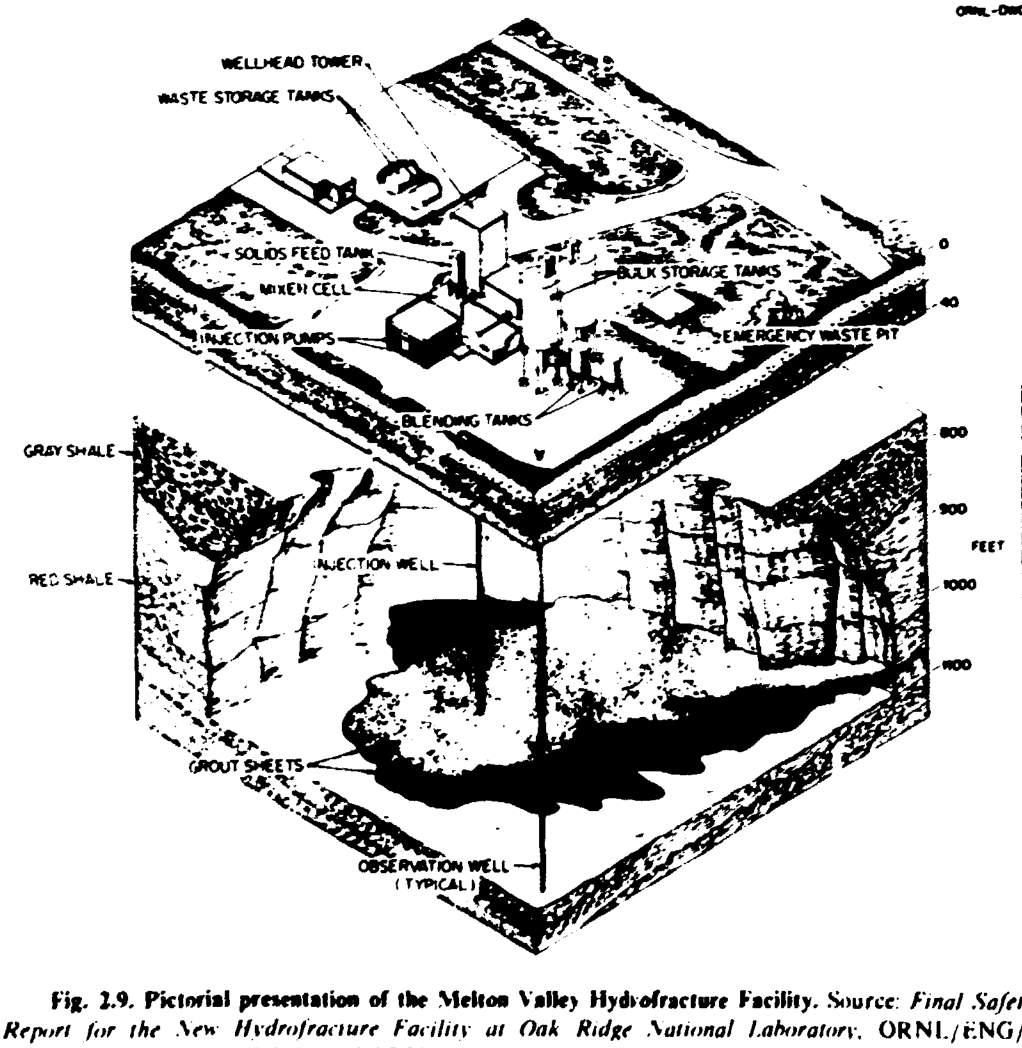

Fig. 2.9. Pictorial presentation of the Melton Valley Hydrofracture Facility. Source: *Final Safety Analysis Report for the New Hydrofracture Facility at Oak Ridge National Laboratory*, ORNL/ENG/INF-81/2, UCC-ND Engineering Division and ORNL Operations Division, Oak Ridge, Tenn., January 1982, Fig. 4.1-1.

The original hydrofracture facility, used from 1964 to 1979, was located in the SW corner of SWDA No. 5. It completed its function and is no longer used. A total of eight experimental injections were made in 1964 and 1965, during which time a total of 1840 m^3 (0.49 million gal) of waste plus water containing 53 TBq (1,436 Ci) of ^{90}Sr and 194 TBq (5237 Ci) of ^{137}Cs was injected at a depth between 288 m (945 ft) and 266 m (872 ft). Between December 1966 and May 1979, a total of 18 operational injections were made at depths between 266 m (872 ft) and 241 m (792 ft). These injections totaled 5410 m^3 (1.42 million gal) of waste plus water containing 1.43 PBq (38,640 Ci) of ^{90}Sr and 25.3 PBq (683,881 Ci) of ^{137}Cs together with much smaller quantites of other radioactive elements including some transuranics. None of the radiological surface water and groundwater studies indicate that migration of radionuclides has occurred.

2.5.7.2 Nonradioactive liquid wastes

Storm runoff system. Storm drainage from ORNL facilities flows from numerous open ditches, culverts, and storm sewers into WOC or into small tributary streams flowing through the developed areas. Small tributaries also carry runoff from the southern slope of Chestnut Ridge north of ORNL and the northern slope of Haw Ridge south of the central site area. White Oak Creek has been subjected to occasional flooding in the past. Channel modifications have been made to increase the rate of flow through the central site area. There has been no flooding since these changes were made. Runoff from 7500- and 7900-area facilities flows into the Melton Branch, which joins WOC near SWDA No. 5. Runoff from the Consolidated Fuel Reprocessing Facility area enters the Melton Hill Reservoir at Gallaher Bend near Clinch River Kilometer 53.1 (Clinch River Mile 33).

Sanitary sewage system. The central treatment plant (Bldg. 2521), constructed in 1973, is a two-stage, series-flow aeration lagoon system providing secondary treatment. The lagoons are lined with a membrane to prevent infiltration. Air is supplied by a blower and distributed by a manifold header system to laterals feeding aerators located on the lagoon bottoms. The two lagoons contain approximately 3800 m^3 (1 million gal) each and provide a total detention time of about 11 d. The exposed water surface area is about 0.3 ha (0.75 acre) per lagoon. The average flow through the plant in 1981 was 685 m^3/d. (Minimum flow was 227 m^3/d; maximum flow was 1775 m^3/d.)

Effluent quality criteria are determined by a national pollutant discharge elimination system (NPDES) permit (see Table 2.11). Each parameter is monitored, and the frequency and type of sample is prescribed in the NPDES permit. Composite samples (24 h) for ammonia, biological oxygen demand (BOD), and suspended solids are taken weekly. Fecal coliform bacteria samples are grab samples taken monthly. Grab samples for chlorine residual and pH are taken daily, and grab samples for settleable solids are taken weekly.

Settleable solids, pH, and fecal coliform bacteria were in compliance with NPDES permit criteria throughout 1981. Suspended solids normally ran about 30% of the NPDES standard, but during a 2-week period in April the concentration standard was exceeded. However, the total quantity of suspended solids released did not exceed the permit limitations.

Monitoring results for ammonia, BOD, and chlorine residual effluent concentrations are shown in Fig. 2.10. Chlorine residual concentrations were outside NPDES permit ranges on 26 d during 1981. Both NH_3 and BOD exceeded concentration limits in the effluent for several months of the year.

The facilities in Melton Valley such as the CFRF (7600 area) and a few isolated areas where only a few employees work are served by septic tanks and associated drain fields. No discharges to surface streams occur from these facilities. The HFIR hauls its sewage to the central treatment plant.

Waste discharge to White Oak Lake. Nonradioactive liquid wastes are discharged to White Oak Lake by way of WOC and Melton Branch. The average quantities of nonradioactive chemicals discharged daily into White Oak Lake from normal operation of ORNL facilities are listed in Table 2.12.

Table 2.11. NPDES effluent quality criteria for sanitary waste treatment plant

Effluent constituent	Discharge limits Quantity (kg/day)	Concentration (mg/L)
Ammonia (N)[a]	6.8[b]	5
BOD[a]	27	20
Suspended solids[a]	41	30
Fecal coliform bacteria, No./100mL	NA[c]	(400)[d]
Chlorine residual	NA	0.5-2.0
pH, standard units	NA	6.0-9.0
Settleable solids	NA	0.5

[a]Daily maximum.

[b]Multiplier factors for converting International System of Units (SI) to English units are located on inside back cover.

[c]NA = not applicable.

[d]Weekly geometric mean.

Source: ORNL NPDES permit.

2.5.8 Solid Waste Systems

2.5.8.1 Radioactive wastes

Solid wastes containing, or that have been judged potentially to contain, radionuclides are disposed of according to type of material present: ^{235}U, TRU, or general radioactive waste.

Uranium-235 must be handled and accounted for in accordance with Health Physics Procedure 2.4, "Source, Special Nuclear, and Special Materials Controls,"[14] and the amount of fissile material present in each package must be determined before its delivery for transport to the storage area. Fissile material is stored in unlined auger holes; in no case can a single package contain more than 200 g (0.44 lb) of ^{235}U unless prior approval is obtained from the ORNL Criticality Safety Review Committee. When filled, the holes are capped with concrete and a record kept of the location and contents.

Transuranic wastes are those containing greater than 370 Bq/g (>10 nCi/g) of ^{233}U or transuranic nuclides and are handled according to the radiation level of the individual packages. (TRU wastes containing less than 370 Bq/g are disposed of as LLW.) About 75 m^3/year (2600 ft^3/year) of TRU wastes are stored retrievably for eventual transportation to a federal repository.[2]

Transuranic waste reading less than 2 mSv/h (200 mrems/h) on contact is normally packaged in stainless steel 110- or 210-L (30- or 55-gal) drums by the waste generator.[2] After tagging, the

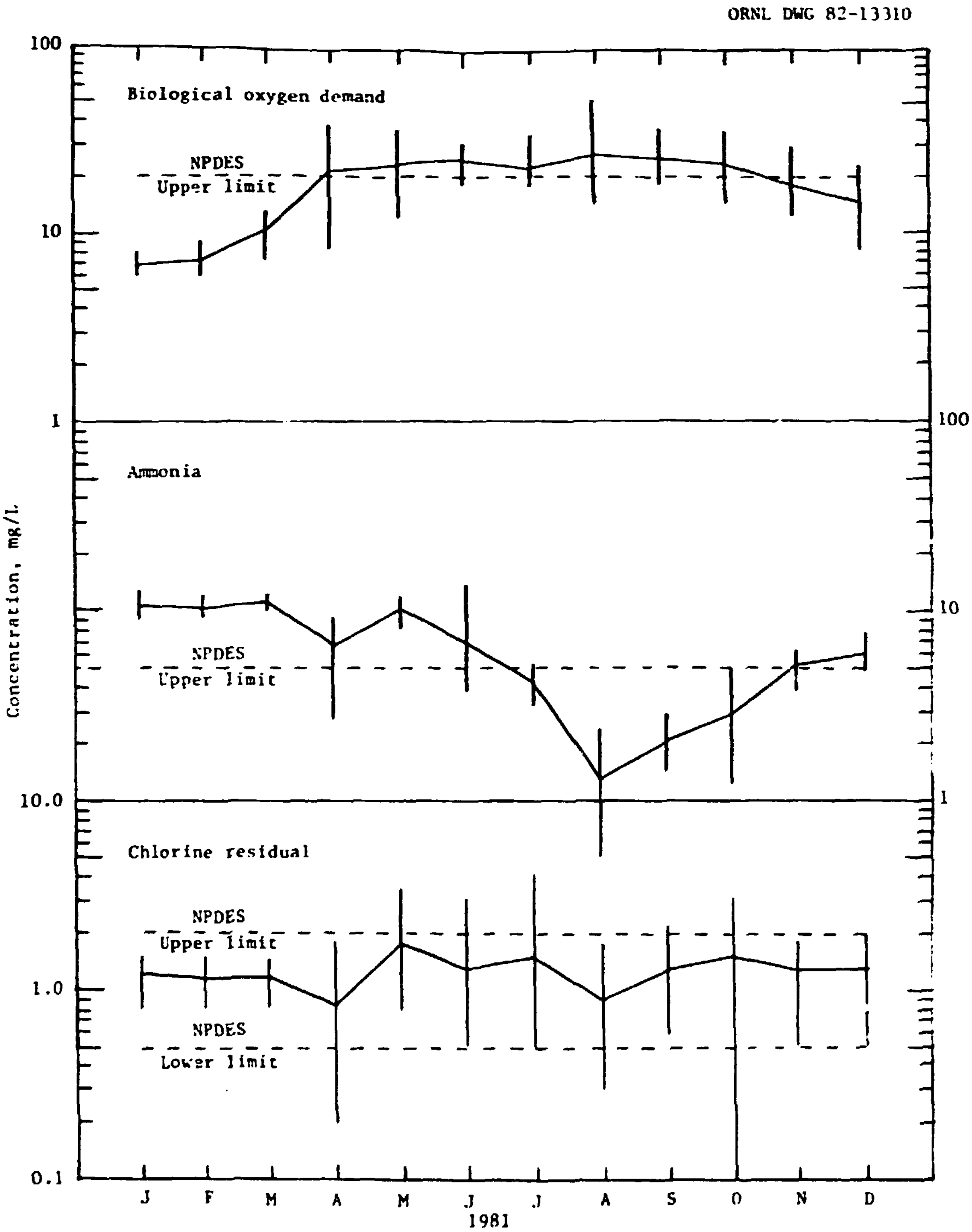

Fig. 2.10. Concentrations of biological oxygen demand, ammonia, and chlorine residual in sanitary treatment plant effluent, 1981. The curves connect monthly mean values; the verticle lines show the range of values measured during the month. Source: NPDES monthly reports, 1981.

Table 2.12. Estimated waste loadings in White Oak Creek and Melton Branch from ORNL facilities

Facility	Average loading (g/day)																	Average flow (L/sec)
	BOD	Suspended solids	Ammonia	Total dissolved solids	Phosphate	Phenol	Ag	Al	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn	
White Oak Creek																		
Bldg. 4500 cooling tower		6.5E3		3.6E5	2.0E3			6.5E1					9.8E1		3.3E1		2.0E2	3.79
ORR cooling tower		5.7E3		3.1E5	1.7E3			5.7E1					8.5E1		2.8E1		1.7E2	3.28
Bldg. 4500 process water			4.2E2	7.6E4	6.3E1	2.9E0		3.8E2		2.1E0	6.2E0	1.7E1	1.4E2	1.5E1	4.7E0	1.1E1	3.4E1	6.57
Bldg. 3518 acid neut. facility			1.7E1	3.8E5	4.7E2	7.8E-1	4.0E0	1.2E2		2.8E0	1.0E1	1.8E1	8.1E2	1.2E1	8.3E0	3.0E0	7.3E1	4.75
Bldg. 3544 process waste treatment			7.9E2	7.4E5	1.1E2	3.4E0		7.2E2		<3.4E0	7.6E0	9.1E0	3.2E2	1.0E1	8.9E0	7.1E0	9.2E1	12.9
Sanitary treatment facility	1.5E4	7.4E3	4.8E3		1.3E3			3.8E1										
Coal pile runoff		5.6E2	4.1E1	2.8E5	4.1E2	2.2E-1	1.2E0	4.2E3	5.5E1	1.8E1	5.6E0	8.0E1	1.7E4	3.0E2	8.0E1	4.1E0	2.1E1	9.9
Other cooling tower blowdown		4.3E3		2.4E5	1.3E3			4.3E1					6.5E1		2.2E1		1.3E2	2.50
Total loading	1.5E4	2.5E4	6.0E3	2.4E6	7.3E3	7.3E0	5.2E0	5.7E3	5.5E1	2.6E1	2.9E1	1.2E2	1.9E4	3.4E2	1.8E2	2.7E1	9.1E2	41.2
Melton branch																		
HFIR process waste			1.4E1	4.6E4	2.6E1	2.6E-1	<1E0	1.0E1		3.5E-1	8.7E-1	5.4E0	1.3E1	5.1E-1			4.1E0	0.63
HFIR cooling tower blowdown		1.2E4		6.6E5	3.6E3			1.2E2							6.0E1		3.6E2	6.94
TRU process waste			4.6E0	7.3E3	7.3E0	9.0E-2	<1E0	3.5E0		1.9E-1	4.3E-1	1.0E0	4.6E0	6.1E-1			2.4E1	0.44
Total loading		1.2E4	1.9E1	7.1E5	3.6E3	3.5E-1	<2E0	1.3E2		5.4E-1	1.3E0	6.4E0	1.8E1	1.1E0	6.0E1		3.9E2	8.0

Source: Letter, K. W. Sommerfeld to J. A. Lenhard, "EPA Draft Permits for Oak Ridge Facilities", December 4, 1981.

waste drums are transferred to the Retrievable Drum Storage Facility, which consists of concrete block structures 85% below grade, having total storage capacity for approximately 3500 drums. Transuranic waste reading more than 2 mSv/h (200 mrems/h) on contact is normally packaged in reinforced concrete casks by the waste generator. The casks are stored retrievably in trenches [and since January 1980, in a (below grade) reinforced concrete building]. TRU wastes with very high beta-gamma activity levels are stored in stainless steel-lined wells with concrete shield plug closures.[2]

General radioactive waste disposal is accomplished in most cases by depositing the waste below grade in either trenches or auger holes. All trench development is accomplished using good engineering practices, and due consideration is given to the topological and hydrological features of the site. Geologic and hydrologic conditions at the SWDAs and history of their use is discussed elsewhere.[15] The trenches are constructed and maintained to isolate the waste from surface water and groundwater. The trenches are nominally 15 m (50 ft) long and 3 m (10 ft) wide; the depth is normally 3–4.5 m (10–15 ft) and is always limited to at least 0.6 m (2 ft) above the known high-water table. If, because of unanticipated circumstances, the excavation falls below the water table, the trench is backfilled with Conasauga shale to a depth of at least 0.6 m (2 ft) above the existing water. The trenches are graded to slope toward one end (approximately 1:25 slope). A monitoring well is installed after trench closure.

More than 170,000 m^3 (6 million ft^3) of solid waste have been buried in ORNL SWDAs Nos. 1–6 (Fig. 2.11); SWDAs Nos. 1–4 have been closed. SWDAs Nos. 5 and 6 are currently in operation, although use of SWDA No. 5 is reserved for retrievable storage for TRU waste. Alternatives for management of ORNL retrievable TRU waste have been evaluated and are described elsewhere.[16]

Solid waste originates from about 20 sources at ORNL. Shipments also have been received from other facilities in accordance with agreements with DOE. Table 2.13 lists the historical record of materials stored in the ORNL facilities. Accurate records of the types and quantities of radioactive wastes buried are not available because early burial practices were not governed by the current requirement for identification and segregation. A recent report,[17] which provides a data base for inventories and projections of spent nuclear fuel and radioactive waste, estimates that at ORNL about 5 kg (11 lb) of TRU fuel elements have been buried as waste. In addition, it is estimated that there is up to 1000 m^3 (35,000 ft^3) of contaminated soil from liquid waste disposal containing about 0.3 kg (0.7 lb) of TRU elements.

Detailed descriptions of current collection, retention, and retrievable practices for radioactive waste are given elsewhere.[18]

2.5.8.2 Nonradioactive wastes

Nonradioactive solid wastes are categorized as nonhazardous or hazardous. Each year about 17 Gg (19,000 tons) of nonhazardous waste and about 90 Mg (100 tons) of hazardous waste are generated at ORNL.

The types and quantities of nonhazardous wastes are shown in Table 2.14. Fossil fuel waste and construction material refuse comprise the principal types of materials in this category. Methods of disposal are indicated in Table 2.14. The shallow water table conditions at the Y-12 Bear Creek Valley sanitary landfill made it necessary to select a new landfill for disposal of nonradioactive and nonhazardous wastes. The new landfill, located on Chestnut Ridge between ORNL and Y-12 near Mt. Vernon Cemetery, is being designed to accept sanitary wastes from ORNL, Y-12, and ORGDP. This landfill will be permitted by the state of Tennessee and will be operated in accordance with state requirements. The contractors landfill is located about 1.6 km (1 mile) west of the ORNL central site. Debris is deposited at the edge of the open pit. If waste that can be scattered by the wind is present, the debris in the pit is covered before the close of the work day.

Hazardous materials consist of four major groups of materials: asbestos, compressed gases packaged in cylinders, chemicals, and waste oils. The types and quantities of these materials are shown in Table 2.15. Such wastes may be placed in retrievable storage on the site or disposed of as

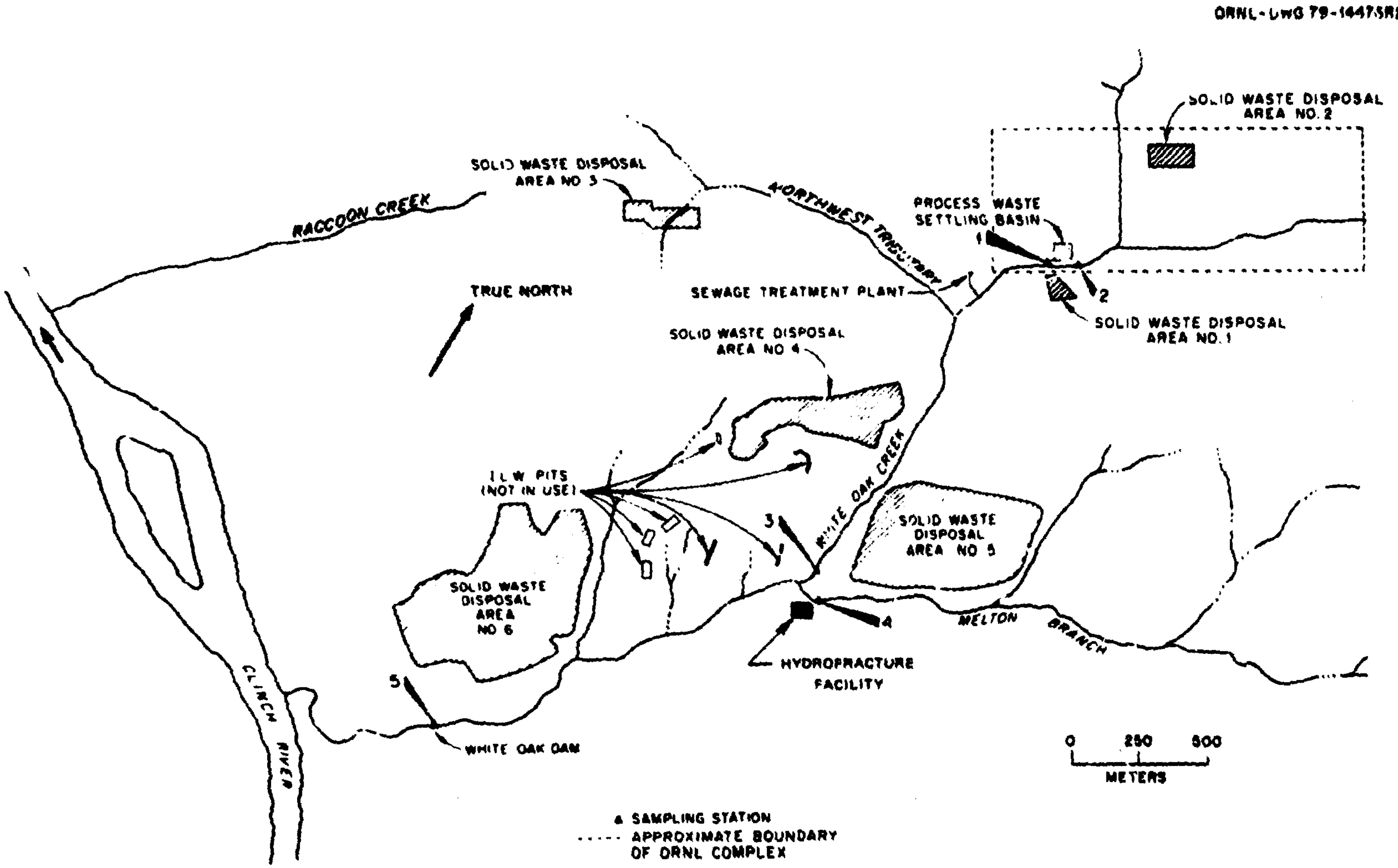

Fig. 2.11. Map showing ORNL solid waste disposal areas.

Table 2.13. Total annual activity, volume, weight of solid waste buried or stored

Fiscal year	Activity[a] (TBq)	Volume[a] (m^3)	Weight[a] (Gg)	Fiscal year	Activity[a] (TBq)	Volume[a] (m^3)	Weight[a] (Gg)
1943	74	710	0.1	1963	740	9,400	1.8
1944	74	710	0.1	1964	740	9,100	1.8
1945	74	710	0.1	1965	370	5,300	0.9
1946	74	710	0.1	1966	370	4,500	0.9
1947	370	4,000	0.9	1967	370	5,600	0.9
1948	370	4,000	0.9	1968	740	6,800	1.4
1949	370	4,000	0.9	1969	370	5,400	0.9
1950	370	4,000	0.9	1970	370	3,600	0.4
1951	370	4,000	0.9	1971	400	4,700	1.0
1952	370	5,700	0.9	1972	370	3,700	0.9
1953	370	5,700	0.9	1973	330	3,000	0.7
1954	370	5,700	0.9	1974	330	3,400	0.7
1955	370	5,700	0.9	1975	74	3,200	0.6
1956	370	5,700	0.9	1976[b]	400	3,500	0.7
1957	740	9,000	1.8	1977	97	1,240	0.2
1958	740	9,000	1.8	1978	200	2,400	0.4
1959	740	9,000	1.8	1979	2,050	2,100	0.6
1960	740	9,000	1.8	1980	2,340	2,350	0.6
1961	1,500	15,000	2.7	1981	4,290	[illegible],800	0.8
1962	1,100	12,000	2.3				

[a]Multiplier factors for converting International System of Units (SI) to English units are located on inside back cover.

[b]July, 1, 1975 through September 30, 1976 — reflects change in fiscal year.

Source: Gilbert/Commonwealth, Programmatic Assessment of Radioactive Waste Management, ORNL/Sub-80/13837/3, January 1980, adapted from Table 5.1-1, updated by Tom Grizzard, Operations Division of the Oak Ridge National Laboratory.

Table 2.14. Estimated annual quantities of nonhazardous wastes, ORNL

Waste	Quantity	Method of disposal
Miscellaneous wastes		
Old tires, each	1,150	Sold
Old batteries, each	290	Sold
Scrap metal, kg[a]	276,000	Sold
Paper products, kg	118,000	Sold
Construction material, kg	3,600,000	Contractor's landfill
Cafeteria and office waste, kg	1,700,000	Y-12 landfill
Cooling tower sludge, m^3	42	Y-12 landfill
Fossil fuel waste		
Fly ash, kg	11,000,000	Contractor's landfill
Coal-pile runoff sludge, kg	50,000	Contractor's landfill
Total, kg	17,000,000	

[a]Multiplier factors for converting International System of units (SI) to English units are located on inside back cover.

Source: B. M. Eisenhower, et al., Current Waste Management Practices in Operations at Oak Ridge National Laboratory, ORNL-5917, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1982.

indicated in Table 2.15. Asbestos and animal carcasses are placed in dedicated trenches in SWDA No. 6 and covered the same day. Gas cylinders, nonradioactive chemicals, and PCB-contaminated wastes are transported off the site to a commercial hazardous waste facility for disposal. Hazardous wastes that also contain radioactivity are currently placed in aboveground retrievable storage on the site until a suitable treatment method and/or disposal site is available (Sect. 2.4.2).

2.5.9 Excess Property Disposition

Retired property items such as vehicles, used laboratory equipment, scrap materials, computer software, used mercury batteries, etc., are transferred to UCC-ND Property Sales at ORGDP for sale to the public. Waste oil is sold at the X-10 site. Other salvage items, such as obsolete books and certain equipment, are offered to the state for transfer as gifts to schools or other institutions.

Table 2.15. Estimated annual quantities of hazardous wastes, ORNL

Waste	Quantity	Method of disposal
Asbestos material, kg[a]	11,000	SWDA No. 6[b]
Gas cylinders (ignitable, corrosive, reactive gases), kg	400	Storage[c]
Chemical waste		
Photographic waste, m^3	20	WOC[d]
Organic chemicals, kg	27,000	COF[e]
Inorganic chemicals, kg	10,000	COF
Organic solvents, kg	9,000	COF
Carcinogenic waste, kg	34,000	COF
Acids and bases, kg	4,500	WOC[f]
Reactive chemicals, kg	36	Storage[c]
Oils[g]		
Noncontaminated, m^3	80	Sold
PCB-contaminated		
<500 ppm, m^3	9	COF
≥ 500 ppm, m^3	300	COF
Animals, bedding, kg	150,000	SWDA No. 6[h]
Total, kg	~ 470,000	

[a]Multiplier factors for converting International System of Units (SI) to English units are located on inside back cover.

[b]To dedicated trench in solid waste disposal area (SWDA) No. 6.

[c]Cylinders and reactive chemicals are stored in hazardous waste storage facility.

[d]Discharged to White Oak Creek after silver recovery treatment.

[e]Commercial off-site disposal.

[f]Discharged to White Oak Creek after neutralization.

[g]Quantities include waste oil from X-10 site facilities and from divisions located at Y-12.

[h]Materials from ORNL Biology Division located at Y-12 site are placed in dedicated trench in SWDA No. 6.

Source: B. M. Eisenhower et al., Current Waste Management Practices in Operations at Oak Ridge National Laboratory, ORNL-5917, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1982.

2.5.10 Occupational Health

The ORNL Health Division establishes health standards that provide safe working conditions. In fulfilling its responsibility, the Health Division performs the following in addition to its other functions:

- Assists employees in maintaining their health by controlling exposure to the stresses and hazards of the work place.
- Evaluates the health status and capabilities of prospective and current employees and advises management on their placement in jobs they can perform without endangering themselves or others.
- Provides medical care for occupational illnesses or injuries using consultants as indicated to achieve optimal recovery while conforming to the legal, political, and social constraints on the consultants.
- Provides emergency or primary care for nonoccupational illnesses and injuries to enable the employee to continue work or, if needed, refers to outside medical professionals.
- Encourages and assists in rehabilitation of employees impaired by accident or disease and evaluates disability claims under the UCC Pension Plan or Workers Compensation Laws in cooperation with Employee Relations Managers.
- Encourages health maintenance through periodic medical examinations of all employees.
- Communicates to each employee all significant findings of each examination and advises appropriate action, noting in the medical record what has been done.

2.5.11 Safeguards and Security

Standard Practice Procedures (SPPs) for operating ORNL are consistent with policies required by DOE. Of 18 SPPs defined in the "D" Series Procedures category, "Accounting and Materials Handling," approximately one-half are devoted to safeguards. Specific procedures titles include the following:

Shipments of Fissile and Other Radioactive Materials
Control of Government Property and Material
Control of Rare and Precious Metals
Receipt and Shipment of Hazardous Materials
Control of Hazardous Materials

Category No. 8 applies entirely to security policies and includes among ten procedures those pertaining to protection of classified information, visitor control, and security requirements for the shipment of classified and strategically important material. The SPPs are augmented from time to time, as appropriate, and revised as required by need. They define protocols that provide for effective safeguards and security and are followed consistently in the operation of ORNL.

2.5.12 Emergency Preparedness

It is UCC-ND policy to maintain an emergency preparedness program to provide the maximum practicable protection of employees, DOE contractor personnel, members of the public, and property in the event of emergencies involving company activities. It is the responsibility of the ORNL Director to establish an appropriate emergency planning organization to implement the emergency preparedness program and to ensure that the emergency plans and procedures developed comply with the requirements of the DOE Order 5500.A, Emergency Planning, Preparedness, and Response for Operation. The Director also ensures that the emergency preparedness program is coordinated with necessary offsite authorities and provides for the periodic review and evaluation of emergency plans and procedures to ensure that they are responsive to potential risks of current operations. The following SPPs are applicable:

D-5-1 "Contamination Damage to Personal Property"
D-5-2 "Mutual Aid Firefighting Agreement for Oak Ridge Installations"
D-5-8 "Public Information Releases to News Media"
D-5-16 "Unusual Occurrences Reporting"

2.6 ENVIRONMENTAL MONITORING

A comprehensive ORNL program for waste management and environmental pollution control is maintained in accordance with the provisions of DOE Order 5480.1, Environmental Protection, Safety, and Health Protection Program for DOE Operations. It is also maintained in accordance with other related requirements in other DOE orders and the applicable policies of local, state, and federal regulatory bodies including the EPA and UCC-ND SPPs.

Central coordination of the environmental monitoring program is the responsibility of ORNL's DEM. Monitoring information from ORNL is combined with that from other UCC-ND–operated plants in the Oak Ridge area. Through the coordination of the UCC-ND Office of Health, Safety, and Environmental Affairs, it is reported annually as, for example, the environmental monitoring report for 1980.[19]

Methods and procedures utilized in environmental management activities at ORNL are described in detail by the DEM.[6] The manual of procedures issued by the department is revised as appropriate as changes in ORNL programs and monitoring requirements occur.

2.6.1 Waste Operations Control Center

Gaseous and liquid waste disposal systems throughout ORNL are monitored in the Waste Operations Control Complex (Bldg. 3105). [A radiological waste improvement project has begun at ORNL which includes the construction of a new Waste Operations Control Center (Bldg. 3125) that will incorporate a modern data acquisition system.[20] Construction of the building was completed in 1982. The center is scheduled for completion in 1984.] The control complex has instruments for monitoring and recording, and contains visible and audible alarms for surveillance of the liquid and gaseous disposal systems. Remote instrumentation channels are telemetered to the control complex. In the event of an abnormal activity release or an exceeded operating limit, the shift operator must alert supervision and the respective facility so that corrective steps can be taken immediately.

The primary benefit of the new centralized, automated, computer-based, radioactive waste data acquisition monitoring system will be to relieve nuclear facility operating personnel from the task of collecting and processing the large volume of data required to meet regulatory and operational radiological control requirements; it will provide rapid access to critical data. By automating the radioactive waste monitoring process, calibration can be performed frequently in a repeatable, systematic fashion. Reliability is enhanced by self-testing and on-line diagnostics that provide immediate indication of malfunctions.

The data acquisition monitoring system will provide a degree of flexibility by incorporating microprocessor-based data concentrator stations for data acquisition. This will allow remote interrogation of the system for evaluation of equipment malfunctions, alarm limits, and alarm status. The data concentrator stations will feed a central processing unit (CPU) capable of performing more detailed data manipulation and interrogation for more detailed analysis and report generation. In addition, the CPU will be capable of supporting peripherals for real-time display of critical parameters.

2.6.2 Air Sampling

The staff of DEM monitors airborne pollutants (radioactive and nonradioactive) in local, perimeter, and remote areas of ORNL. There are 23 LAM stations, 9 PAM stations, and 7 RAM stations. Although the monitoring facilities are different for each of the three types of stations, most of the stations provide for the collection of (1) airborne radioactive particulates by air-filtration techniques, (2) radioactive particulate fallout materials by impingement on gummed paper trays, (3) rainwater for measurements of fallout occurring as rainout, and (4) ^{131}I using charcoal cartridges. High-volume air samplers and tritium monitors have also been installed at several LAM stations. External gamma radiation background is measured at all stations using thermoluminescent dosimeters.

Measurements of ambient concentrations of fluorides and SO_2 are obtained on a regular basis within the ORR, although not at the X-10 site. The current sampling procedure for fluorides is to obtain 7-d samples collected on K_2CO_3-treated paper and analyze weekly by specific ion electrode. Ambient SO_2 concentrations are obtained at two continuous monitoring stations at the Y-12 site. Suspended particulate sampling is performed at 24-h intervals. The data[19] indicate that in 1980 the measured environmental concentrations of fluorides, suspended particulates, and SO_2 were in compliance with applicable standards.[21]

2.6.3 Biological Sampling

Soil and grass samples are collected annually at the PAM and RAM stations. The grass and soil samples are analyzed for uranium, plutonium, and other radioisotopes using gamma spectroscopy and radiochemical techniques. Various other soil, sediment, and vegetation samples are taken in the environs when necessary.

The biological sampling program centers on the capture of fish from the Clinch River and its tributaries, the collection of milk samples (local and remote), and the study of road-killed animals. The fish samples are analyzed by atomic absorption for mercury and by gamma spectrometry and radiochemical techniques for radionuclides that may contribute to the radiation dose in man. Milk samples are collected weekly at the local milk stations and once during a 5-week interval at the remote milk stations. The milk samples are analyzed for ^{131}I and ^{90}Sr. Local produce is also collected from time to time for analysis of radioactivity and trace metal content. The road-killed animals are analyzed for gamma activity and for specific isotopes (e.g., ^{90}Sr). Numerous special projects, such as studies on accumulation of radioactivity in insect populations (wasps, bees, etc.), are done to provide information about the interaction of radionuclides and the environment.

2.6.4 Water Sampling

The concentration of radionuclides in water is determined by the collection and analysis of rainwater and water samples from designated sites. These sites include Melton Hill Dam, White Oak Dam, WOC, ORGDP water intake, Kingston water supply, and potable water at ORNL. Depending on the location, water samples are collected daily, weekly, or monthly. The samples are analyzed by gamma spectrometry, ion exchange, atomic absorption, alpha range analysis, and gravimetric, fluorometric, volumetric, colorimetric, turbidity, and infrared techniques among others.

Nonradiological water quality monitoring of the streams on and adjacent to ORNL is performed at three stations: WOC at White Oak Dam, Clinch River at Melton Hill Dam, and at Clinch River at the ORGDP sanitary water intake. The data collected at Melton Hill Dam, which is about 3.7 km (2.3 miles) upstream of the confluence of WOC with the Clinch River, are considered as representative of baseline quality for comparison with data collected at the ORGDP sanitary water intake. The data collected at WOC define the chemical characteristics of the ORNL effluent entering the Clinch River. Water samples are collected for analysis of nonradioactive substances and are composited for monthly analysis by procedures recommended by the EPA.[22]

The concentrations of nonradioactive substances analyzed in 1980 in water samples from the three locations noted above are listed in ref. 18, Tables 15 through 17. The average concentrations of all substances analyzed were in compliance with Tennessee stream guidelines.[23,24] ORNL received an NPDES permit in 1975 (see Sect. 2.5.7.2). The compliance experience for 1980 is shown in Table 3.15.

2.7 TRANSPORTATION

2.7.1 Area and Site Road Systems

The ORNL controlled area is traversed by approximately 150 km (93 miles) of roads [approximately 40 km (25 miles) of primary and secondary roads and 110 km (68 miles) of access and patrol roads]. ORNL roadways provide vehicular access to all buildings and remote facility sites. The extent of road use is comparable to residential traffic volumes on the primary roads.

ORNL has seven major parking areas that encompass 10 ha (25 acres) of paved lots and accommodate 2900 vehicles. Currently, the vehicle parking spaces experience approximately 90% utilization during normal operations of ORNL.

2.7.2 Onsite Shipments

Normal operations of ORNL require a fleet of 500 automobiles, pickup trucks, heavy trucks, and 116 heavy equipment vehicles. An infinite variety of inter-site transport occurs. Cumulative mileage is approximately 3.2 million km (2 million miles) per year.

2.7.3 Offsite Shipments

Materials and products are transported to and from ORNL facilities by air freight, air express, and truck. Nonradioactive materials are transported by commercial carriers, who are responsible for safe delivery. Approximately 2 million kg (4.4 million lb) of nonradioactive chemicals are shipped to ORNL per year. Of these, industrial gases comprise approximately 75%, and inorganic acids, required primarily for water treatment, approximately 20%.

Radioactive materials are transported from the Isotopes Shipping Department (Bldg. 3038) in containers that comply with applicable shipping regulations and that meet the approval of the DOT through a DOT permit. The Operations Division made approximately 450 shipments of stable isotopes and more than 1200 shipments of radioactive isotopes in 1981; about 20% were shipped by truck and 80% by air. Annual sales of these products is now $15 million.

ORNL is permitted under RCRA as a hazardous waste generator and transporter. The hazardous wastes are shipped by commercial carrier to an offsite commercial facility for disposal. The current contract for disposal of hazardous wastes is with Chemical Waste Management, Inc., which utilizes their hazardous waste facility at Emelle, Alabama. The quantities transported (indicated in Table 2.15) include hazardous wastes generated by divisions located at Y-12. Table 2.15 also quantifies animal waste products transported for burial in a dedicated trench in SWDA No. 6 in Melton Valley from the Biology Division at Y-12.

2.8 USES OF RESOURCES

The R&D activities in which ORNL is engaged incur the use of many resources. Because the operation of ORNL is highly labor intensive, the irreversible commitment of natural resources is comparatively small for the operating costs involved. A brief summary follows of the principal resources used for ORNL operations. Also given are cross references to other sections of this report where descriptions of individual resources and analyses of their uses are given.

2.8.1 Electricity

Current average electrical power demand for ORNL operations ranges from 17 to 25 MVA; the maximum peak load requirement, as judged from recent history, is approximately 36 MVA (see Sect. 2.5.3).

2.8.2 Water

The current average water requirement for ORNL operations is approximately 0.22 m^3/s (5 Mgd) (see Sect. 2.5.1).

2.8.3 Fuel

Fuel consumption for transportation, heating, and power generation varies annually and depends on programmatic requirements, weather conditions, and occurrence of emergency conditions. Typical requirements are the following:

coal	29,000 tonnes per year (32,000 tons per year)
oil	
steam	0–57 m^3/year (0–15,000 gal/year)
emergency power	20 m^3/year (5300 gal/year)
gasoline	750 m^3/year (200,000 gal/year)
natural gas	1500–63,000,000 m^3/year (50,000–2,200,000,000 ft^3/year) depending on availability

2.8.4 Chemicals and Other

Approximately 2 million kg (4.4 million lb) of chemicals are used annually in ORNL operations. Approximately 75% of this amount is for industrial gases; 20% is for inorganic acids, primarily for water treatment.

Rare metals are used for R&D. Some of these are effectively irretrievable if they have been irradiated or, as in the case of iridium, consumed experimentally.

2.8.5 Land

The ORNL site is considered to be 3543 ha (8754 acres) within the perimeter of the designated buffer zone surrounding the ORNL central site and its associated outlying facilities (Fig. 2.12). The land areas used by or associated with the various facilities are given in Table 2.16. The ORNL central site facilities (Sect. 2.3.2), the SWDAs (Sect. 2.5.8), and the outlying facilities (Sect. 2.3.3), occupy about 20% of the ORNL site. The remaining 80% is buffer zone consisting primarily of the NERP (Sect. 2.3.3.3) and nondesignated areas, both of which are predominantly forested. Roads and power lines traverse the forests in a number of areas.

Most of the land on the ORR is subject to forest management administered through the Environmental Sciences Division at ORNL. Forest management in the ORNL buffer zone and on the remainder of the ORR has involved the planting of pines on abandoned agricultural lands after acquisition of the land by the federal government in the 1940s and 1950s, clearing of immature second-growth hardwood-pine forests for planting of pine, thinning and cutting of both hardwood and pine forests for pulpwood and sawtimber, and other management practices. The objectives of the forest management are coordinated with those of other land uses on the ORR, such as NERP activities and waste management.

2.8.6 Manpower

As of early 1982, the manpower of ORNL was 4906. The number of subcontractor personnel is not included in this level. The number of personnel is expected to decrease slowly in the next several years.

2.8.7 Capital

The operating budget for ORNL in FY 1982 is $335 million. The capital equipment expenditures increase this total to $359 million. Approximately 25% of the operating budget is devoted to subcontracting.

2.9 CONSTRUCTION ACTIVITIES

Construction of new facilities and/or modifications to existing ORNL facilities have taken place continually since ORNL was established and is not expected to cease. Table 2.17 lists construction projects at ORNL in 1980 and in 1981. All facilities are on federal property administered

Fig. 2.12. Land-use map of ORNL and environs. Legend: D = contractor's landfill; GCR = gas-cooled reactor area, present site of the Consolidated Fuel Reprocessing Facility; HPRR = Health Physics Research Reactor; ILWP = intermediate-level liquid waste pits, use discontinued in 1965; ILWT = intermediate-level liquid waste trenches, use discontinued in 1965; NERP = National Environmental Research Park; NSF = new shale-fracturing facility; OSF = old shale-fracturing facility; PW = process waste–settling basin; SS = substation, electric; SW = solid waste disposal areas, low-level solid wastes; TSF = Tower Shielding Facility; R = water reservoir; TR = target range; WP = waste pit. Sources: *Oak Ridge Reservation Land-Use Plan*, DOE/ORO-748, rev. 1, U.S. Department of Energy, Oak Ridge Operations, Oak Ridge, Tenn., 1980; "Topographic Map," U.S. Geological Survey, 1:24,000 series; *Environmental and Safety Report for Oak Ridge National Laboratory*, NUS-3892, NUS Corporation, Rockville, Md., Sept. 30, 1981, Fig. 4.3-3.

Table 2.16. Land use in the ORNL buffer zone

Area	Hectares[a]
ORNL central site	382
Solid waste storage areas	236
Tower Shielding Facility	11
Health Physics Research Reactor	43
Target range, substation, and reservoir	14
National Environmental Research Park	749
Non-designated areas (primarily forested)	2108
Total	3543

[a]Multiplier factors for converting International International System of Units (SI) to English units are located inside back cover.

Source: U.S. DOE -- Oak Ridge Reservation Land-Use Plan, U.S. DOE Technical Information Center, DOE/ORO-748 Rev. 1, Oak Ridge, Tennessee.

Table 2.17. Projects under construction at ORNL, 1980 - 1981

Facility number	Designation	Facility area (m^2)	Land area disturbed (ha)
0961	ORNL Visitor's Overlook	460	0.1
0962	Radio transmitter facility, Chestnut Ridge	9	0.04
1057	100 m meteorological tower	37	0.04
1504	Addition to Aquatic Ecology Laboratory	675	0.08
2528	Added space for coal conversion	111	0.04
2639	Coal yard runoff treatment building	52	0.04
3130	Waste Operations Control Center	381	0.04
5500	Second floor addition	327	negligible
6007	Joint Institute for Heavy Ion Research	367	0.04
6555	30 m meteorological tower	37	0.04
7040	Gas cylinder storage	320	0.04
7571	30 m meteorological tower	37	0.04
7740	Radio transmitter facility, Melton Hill	9	0.04
7860	New Hydrofracture Facility	373	2.2

Source: C. M. Carter, UCC-ND Engineering.

by DOE. Proposals and designs for each new facility constructed at the behest of DOE include an assessment of the environmental impact that will result as a consequence of the proposed action and must accommodate to the intent of the National Environmental Policy Act of 1969.

Before and during construction, staff members of the DEM and other personnel monitor the construction activities and make mitigation recommendations to management if appropriate.

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3. CHARACTERIZATION OF EXISTING ENVIRONMENT

3.1 GEOLOGY[1,2]

3.1.1 Topography

3.1.1.1 Regional characterization

The Oak Ridge National Laboratory (ORNL) site is located in the Appalachian Highland Physiographic Division of the eastern United States. Within the division, areas of distinctively different lithology, stratigraphy, structure, and geomorphic history are divided into physiographic provinces. A physiographic map of Tennessee is shown in Fig. 3.1. The site is located in the Valley and Ridge Physiographic Province near the boundary with the Cumberland Plateau.

Overall drainage in the Valley and Ridge Physiographic Province follows northeast-southwest trending valleys. Major streams flow across this trend for short distances because of entrenchment of ancient stream courses that have gradually eroded downward to their present levels. Remnants of river terraces, often over 30 m (100 ft) above the present floodplain, represent ancient floodplains that were severely eroded as the streams cut downward to the present levels.

3.1.1.2 Local characterization

Site topography conforms to the regional trend. It is characterized by a series of alternating elongated and parallel valley troughs and ridges trending northeast to southwest in general accord with the strike of the underlying rock strata. The valleys have been eroded in areas underlain by the less resistant limestone and shale strata, whereas the ridges are underlain by the more resistant sandstone, shale, and cherty dolomite formations.

Surface elevations range from about 226 m (740 ft) at the Clinch River to about 413 m (1356 ft) at the crest of Melton Hill. The succession of alternating ridges and valleys in the ORNL site area, in order from the Clinch River in the southeast to the northwest is as follows: Copper Ridge, Melton Valley, Haw Ridge, Bethel Valley, and Chestnut Ridge. Figure 3.2, a topographic map of the ORNL site and vicinity, illustrates these valley and ridge relationships.

The central site facilities lie in Bethel Valley. The remainder of the facilities, including ORNL's solid and liquid radioactive waste disposal areas, are in Melton Valley. The site and buffer zone, encompassing 3550 ha (8771 acres), lie almost entirely within the 17 km^2 (6.5 sq miles) White Oak Creek (WOC) drainage basin.

3.1.2 Stratigraphy, Structure, Tectonics, and Seismicity

3.1.2.1 Stratigraphy

Nine geologic formations or groups ranging in age from Early Cambrian to Early Mississippian have been mapped within the Oak Ridge Reservation (ORR). All of the formations are of sedimentary origin, either chemical (limestone and dolomite) or clastic (sandstone and shale). From oldest to youngest they include the Rome formation, the Conasauga group, the Knox group, the Chickamauga limestone, the Sequatchie formation, the Rockwood formation, the Chattanooga shale, the Maury formation, and the Fort Payne chert. Table 3.1 is a generalized geologic section of the bedrock formations in the Oak Ridge area. Figure 3.3 is a geologic map of the ORR showing the strike of the strata and the major faults.[3]

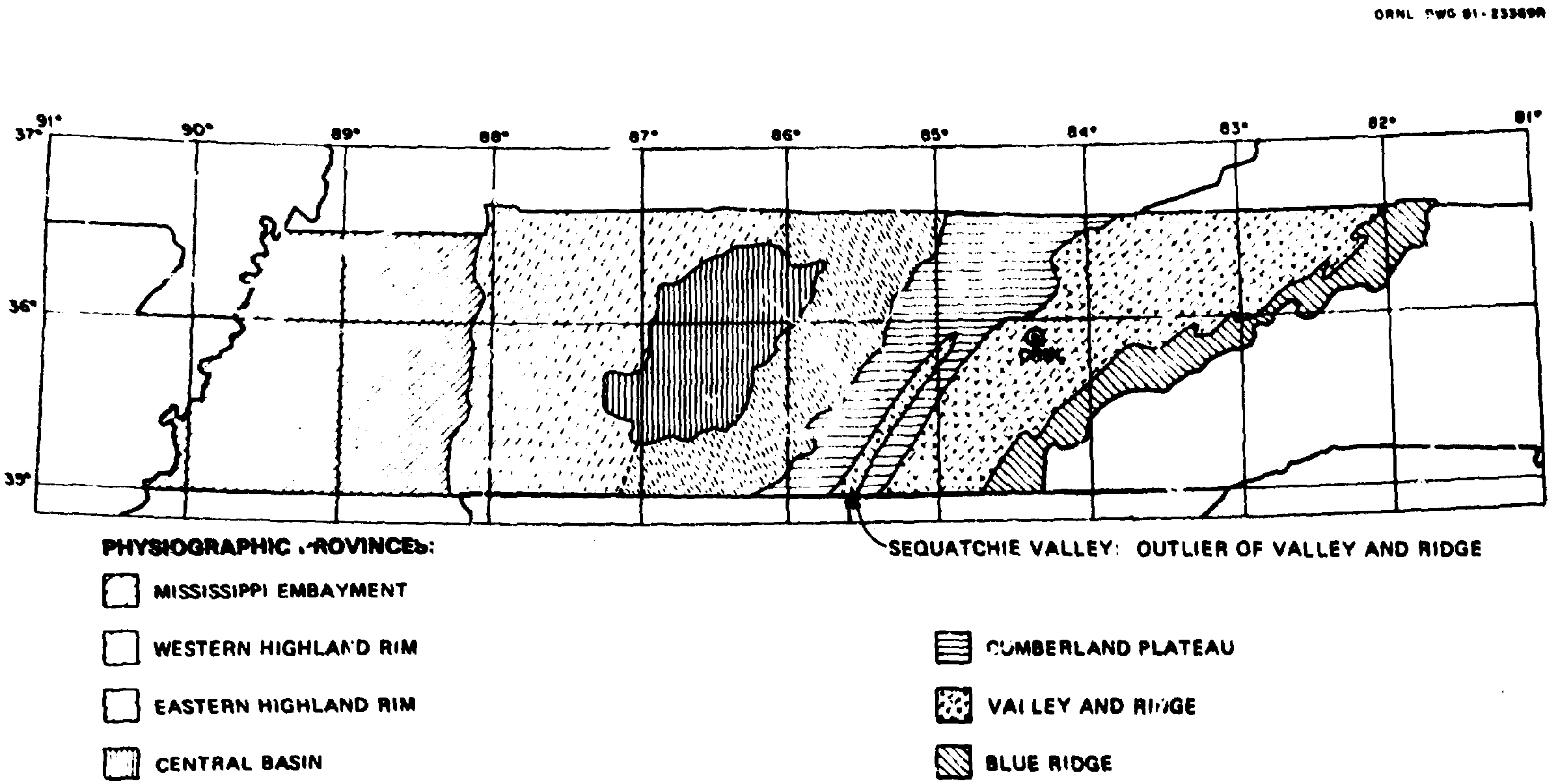

Fig. 3.1. Physiographic map of Tennessee. Source: R. A. Miller, *The Geologic History of Tennessee*, Tennessee Division of Geology, Bul. 74, Nashville, Tenn., 1974.

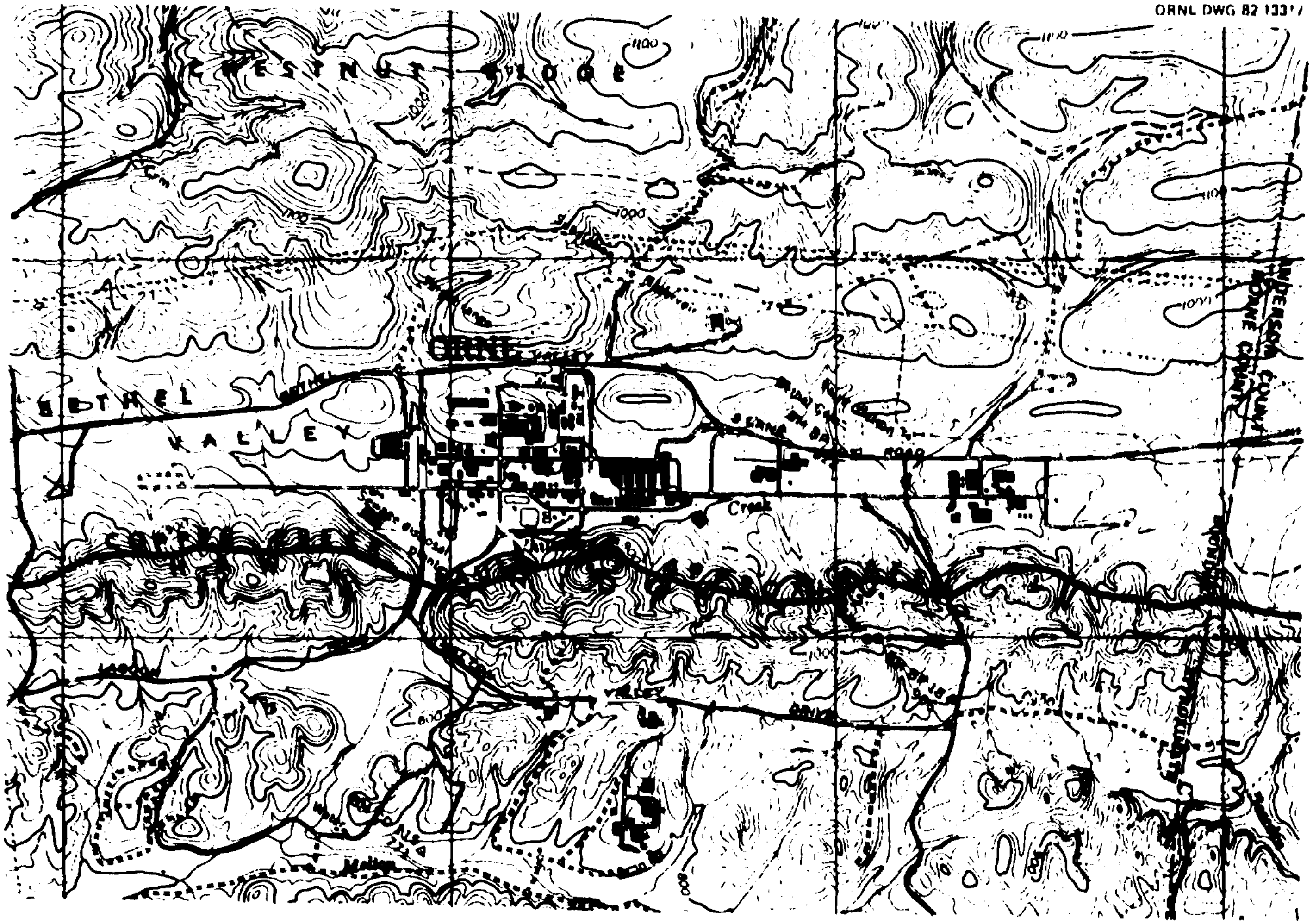

Fig. 3.2. Topographic map of ORNL site. Source: Tennessee Valley Authority, Maps and Survey Branch, prepared for Oak Ridge Operations Office, U.S. Atomic Energy Commission, June 1974 (modified).

Table 3.1. Generalized geologic section of the bedrock formations in the Oak Ridge area

System	Group	Formation	"Member" or Unit	Thickness (m)	Characteristics of rocks
Mississippian		Ft. Payne "chert"			Impure limestone and calcareous siltstone, with much chert
	?	Chattanooga Shale & Maury Formation			Shale, black, fissile
Devonian					
Silurian					
	Rockwood group	Brassfield		310+	Shale, sandy shale, sandstone; calcareous; red, drab, brown
		Sequatchie			
Ordovician			?		
	Chickamauga group		H	90	Limestone, shaly limestone, calcareous siltstone, and shale; mostly gray, partly maroon; with cherty zones in basal portions
			G	90	
			F	8	
			E	115	
			D	50	
			C	35	
			B	65	
			A	75	
	Knox group			800	Dolomitic limestone; light to dark gray; with prominent chert zones
Cambrian	Conasauga group	Maynardville Limestone		450	Shale; gray, olive, drab, brown; with beds of limestone in upper part
		Conasauga Shale	Pumpkin valley		
		Rome Formation		310+	Sandstone and shale; variegated with brilliant yellow, brown, red, maroon, olive-green; with dolomitic limestone lenses

Source: P. B. Stockdale, Geologic Conditions of the Oak Ridge National Labor..ory (X-10) Area Revelant to the Disposal of Radioactive Waste, ORO-58, Oak Ridge Operations, Oak Ridge, Tenn., Aug. 1, 1951, Plate II.

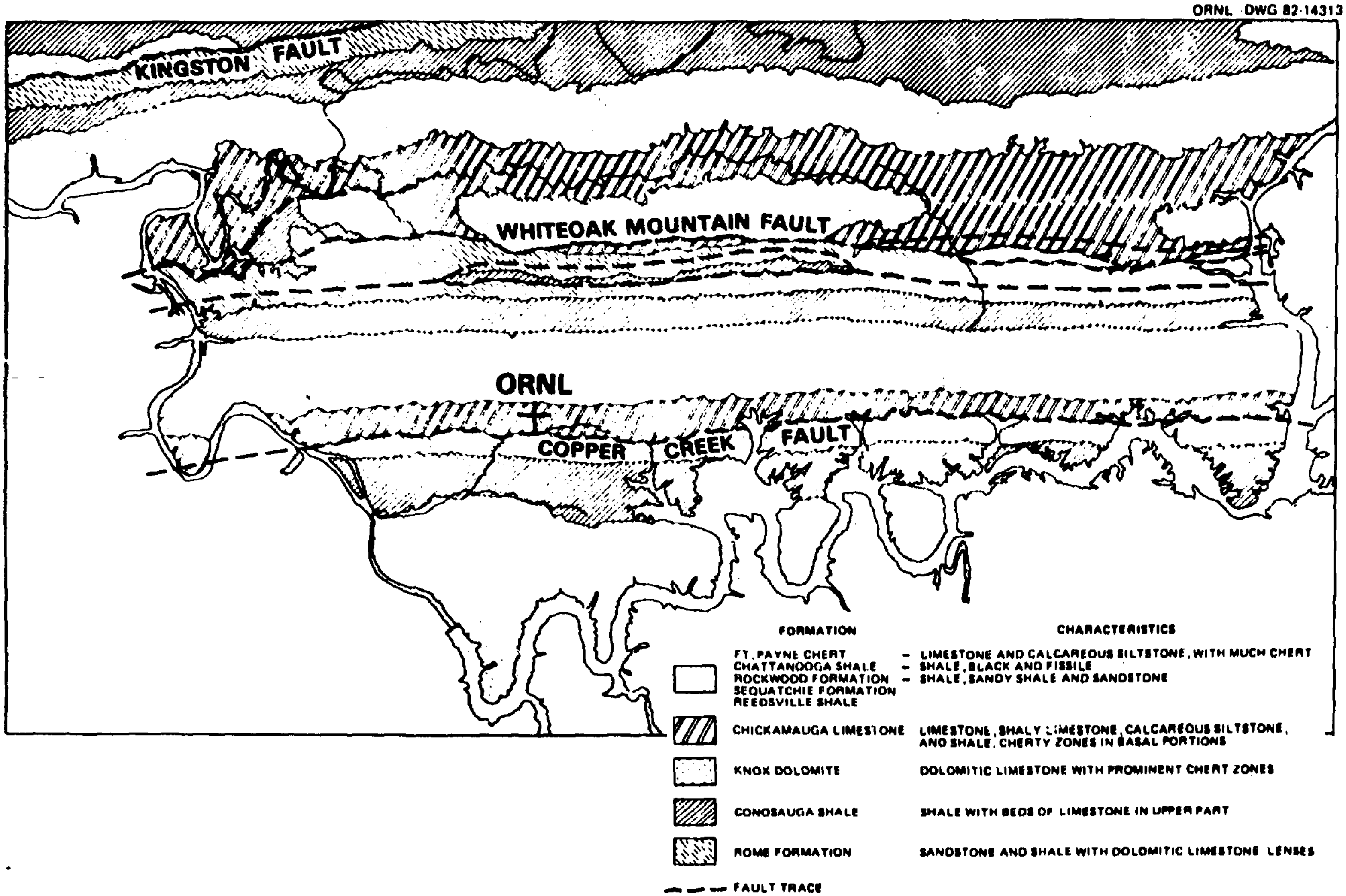

Fig. 3.3. Geologic map of the Oak Ridge Reservation. Source: W. M. McMasters, *Geologic Map of the Oak Ridge Reservation, Tennessee*, ORNL/TM-713, Oak Ridge National Laboratory, Oak Ridge, Tenn., November 1963.

Of the nine units mapped within the reservation, four underlie the WOC drainage basin. From northwest to southeast these are (1) the Knox group, a predominantly dolomite strata of Cambrian and Ordovician ages underlying Chestnut Ridge to the north and Melton Hill and Copper Ridge to the south; (2) the Chickamauga limestone of Ordovician age, which underlies Bethel Valley; (3) the Rome formation, a shale, siltstone, and sandstone unit of Cambrian age which underlies Haw Ridge; and (4) the Conasauga group, Cambrian-age shales interbedded with limestones and siltstones that underlie Melton Valley. The rock is generally covered by a mantle of residual material, in places more than 30 m (100 ft) thick. Soils developed on the Rome, Conasauga, and Chickamauga are generally thin [less than 5 m (16 ft) except somewhat thicker where shale is deeply weathered]. Knox residuum is generally thick but irregular. Appendix B presents a summary description of the four major rock units in the vicinity of ORNL.

3.1.2.2 Structure

The western part of the Tennessee section of the Valley and Ridge Physiographic Province is structurally characterized by major subparallel thrust faults that trend northeast and dip southeast. During the Late Paleozoic era, relatively flat-lying marine sediments were subjected to uplift and compressional forces originating from the southeast. The strata reacted to the pressure by developing faults and folds. Along most of these faults, the Rome formation has been thrust over younger formations. The principal structural features of the ORNL site area are the strata that strike approximately N 56° E and dip southeast at angles commonly between 30 and 40° and two major thrust faults: the Copper Creek Fault and the Whiteoak Mountain Fault (Fig. 3.3).

Copper Creek Fault. The Copper Creek Fault extends northeastward across the entire width of Tennessee, bringing the Rome formation to the surface throughout its length. In the Oak Ridge area the trace of the fault appears along the northwestern flank of Haw Ridge (Figs. 3.2 and 2.12) The ORNL site straddles the trace with the main ORNL complex lying to the north and the waste disposal facilities of Melton Valley to the south.

In the site area, the Rome formation was thrust over younger rocks of the Chickamauga group for a horizontal distance estimated to be in kilometers. The stratigraphic displacement is approximately 2200 m (7200 ft). About 105 km (65 miles) southwest of the site, the fault becomes a complex zone and merges with the Whiteoak Mountain Fault.

Whiteoak Mountain Fault. In the Oak Ridge area, the Whiteoak Mountain Fault is a complexly branching thrust fault along which lower shales of the Rome formation have been thrust over Middle Cambrian and younger rocks. The Whiteoak Mountain Fault originates about 6 km (4 miles) northeast of the ORR near Clinton by the merging of the Hunter Valley and Wallen Valley faults and extends southwestward across the state.

The nearest trace of the Whiteoak Mountain Fault system is 3 km (2 miles) north of the site. Data from outcrops and deep bore holes in the vicinity of the site indicate that the Whiteoak Mountain Fault and its subsidiaries are deeper than 610 m (2000 ft) at the site. No evidence of post–Paleozoic displacement exists along either the Whiteoak Mountain or Copper Creek fault systems.

3.1.2.3 Tectonics and seismicity

Regional tectonics. Tectonic forces, directed toward the northwest, deformed the rocks of the Appalachian geosyncline late in the Paleozoic era. In the Piedmont and Blue Ridge provinces, deformation was the largest, and rocks were metamorphosed and injected with magma. This area was thrust to the northwest along boundary faults such as the Great Smoky Fault. The result of this thrusting was the shingling of the Valley and Ridge boundary into a series of thrust sheets. It is generally accepted that these thrust sheets do not extend into the basement but are bounded at depth by a lateral sole fault (Fig. 3.4). This sole fault is assumed to be in some readily deformable formation above the crystalline basement. Figure 3.4 shows a cross section within the Valley and

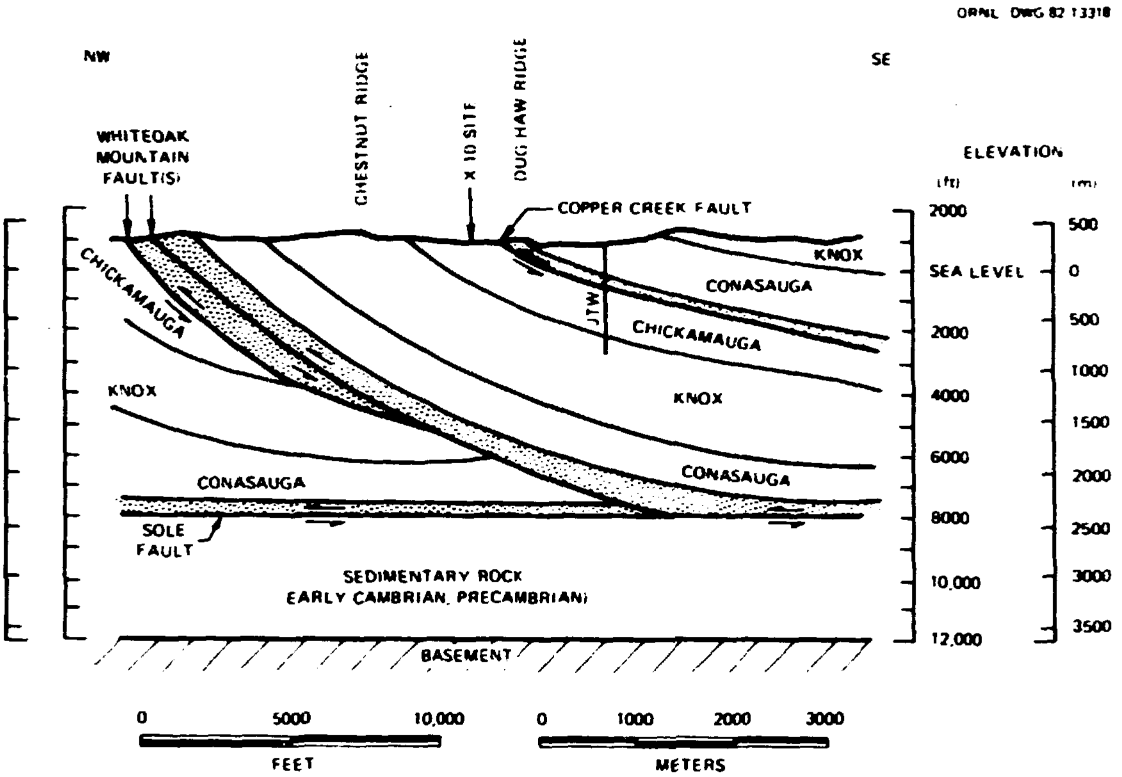

Fig. 3.4. Area geologic cross section, ORNL site. Source: *Clinch River Breeder Reactor Plant Environmental Report*, vol. 1, Docket No. 50-537, Project Management Corporation, April 1975, Fig. 2.4-10.

Ridge Physiographic Province indicating the sole fault to be at a depth of 2700 m (9000 ft) and the crystalline basement to be 4000 m (13,000 ft).[1]

Because the youngest stratigraphic units mapped in the Valley and Ridge Physiographic Province of southern Appalachia are of Pennsylvanian age, geologists believe that all the structural features of the primary Appalachian system were formed by the end of the Paleozoic era during what is now called the Appalachian Revolution. Although numerous faults exist within the area, they all originated during that orogenic period; apparently, major tectonic activity ceased completely thereafter. No physiographic evidence indicating tectonic activity, such as stream offsets, displacement of alluvial deposits, or dislocations of Plio-Pleistocene terrace materials, has been observed along any of these thrust-fault areas. Consequently, there is no reason to expect current or future translocations of these tectonic relics.[3,4,5]

Seismic History. Recent seismic events that were capable of producing a shock in the Oak Ridge area and that were recorded in the literature since 1800 are listed in Appendix B, Table B.1. Data for the older earthquake incidents are largely estimates extrapolated from nonspecific newspaper reports. In addition, these nineteenth century records generally show a definite bias toward earthquakes of higher intensity, an attitude that reflects the inherent limitations of intensity measurements during that period. The inability to record low-intensity earthquakes (no instrumentally recorded earthquakes) also explains the fewer tectonic incidences recorded in the earlier time interval. Some moderate-intensity earthquakes of the nineteenth century almost certainly went unreported because the region was sparsely populated at that time.

The more recent seismic records indicate that the Appalachian region extending from Chattanooga to southwestern Virginia averages one to two earthquakes per year. This seismic activity is not uniform but consists of extended periods with no shocks followed by a burst of earthquakes. The maximum shock experience in the Oak Ridge area was of intensity VI on the Modified Mercalli scale (MM), recorded on March 28, 1913.[5] Great distant earthquakes, such as the New Madrid series of 1811 and 1812 and the Great Charleston Earthquake of 1886, have affected the site with intensities greater than or equal to the maximum intensity of shocks involving regions that surround the site.[4] From a plot made on a map of the southeastern United States (Fig. 3.5) of the epicenters of earthquakes, the areas of continuing seismic activity can be identified.[6] The following are the four areas of major current tectonic mobility:

1. The Mississippi Valley encompasses the New Madrid region of Arkansas, Kentucky, Missouri, and Tennessee. This seismic province includes the epicenter of the great series of New Madrid earthquakes, which repeatedly attained an MM intensity of XII. This area lies more than 400 km (250 miles) northwest of ORNL. The New Madrid quakes attained an intensity of V to VI in the Oak Ridge area.
2. The Lower Wabash Valley is located in the southern regions of Illinois and Indiana. A southern Illinois earthquake of MM intensity VII in 1968 was felt over a 1,000,000-km^2 (400,000-sq-mile) area including a mild shock of intensity II to III in the Oak Ridge vicinity. ORNL lies more than 370 km (230 miles) southeast of this region of active seismicity.
3. Charleston, South Carolina, was the site of one of the greatest historic earthquakes experienced in the eastern United States. The August 31, 1886, shock of MM intensity IX was felt over the entire eastern coast and registered an intensity of V to VI in the Oak Ridge region. Recurrent seismic activity continues in this area, which is 520 km (325 miles) southeast of ORNL.
4. The Appalachian Mountains of eastern Tennessee and western North Carolina are centers that exhibit moderate seismic activity at the frequency of one to two shocks per year. Part of this seismic area lies only 80 km (50 miles) east of the ORNL site and accounts for most of the seismicity native to the eastern Tennessee region.

As discussed previously, no correlation has been observed between recorded earthquakes on the ORR and superficial tectonic structures of the Valley and Ridge Physiographic Province. During historic times, the zone of relatively high seismicity in the adjacent Blue Ridge Physiographic Province has involved only movements of low intensity that probably represent minor adjustments of highly disturbed rock formations.[6]

Algermissen prepared a seismic-risk map of the United States (Fig. 3.6) to assist in establishing design requirements for buildings in various regions of the country.[6] Seismicity ratings were based either on a historical earthquake of considerable intensity or on frequency of seismic incidences regardless of intensity. The ORR lies in what Algermissen designated as Seismic Zone 2, which is an area of moderate activity.

Algermissen and Perkins provide probabilistic estimates for the frequency of occurrence of earthquakes of a given horizontal acceleration.[7] It must be emphasized that their estimates apply only to foundations that are coupled to bedrock. For foundations coupled to bedrock at any location within the southern Appalachian region (e.g., ORNL), there is a 10% probability that the horizontal acceleration will exceed 7% of gravity (equivalent to an MM intensity of VII) in a 50-year period. The equation $\log a = (I/3) - (1/2)$ is a universally recognized empirical relationship between horizontal acceleration (a) and MM intensity (I).[8] Accordingly, a horizontal acceleraton of 70 cm/s^2 (27.6 in./s^2) (7% of gravity) is equivalent to an MM intensity of VII.

Algermissen and Perkins' probabilistic estimate agrees reasonably well with the seismic history of the ORNL site. Appendix B, Table B.1 lists five earthquakes in the last 165 years that produced an MM intensity of V to VI within the vicinity of Oak Ridge. During the same time interval, no earthquakes of MM intensity VII or higher were reported. Intensity VII earthquakes occur approximately one order of magnitude less frequently than intensity V to VI earthquakes. This suggests a recurrence interval on the order of 300 to 1000 years for intensity VII earthquakes, an estimate that is consistent with Algermissen and Perkins' probabilistic estimate (a 10% probability of occurrence in a 50-year period is equivalent to a 500-year recurrence interval).

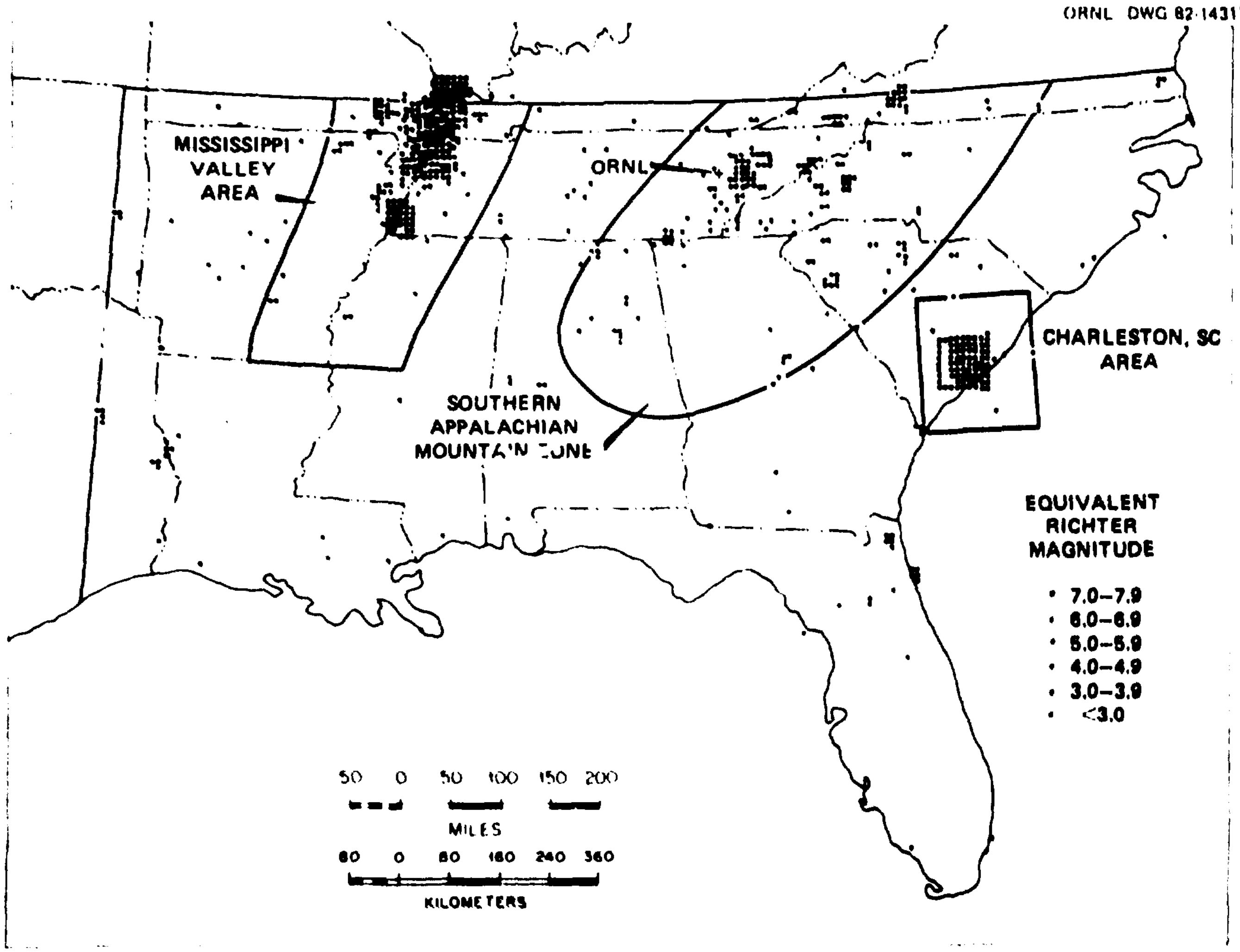

Fig. 3.5. Epicenter locations for all earthquake events in the seismic history of the southeastern United States. Source: W. C. McClain and O. H. Meyers, *Seismic History and Seismicity of the Southeastern Region of the United States*, ORNL-4582, Oak Ridge National Laboratory, Oak Ridge, Tenn., June 1970, Fig. 1.

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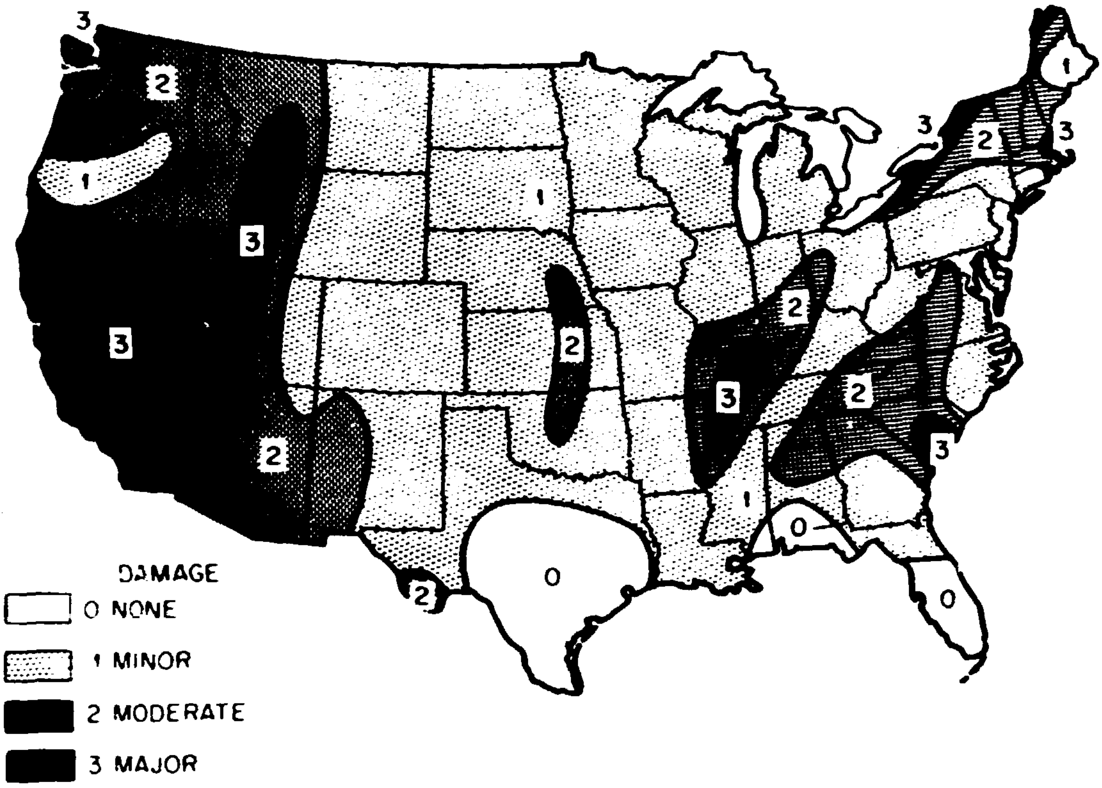

Fig. 3.6. Seismic risk map of the United States. Source: S. T. Algermissen, "Seismic Risk Studies in the United States," pp. 14–27 in *Proceedings of the 4th World Conference on Earthquake Engineering, Santiago de Chile, January 13–18, 1969*, vol. 1, 1969.

Damage caused by intensity VII earthquakes is not severe. Examples of damage to be expected are (1) weak chimneys broken off at the roof line; (2) damage to weak masonry of low standards of workmanship; (3) some cracks in masonry of ordinary workmanship; (4) fall of plaster, loose bricks, and stones; and (5) damage to concrete irrigation ditches.[8]

Although the Oak Ridge area experiences a moderate level of seismic activity, no incidence of surface deformation has been documented. Earthquakes of the types that occur within the region are common throughout the world. The shocks are of normal focus—40 to 50 km (25 to 30 miles) deep. It is highly improbable that a shock of major intensity will occur in the Oak Ridge area for several thousand years. Forces from more seismically active areas will probably be dissipated by distance.

3.1.3 Soils

This section describes the soils that are associated with the different geologic units occurring in the ORNL site area. Appendix B, Table B.2 gives a brief description of physical properties, identifying characteristics, and genetic relationships of the soils in the area. Figure 3.3 is a geologic map of the parent materials from which these soils are derived.

The soils occurring in the ORNL vicinity belong generally to the broad group of ultisols, formerly called red-yellow podzolic and reddish brown lateritic soils. Entisols (formerly lithosols), thin surface soils over bedrock showing little development of soil horizons, are found locally in steeply sloping areas. Small areas of inceptisols are found in alluvial areas adjacent to streams.

Ultisols develop in humid climates of the temperate to tropical zones on old or highly weathered parent material under forest or savannah vegetation. In general, soils in this area are moist, strongly leached, acid in reaction, low in organic matter, and have exchange capacities less than 10 milliequivalents per 100 g (0.22 lb) of soil. However, locally, soils within the area exhibit a wide range of both physical and chemical properties.

3.1.3.1 Physical properties

Depth of the soil profile varies from 15 cm (6 in.) in some of the shale and sandstone areas to depths of 5 m (15 ft) or more in some of the dolomitic limestone areas and alluvial deposits along drainageways. Texture of the surface is predominantly silt loam or cherty silt loam. But in eroded areas, such as commonly found in the Bland soils, the surface may be a silty clay. Texture of the subsoil ranges from cherty silt loam (Bodine soils) to a firm, plastic clay (Talbott and Colbert soils). Entrance of surface water into the soil profile varies from rapid [up to 25 cm/h (10 in./h)] in Bodine soils to slow [less than 5 mm/h (0.2 in./h)] in eroded Colbert and Bland soils. Internal soil drainage ranges from poorly drained in Melvin series to excessively drained in the Bodine and Muskingum series. Other soils such as Pace and Leadvale have fragipan layers [occurring at 60 to 75 cm (24 to 30 in.) in depths] which impede the downward percolation of soil water.

3.1.3.2 Chemical properties

The pH of these soils ranges from nearly neutral in the Bland and young alluvial soils to strongly acidic in some of the weathered upland shale and sandstone soils such as Litz and Lehew. However, pH generally ranges from 4.5 to 5.7 in residual soils of the Oak Ridge area.

The initial rate and direction of movement of many ions (including radionuclides) are largely controlled by the physical properties of a soil system, especially if the contaminant is in the form of a surface application. The chemistry and mineralogy will serve as a modifier to the effect of the physical properties through their chemical capacity in selectively removing certain ions or radionuclides from the soil solution.

The soils derived from the Knox group contain kaolinite as their principal clay mineral. Those from the Conasauga group contain illite and vermiculite as principal clay minerals. The soils derived from the Chickamauga limestone contain a mixture of kaolinitic and illitic minerals with some units probably having a significant amount of montmorillonitic clay minerals. The clay minerals are undersaturated with bases, leaving H^+ in the exchange positions of the clay. Base saturation varies from less than 10% to more than 60%. Generally illitic and vermiculitic clay minerals are more efficient in fixation of potassium and other comparable ions into less available positions than are the kaolinitic minerals. The total amount of fixation will depend on such factors as available surface area (as opposed to area available only through solid state diffusion) and on the thickness of the soil column.

3.2 HYDROLOGY

3.2.1 Description of Surface Streams

3.2.1.1 Tennessee and Clinch rivers

Water that drains from the U.S. Department of Energy (DOE) ORR enters the Clinch River and is subsequently conveyed to the Tennessee River (Fig. 3.7). The Tennessee River is the seventh largest in the United States and drains 105,000 km^2 (40,900 sq miles) including approximately 80% of Tennessee and regions of Alabama, Kentucky, Mississippi, Georgia, Virginia, and North Carolina. Flow in this river system is regulated by the Tennessee Valley Authority (TVA) using 9 multipurpose impoundments on the Tennessee River and 26 dams on tributaries.

The Clinch River originates in southwestern Virginia near Tazewell, Virginia, and flows 560 km (350 miles) to join the Tennessee River at Kingston, Tennessee. The river drains 11,340 km^2 (4410 sq miles), 11% of the Tennessee River watershed. Three dams control the Clinch River's

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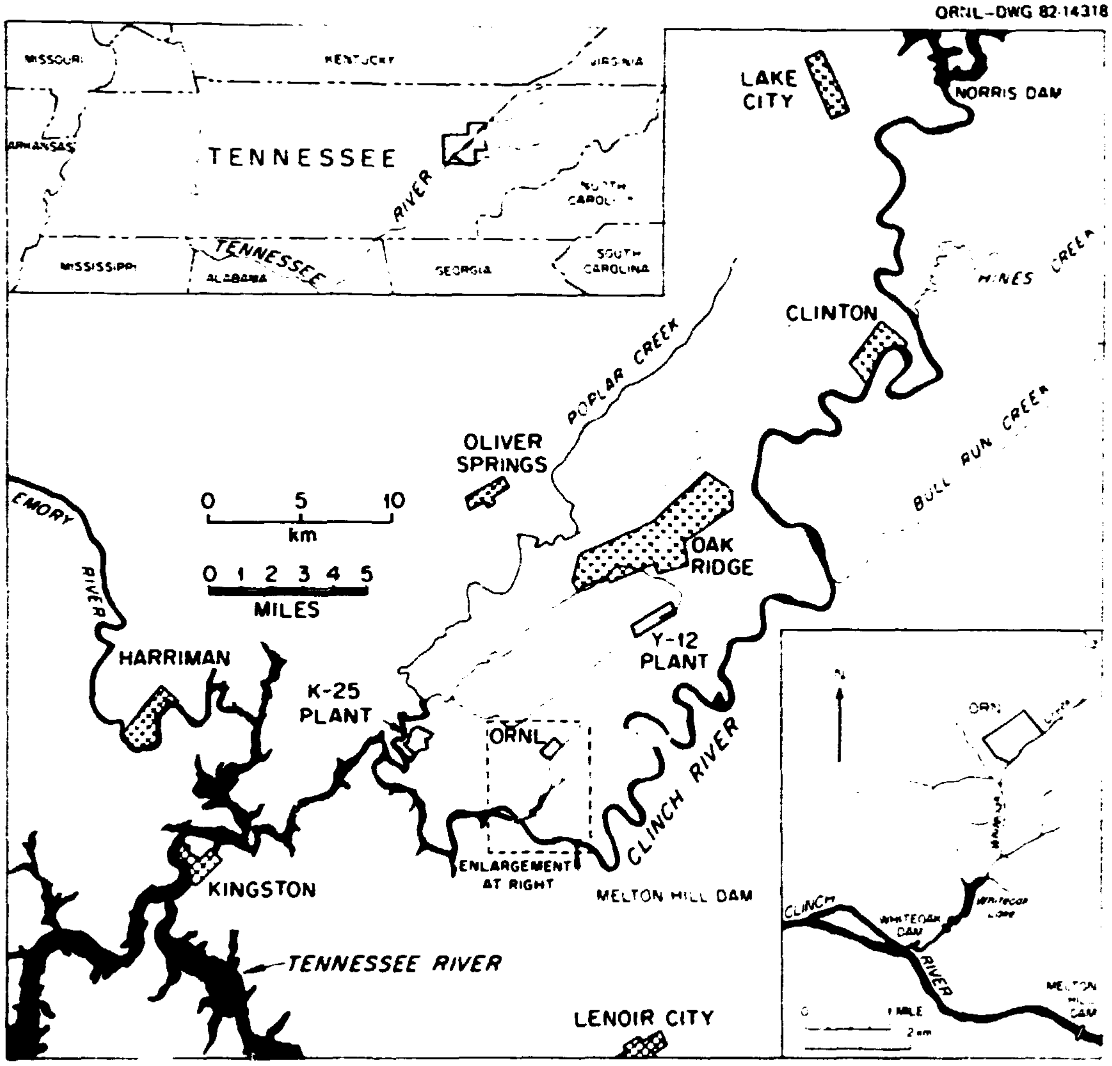

Fig. 3.7. Map showing White Oak Creek relationships to Clinch and Tennessee rivers. Source: R. J. Pickering, *Composition of Water in Clinch River, Tennessee River, and White Oak Creek as Related to Disposal of Low-Level Radioactive Liquid Wastes*, U.S. Geological Survey Professional Paper 433-J, 1970, modified Fig. 1.

flow: Norris Dam, 129 km (80 miles) upstream from the mouth at Clinch River Mile (CRM) 79.9; Melton Hill Dam, 37 km (23 miles) from the mouth (CRM 23.1); and Watts Bar Dam on the Tennessee River, 61 km (38 miles) downstream from the mouth of the Clinch River at Tennessee River Mile (TRM) 529.8.

Norris Dam, built in 1936, is about 50 km (31 miles) upstream of the ORR. The dam provides flood control, regulates flow, has a head of 81 m (265 ft) and a generator capacity of 100 MW, and creates one of TVA's largest storage reservoirs [with a useful storage volume of 2.37 $\times$ 10^9 m^3 (1.92 $\times$ 10^6 acre-ft)].

Melton Hill Dam has approximately 15 m (50 ft) head and creates a reservoir that extends 71 km (44 miles) upstream. The dam was completed in 1963 and provides power production (72 MW), navigation, recreation, some low-flow regulation, but little flood protection; Melton Hill Reservoir has a useful controlled storage of 3.9 $\times$ 10^7 m^3 (3.2 $\times$ 10^4 acre-ft), about 2% that of Norris

Reservoir. Melton Hill Reservoir forms the eastern and southern boundaries of the ORR. Normal pool elevation is 241 m (790 ft), and it is possible to lower the water level to about 230 m (754 ft). Watts Bar Dam on the Tennessee River creates backwaters on the Clinch that extend to Melton Hill Dam, forming the southwestern and western boundaries of the DOE property. The dam has a head of 34 m (112 ft) and 72 MW of generating capacity. TVA completed Watts Bar Dam in 1942 and maintains pool elevation between 225.5 and 225.8 m (740 and 741 ft) from mid-April through September and fall and winter water levels between 224 to 224.6 m (735 to 737 ft).

3.2.1.2 Clinch River tributaries

The largest tributaries of the Clinch are the Powell and Emory rivers. The Powell arises northwest of the headwaters of the Clinch, flows parallel to the Clinch, receiving water from a 2420-km^2 (934-sq mile) area, and intersects the Clinch above Norris Dam at Clinch River Kilometer (CRK) 143 (CRM 88.8). Northwest of the reservation, the Emory River drains a basin of 2240 km^2 (865 sq miles) before joining the Clinch at CRK 7 (CRM 4.4) near Kingston.

The ORR is composed of a series of limited drainage basins through which small streams traverse and ultimately reach the Clinch River (Fig. 3.8). These watersheds generally fall 183 m (600 ft) from the ridge crests to their mouths. Table 3.2 gives the location and drainage areas of the major watersheds on the reservation.

The WOC basin of 16.4 km^2 (6.37 sq miles) includes Bethel Valley (site of most ORNL facilities) and Melton Valley (site of additional facilities and disposal areas for radioactive wastes). Elevations in the watershed range from 372 m (1220 ft) at the crest of Chestnut Ridge to 226 m (741 ft) at the creek mouth at CRK 33.5 (CRM 20.8). The primary tributary of WOC is Melton Branch, joining the main stream at White Oak Creek Kilometer (WOCK) 2.49 or White Oak Creek Mile (WOCM 1.55). The waters of WOC are impounded by White Oak Dam located 1.0 km (0.6 mile) above the stream mouth. The dam is an earthen structure about 4.6 m (15 ft) high with a steel cofferdam and gate built as a highway fill where White Wing Road (Tennessee State

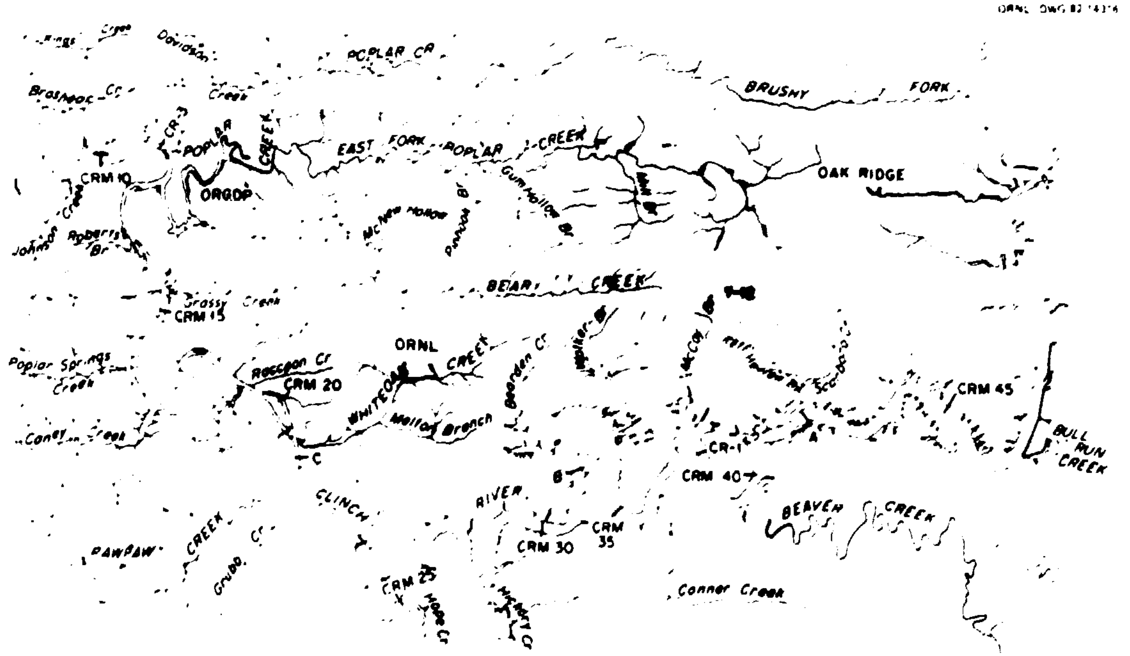

Fig. 3.8 Map showing surface waters of the Oak Ridge area. Source: *Environmental Assessment of the Oak Ridge Gaseous Diffusion Plant Site*, U.S. Department of Energy, DOE/EA-0106, December 1979, Fig 4.4.

Table 3.2. Location and drainage areas of Clinch River tributaries

Stream	Mouth location	Drainage Area (km^2)
Emory River	CRK[a] 7.1[b]	2240[b]
Poplar Creek	CRK 19.3	352
East Fork Poplar Creek	PCK[c] 8.8	77.2
Bear Creek	EFPCK[d] 2.36	18.5
White Oak Creek	CRK 33.5	16.5
Melton Branch	WOCK[e] 2.49	3.83
Hickory Branch	CRK 45.7	17.9
Walker Branch	CRK 53.1	3.89
Conner Creek	CRK 57.1	16.6
Beaver Creek	CRK 63.7	234.4
Bull Run Creek	CRK 75.1	269
Hinds Creek	CRK 105.9	164.5
Coal Creek	CRK 120.7	94.8
Big Creek	CRK 133.5	1[illegible].3
Powell River	CRK 142.9	2429

[a]CRK = Clinch River Kilometer.

[b]Multiplier factors for converting International System of Units (SI) to English units are located on inside back cover.

[c]PCK = Poplar Creek Kilometer.

[d]EFPCK = East Fork Poplar Creek Kilometer.

[e]WOCK = White Oak Creek Kilometer.

Source: TVA Division of Water Control Planning, Hydraulic Data Branch, Drainage Areas for Streams in the Tennessee River Basin, Report 0-5829, Chattanooga, Tenn., May 1958.

Highway 95) crosses the creek. White Oak Dam was constructed in October 1943 to regulate the dispersion of radionuclides and chemical pollutants discharged from ORNL. The dam has recently been reinforced, and a new sluiceway is being installed. White Oak Lake is now a standing pool that can function as an emergency storage pond in the event of a major accidental release of contaminants.

The 12-km (7.4-mile) drainage basin of Bear Creek begins at the southwestern boundary of the Y-12 Plant. This creek meanders westward through Bear Creek Valley and then flows northwest to join East Fork Poplar Creek. The catchment is about 65% wooded; the remainder consists of [illegible] field. Although the creek does not serve as a watershed for the main site of the Y-12 Plant, drainage from waste disposal and refuse areas serving the Y-12 Plant, ORNL, and Oak Ridge Gaseous Diffusion Plant (ORGDP) are collected in this basin.

The Walker Branch watershed is currently being used by the ORNL Environmental Sciences Division in experiments on nutrient cycling in an undisturbed ecosystem;[9] consequently, it has been the subject of detailed hydrological analysis.[10-12] The drainage basin lies 3.6 km (2.6 miles) northeast of the X-10 site and originates on Chestnut Ridge.

3.2.1.3 Flow characteristics

Clinch River. Flow in the Clinch River is highly regulated by releases from Norris Dam and Melton Hill Dam. Surface water flows are measured by TVA at both dams. At the mouth of WOC, the Clinch River's flow is primarily influenced by discharges from Melton Hill Dam, although the actual water level at this point is regulated by both Watts Bar Dam and discharges from Melton Hill.

The average discharge from Melton Hill Dam from 1963 through 1979 was 150 m^3/s (5280 cfs). Average summer discharge (June through September) was 134 m^3/s (4720 cfs).[13] Except during periods of heavy rainfall, discharge from Melton Hill results mostly from power generation. Two turbines exist in the Melton Hill powerhouse. Flow through a single turbine (at normal pool elevation) results in discharge of approximately 283 m^3/s (10,000 cfs). At Melton Hill, power is typically generated to help meet peak loads. Depending on the season and the availability of water, power may be generated during mid-morning, the afternoon, or early evening. Therefore, the Clinch River below Melton Hill typically has periods of zero flow followed by one or more hours of flow at 283 to 566 m^3/s (10,000 to 20,000 cfs). The pulsatory flow pattern in the lower Clinch River affects the flow of tributaries. For example, outflow from WOC can be abruptly blocked or even reversed during power-generating releases from the dam. Between periods of water release from Melton Hill Dam, the Clinch River near the WOC confluence is an almost slack pool with its water level regulated by Watts Bar Dam.

Days of no discharge from Melton Hill are not uncommon. Continuous periods of no flow have extended as long as 29 days in 1966, 11 days in 1967, and 8 days in 1968. These resulted primarily from attempts to control aquatic weed growth in Melton Hill Reservoir. Statistics on periods of zero discharge between 1963 and 1972 (Table 3.3) indicated that, on the average, almost 13 single days of no release occurred annually, and 3-d periods of no release occurred more than twice per year.[14]

Under certain operating conditions at Watts Bar, Fort Loudoun, and Melton Hill dams, flow reversals can occur in the Clinch River.[14] In connection with the proposed synfuel facility, TVA performed a special study to measure velocities at CRK 23.3 (CRM 14.5) during August 1981. The measurements taken suggest that the flow reversals are of short duration and low magnitude.[13]

Table 3.3 Periods of zero-release from Melton Hill Dam (May 1963 through October 1972)

Consecutive days of zero release	Number of occurances
1	114
2	73
3	22
4	9
5	2
>5	5

Source: Data from Table 2.5.2, Project Management Corporation, Clinch River Breeder Reactor Plant Environmental Report, Vols. I-III, Docket No. 50-537, April 1975.

White Oak Creek. Originating on the forested slopes of Chestnut Ridge, WOC flows southwest through Bethel Valley (Fig. 3.8); these areas are underlain by the Knox dolomite and Chickamauga limestone respectively. These two formations are water bearing, and discharge from the Knox is the main source of base flow in the creek.[15,16] After flowing through the main ORNL site, the creek passes through a gap in Haw Ridge (Rome formation) and enters Melton Valley, underlain by the Conasauga shale. These two formations have low yield and contribute little to the creek's base flow. Since much of the WOC basin is underlain by the Rome and Conasauga formations, base flow in the creek is generally low and has been observed to drop to zero (Table 3.4). Discharges from ORNL's wastewater treatment systems substantially augment the dry weather flow of WOC.

After flowing through the gap in Haw Ridge, WOC is joined by Melton Branch, and about 0.5 km (0.3 mile) downstream it enters White Oak Lake. The water level of the lake is controlled by a vertical sluice gate, which remains in a fixed position during normal operations. White Oak Lake is a small, shallow impoundment, and its water level will fluctuate because of storm events or prolonged rainfall. Normal lake level since 1960 has been 227 m (745 ft) above mean sea level (msl), creating a pool surface area of approximately 9.8 ha (24 acres)[17] with approximately a 2-d retention time.[18]

Because of potential leakage and suspected instability of White Oak Dam, White Oak Lake's water level was gradually lowered 0.9 m (3 ft) to an elevation of 226.2 m (742 ft) in November 1979. At this water level White Oak Lake has a surface area of 4.6 ha (11.5 acres) and a retention time of less than 24 h.[18] Construction of a berm to stabilize the dam was completed in March 1980, and work on a new larger sluiceway is in progress. The new sluiceway will have a design capacity of 56.6 m^3/s (2000 cfs), thus accommodating the discharge calculated as the maximum possible flood. The new sluiceway will also have a dual system of weirs that will allow accurate flow measurement and sample collection over the full range of discharge. Like the existing sluiceway, the new structure will have floodgates to allow temporary impoundment of flow in the event of an accidental spill. Upon completion of the new weirs, it has been recommended that White Oak Lake's level be returned to 227 m (745 ft).[17]

In the portion of WOC from the dam to the mouth, water levels are affected by the Clinch River's stage. During summer months (mid April through October), Watts Bar Reservoir's pool elevation creates a backwater that extends upstream to White Oak Dam. This portion of the creek is referred to as the WOC embayment,[18] and because its flow is externally regulated, the WOC watershed is generally considered to be the 15.5-km^2 (5.98-sq-mile) area above the dam.[19] During the winter months, the embayment resembles a large mudflat. During summer months, the embayment is subject to daily water level fluctuations (usually <0.5 m or 1.5 ft) and flow reversals due to discharges from Melton Hill Reservoir.[18] On numerous occasions researchers have observed strong upstream flows of about 30 cm/s ($\sim$1 ft/s) in the embayment. These flows usually subsided within 15 min and were followed by strong downstream flows of similar duration.

Flood flows in the WOC basin have been extensively analyzed[19] because of concern about release of radionuclides, especially through sediment transport. Peak discharges in the watershed have not been accurately measured because the flows exceed the capacity of the weirs or gauges. Several methods of estimating flood discharge were considered.[19] The estimates obtained using the equations of Randolf and Gamble[20] (Table 3.5) are based on the longest, most current record and appear to agree most favorably with available local data. The estimated peak flows at White Oak Dam for four recent floods are presented in Table 3.6.

Values for maximum, minimum, and average flows of the reservation tributaries emptying into the lower Clinch River are given in Table 3.4. These data, collected by the U.S. Geological Survey (USGS), reflect measurements taken over limited periods of record. Based on more recent research in the WOC basin,[19] it is believed that the reported maxima are underestimates of flood flows.

3.2.1.4 Surface water use

Major surface water uses in the Oak Ridge area include withdrawals for industrial and public supplies, commercial and recreational navigation, and other recreational activities such as fishing

Table 3.4 Flow characteristics of some of the major tributaries on the Oak Ridge Reservation

Stream	Gage location	Discharge					Period of record
		Maximum		Minimum		Average (m^3/s)	
		(m^3/s)	Date	(m^3/s)	Date		
Melton Branch	MBK[a] 0.16[b]	6.85	03/11/62	0	09/02/62	0.07	1955-1963
White Oak Creek	WOCK[c] 2.65	18.2	08/30/50	0	09/16/61	0.27	1950-1953 1955-1963
White Oak Creek	WOCK 0.96	18.9	12/29/54	0	(During power releases from Melton Hill Dam)	0.38	1950-1953 1955-1963
East Fork Poplar Creek	EFPCK[d] 5.31	73.9	07/06/67	0.37	08/16/69	1.37	1960-1970
Bear Creek	BCK[e] 1.29	16.8	03/12/63	0.01	08/12-14/62		
Poplar Creek	Mouth	180	03/12/63	0.14	10/27/63	4.67	1961-1965

[a]MBK = Melton Branch Kilometer.
[b]Multiplier factors for converting International System of Units (SI) to English units are located on inside back cover.
[c]WOCK = White Oak Creek Kilometer.
[d]EFPCK = East Fork Poplar Creek Kilometer.
[e]BCK = Bear Creek Kilometer.
Source: U.S. Geological Survey Water-Supply Papers: 1276, 1336, 1386, 1436, 1506, 1556, 1626, 1706, and 1910.

Table 3.5. Estimates of flood discharge at White Oak Dam during various recurrence intervals computed from the equations of Randolph and Gamble

Recurrence interval (year)	Flow (m^3/s)	Flow (cfs)
2	13.9	490
5	22.4	790
10	28.7	1015
25	37.7	1330
50	45.0	1590
100	53.0	1870

Source: D. E. Edgar, An Analysis of Infrequent Hydrologic Events with Regard to Existing Streamflow Monitoring Capabilities in White Oak Creek Watershed, ORNL/TM-6542, Oak Ridge National Laboratory, Oak Ridge, Tenn., October 197[illegible].

Table 3.6. Data at White Oak Dam for four floods

Date	Precipation		Estimated peak discharge (m^3/s)	Estimated recurrence interval (year)
	Total (cm)	Duration (h)		
Mar. 15-16, 1973	17.3[a]	48	25.8[a]	5.7
Nov. 27-28, 1973	22.1	48	42.2	35
Apr. 2-4, 1977	14.7	41	18.7	2.3
June 7-8, 1978	9.6	48	8.07	1-1.5

[a]Multiplier factors for converting International System of Units (SI) to English units are located on inside back cover.

Source: D. E. Edgar, An Analysis of Infrequent Hydrologic Events with Regard to Existing Streamflow Monitoring Capabilities in White Oak Creek Watershed, ORNL/TM-6542, Oak Ridge National Laboratory, Oak Ridge, Tenn., October 1978.

and swimming. The Clinch River is a component of the inland waterway system which permits commercial navigation to the Gulf of Mexico. Boat traffic through the lock at Melton Hill Dam consists principally of recreational boats, with minimal barge traffic. Between 1966 and 1975 the number of barges locked through Melton Hill Dam ranged from 2 to 14 per year.[21]

Water is withdrawn from the Clinch River at three locations to supply the ORR. Makeup water for the ORGDP recirculating cooling system is withdrawn at CRK 18.5 (CRM 11.5) at a rate of 0.54 m^3/s (12.3 Mgd).[22] None of this water is used for potable purposes. At CRK 23.3 (CRM 14.5) 0.13 m/s (2.85 Mgd) of water is withdrawn from the Clinch River for potable and process purposes at ORGDP. This intake is about 10.4 km (6.5 miles) downstream of ORNL's White Oak Dam outfall.

Other major withdrawals (0.96 m^3/s or 22 Mgd) from the Clinch River to supply ORNL, the Y-12 Plant, the Comparative Animal Research Laboratory (CARL), and the city of Oak Ridge are made at CRK 66.8 (CRM 41.5). This pumping station is 10.6 km (6.6 miles) northeast of ORNL. About 16.9 km (10.5 miles) northeast of ORNL, another major user of Clinch River water is the TVA Bull Run Steam Plant, which withdraws about 25 m^3/s at CRK 76.6 (572 Mgd at CRM 47.6). Table 3.7 lists those industries withdrawing water from the Clinch or Tennessee rivers between Clinton and Watts Bar Dam.

Table 3.7. Industrial water withdrawals from the Clinch-Tennessee River System

Industrial water user	Average withdrawal rate (m^3/s)	Withdrawal source and location	River distance from mouth of White Oak Creek (km)
Withdrawals above White Oak Creek (mouth of CRK[a] 33.5)			
Modine Manufacturing Co.	0.05[b]	CRK 104.7[b]	71.2[b]
Tennessee Valley Authority, Bull Run Steam Plant	25	CRK 77.2	43.7
U.S. Department of Energy, ORNL, Y-12, CARL, and city of Oak Ridge	0.96[c]	CRK 66.8	33.3
Withdrawals below White Oak Creek			
ORGDP	0.13[c]	CRK 23.3	10.2
ORGDP	0.54[d]	CRK 18.5	15.0
Tennessee Valley Authority, Kingston Steam Plant	61.3	ERK[e] 2.9	29.6
Watts Bar Hydro plant, lock, and steam plant	0.02	TRK[f] 851.5	94.5

[a]CRK = Clinch River Kilometer.
[b]Multiplier factors for converting International System of Units (SI) to English units are located on inside back cover.
[c]Process and potable water.
[d]Cooling water makeup only.
[e]Emory River Kilometer.
[f]Tennessee River Kilometer.
Source: F. C. Fitzpatrick, Oak Ridge National Laboratory Site Data for Safety Analysis Reports, ORNL/ENG/TM-19, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1982, updated.

There are nine public water supply systems serving about 91,500 people that withdraw surface water within a 32-km (20-mile) radius of ORNL, as listed in Table 3.8. Of these nine supply systems, only one is downstream of the outfall from White Oak Dam. The intake for Kingston is located at Tennessee River Kilometer (TRK) 914.2 (TRM 568.2), about 0.6 river km (0.4 mile) above the confluence of the Clinch and Tennessee rivers and 34.1 river km (21.2 miles) below the White Oak Dam outfall. As indicated in Table 3.8, Kingston withdraws approximately 9% of its average daily supply from the Tennessee River. The city of Rockwood withdraws about 1% of its average daily supply from Watts Bar Reservoir. Its intake is located 2 km (1.3 miles) from the mouth of King Creek embayment near TRK 890 (TRM 553). The total population served by the

Table 3.8 Public supply surface water withdrawals within about 25 km of Oak Ridge National Laboratory

Public supply system	Population served (thousand)	Average withdrawal rate (m^3/s)	Withdrawal source and location	Distance from ORNL (km)
Clinton	6.2	0.03[a]	CRK[b] 106.7	25.1
Harriman	10.0	0.10	ERK[c] 20.8	21.7
Kingston	5.0	0.014[d]	TRK[e] 914.2	20.9
Lenoir City	6.6	0.04	TRK 967.5	16.6
Loudon	5.2	0.03[f]	TRK 953.0	21.7
Anderson County Utility Board	8	0.03	CRK 89.3	14.5
Cumberland Utility District of Roane and Morgan Counties	4.3	0.008[g]	LEREK[h] 3.5	14.0
First Utility District of Knox County	10.5	0.05	SCEK[i] 2.7	18.7
Hallsdale-Powell Utility District	28.7	0.07[j]	BRCEK[k] 2.1	18.2
West Knox County Utility District	15.0	0.06[l]	CRK 74.2	16.3

[a]Multiplier factors for converting International System of Units (SI) to English units are located on inside back cover.

[b]CRK = Clinch River Kilometer.

[c]ERK = Emory River Kilometer.

[d]Secondary source (9%); spring (91%).

[e]TRK = Tennessee River Kilometer.

[f]Half source (50%); spring (50%).

[g]Secondary source (5%); spring (95%).

[h]LEREK = Little Emory River Embayment Kilometer.

[i]SCEK = Sinking Creek Embayment Kilometer (Tennessee River).

[j]Primary source (70%); spring (30%) outside 25km radius).

[k]BRCEK = Bull Run Creek Embayment Kilometer (Clinch River).

[l]Primary source (90%); well (10%).

Source: F. C. Fitzpatrick, Oak Ridge National Laboratory Site Data for Safety Analysis Reports, ORNL/ENG/TM-19, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1982, updated.

public water systems using surface water supplies in the area within a 32-km (20-mile) radius of ORNL and from the Tennessee River outside that area down to the city of Chattanooga is in excess of 370,000.[21]

Recreational use of the waters in the Oak Ridge area is heavy. Surface water uses include boating, fishing, waterskiing, and swimming. There is a recreational boat-launching site just above Melton Hill Dam, and a concrete launching ramp and parking area is provided off Tennessee State Highway 95 below Melton Hill Dam. No quantitative data are currently available on the number or amount of fish caught in the tailwater area by sport fishermen for human consumption. However, the principal Clinch River species of fishes taken include crappie, largemouth bass, white bass, bluegill, channel catfish, and sauger. Some smallmouth bass, muskellunge, rockfish, and trout are also taken from the Clinch River system.[23] Forage and rough fishes, including carp and buffalofish, dominate in both number and biomass and provide a commercial fishing harvest.[24] Most of the waterskiing and swimming activity within 8 km (5 miles) of ORNL takes place above Melton Hill Dam where public facilities are provided.

3.2.2 Geohydrology

Groundwater in the Tennessee Valley Region supplies water to many rural residences for domestic use and supplies the base flow to streams and rivers. This section includes discussions of groundwater occurrence in the region, local groundwater use, and geohydrologic conditions at waste disposal facilities.

3.2.2.1 Groundwater occurrence

In the Valley and Ridge Physiographic Province of Tennessee, groundwater generally occurs either in bedrock formations or in residual soil accumulations near the bedrock surface. Alluvial aquifers are of minor importance in the region. Porosity in the shales and carbonate rocks that predominate the region is attributed to fractures and solution cavities.

The ORR is underlain by nine geologic formations or groups (Sect. 3.1.2) ranging in age from Early Cambrian to Early Mississippian. The formations are of sedimentary origin, both chemical (limestone and dolomite) and clastic (sandstone and shale). From the standpoint of occurrence in the area, the most important are the Rome formation, the Conasauga group, the Knox group, and the Chickamauga group. The others occupy relatively small parts of the area.

Information on the groundwater capacity in the sandstone and shale of the Rome formation is sparse because very few wells have been drilled in it. Although limited in number, the existing road cuts and water gaps do indicate that this stratigraphic unit has very little capacity for receiving, storing, and transmitting water.[21] In weathered bedrock the occurrence of water is largely limited to small openings that occur along joints and bedding planes. In addition, the steep terrain underlain by the Rome increases surface runoff and reduces recharge. The thin mantle of residual clay and the near-surface weathered bedrock zone's having slightly enlarged openings probably account for the greater part of water movement in the Rome.[15]

The hydrologic properties of the Conasauga group are somewhat variable because of its heterogeneous composition. Generally the ability of this group to transmit water increases with the thickness of the limestone strata. The lower two members of this geologic unit, located under Melton Valley with poor Maynardville limestone development, are practically devoid of permeability below a depth of 35 m (100 ft).[24] In these instances groundwater occurs principally in the weathered zone where openings along joints and bedding planes have been slightly enlarged by circulating water. Because these enlarged openings occur only to shallow depths, the total capacity for water storage is small.[15] When recharge is limited in summer by evaporation and transpiration losses, discharges from this groundwater reservoir are severely depleted. The more calcareous members of this formation that provide bedrock for Bear Creek Valley often contain cavities that are several meters wide and extend for at least 35 m (100 ft) below the surface.[21] The capacity to transmit water is facilitated by these numerous large solution openings, and springs are particularly common at the Knox and Conasauga interface.[25]

The Knox group is the principal aquifer of the Oak Ridge area and of East Tennessee. The extensive water-storage capacity of this geologic unit is due to fractures of bedrock enlarged by dissolution of the soluble dolomite compounds.[21] Some of these openings even attain cavernous proportions. Sinkholes occur frequently in the outcrop belts, and many sizeable springs arise from the base of the ridges. Depths to the water table reach 39 m (125 ft) at the ridge tops.[15] The position of the water table commonly coincides with the interface between bedrock and the residual clay overburden. The residual material, which is the thickest soil mantle in the area and varies in depth from 9 to 38 m (30 to 125 ft), actually provides the major basin for this unit's groundwater storage. This huge expanse of overburden has a high infiltration capacity, which also tends to minimize overland runoff while maximizing recharge.[25] In most instances, ridges underlain by the Knox also define the watershed divides of the area. The mean yield of springs and wells in the Knox group used for public and industrial water supplies is 1.7×10^{-2} m^3/s (268 gpm) (see Sect. 3.2.2.2). No estimate is available for mean well yield of domestic water wells in the Knox group.

The Chickamauga group is a poor aquifer because it contains so much shale and siltstone. This formation is practically devoid of any large solution cavities, and the only water derived from it probably permeates along the bedding planes and joint partings.[21] Although numerous small openings may occur within, but rarely beyond, 30 m (100 ft) of the surface. rates and quantity of water transport are small. Recharge is further restricted by the high clay content of the overburden.[25] The residual material is typically less than 3 m (10 ft) thick; therefore, most water input is diverted to surface runoff.

Although local, semiconfined, artesian conditions probably exist, groundwater flow on the OkR basically follows water table conditions. Hence, groundwater levels parallel topographic contours, and the water movement is from areas of high elevation to areas of low elevation. Recharge is derived primarily from precipitation, and groundwater discharge is through evapotranspiration, springs, and streams. The characteristics of the various soil series reported to be on the ORR are discussed in Sect. 3.1.3. The major soils are generally silty (grain size 0.06 to 0.002 mm) rather than sandy or clayey. They are very permeable and well drained. However, the dominant clay content of the subsoils outweighs this porosity, and the drainage of this region is characterized by low permeability and fast runoff. The extensive clay subsoils channel much of the hydrological input into surface flow.[21]

Groundwater discharge contributes to the base flow of surface streams that ultimately augment the Clinch River water supply. The Clinch River is a major drainage feature of the area, and its base flow is determined by groundwater discharges to the surface water system. The low water table elevation in areas near the river is expected to be controlled by the river level elevation. It is unlikely that significant groundwater flow could pass beneath the Clinch River except for the case of extensive well pumping on one side, which may lower the local water table.

Depth to the water table varies both spatially and temporally. At a given location, depth to water is generally greatest during the October–December quarter and least during the January–March quarter.[25]

In Bethel Valley, depth to the water table ranges from 0.3 to 11 m (1 to 35 ft), whereas in Melton Valley the range is from 0.3 to 20 m (1 to 67 ft). Seasonal fluctuations tend to be greatest beneath hillsides and near groundwater divides. As much as 4.5-m (15-ft) seasonal variation was reported for Melton Valley. A generalized map showing the range in depth to groundwater in WOC watershed during March 1963 is given in Fig. 3.9.

Water table contour maps are useful, in a general way, for estimating the direction of groundwater movement, especially in the weathered residual soil or unconsolidated materials overlying bedrock. However, direction of movement in the underlying bedrock is influenced more strongly by directional variations in permeability. Groundwater flow in the residual soil is generally toward the individual streams of the surface-drainage network. In Bethel Valley, groundwater in the Chickamauga limestone moves through small solution channels. Although the rate of groundwater flow in the area is not known, the direction and pattern of this flow on the Bethel Valley site is essentially a subdued replica of the topography. Thus, water flows from areas of high elevation to

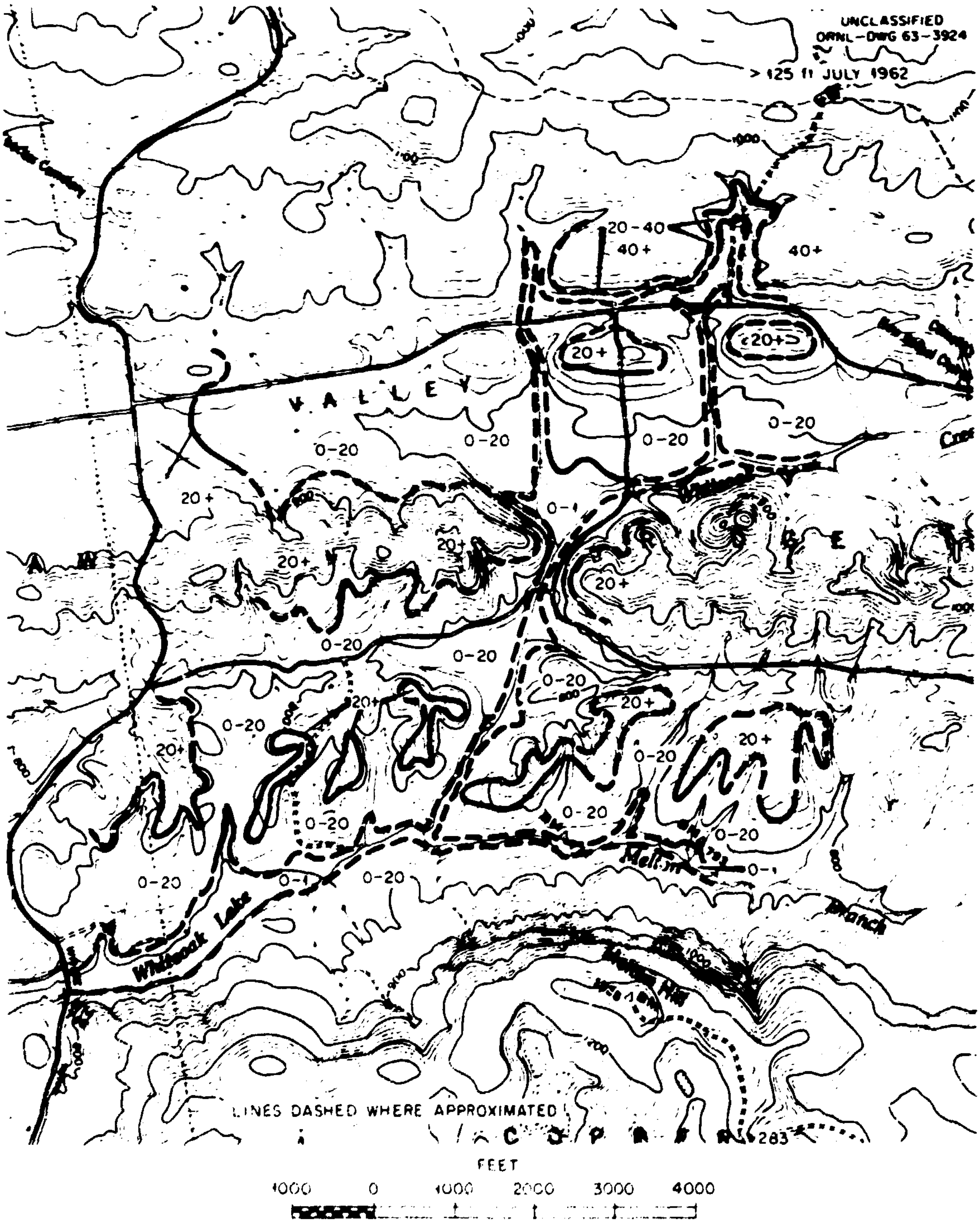

Fig. 3.9. Map illustrating general depth to groundwater in the White Oak Creek basin during March 1963. Source: *Health Physics Division Annual Progress Report for Period Ending June 30, 1963*, ORNL-3492, Oak Ridge National Laboratory, Oak Ridge, Tenn., Sept. 23, 1963.

those of low elevation, and the principal movement is in directions normal to the contour lines. The lay of the land is such that drainage at and below the surface of the Bethel Valley site apparently converges to feed WOC and White Oak Lake. An exception to this situation occurs in the western end of the Bethel Valley site where the groundwater west of a groundwater divide flows west into the Racoon Creek drainage basin rather than into WOC.

Groundwater movement in the Conasauga shale of Melton Valley has been considered in four separate investigations and reviewed by Webster.[26] Each investigation concluded that, within the study area, the primary direction of groundwater movement in the Conasauga is parallel to the strike. This observation suggests that greatest permeability in unweathered bedrock is associated with partings between beds and perhaps with residue of more soluble units. However, Webster reported that factors controlling fluid movement within the Conasauga vary with depth. He concluded that in the uppermost portion of the saturated zone, the slope of the water table (hydraulic gradient) is the primary factor controlling movement. With increasing depth, there is a change in control from the areal hydraulic gradient to control by local hydraulic head distribution within the partings, joints, fractures, or other more permeable zones within the rock. Webster also reported that the rate of movement in limestone beneath Bethel Valley is relatively slow because of the small size of solution cavities observed in drill cores and the slow recovery of wells after pumping. The best current estimate of movement rate in the Conasauga under natural conditions is about 0.17 to 1.8 m/d (0.5 to 6 ft/d) based on tracer tests performed in solid waste disposal area (SWDA) No. 6.[27]

3.2.2.2 Groundwater use

The major portion of the industrial and drinking water supplies in the Oak Ridge area is taken from surface water sources. However, single-family wells are common in adjacent rural areas not served by public water supply systems. As in most of East Tennessee, groundwater on and in areas adjacent to the ORR occurs primarily in fractures in the underlying rocks. Other than those adjacent to the city of Oak Ridge, most of the residential wells in the immediate area are south of the Clinch River. The characteristics of some domestic wells and springs in areas adjacent to the city of Oak Ridge and ORNL are given in Table 3.9. The locations of some water wells in the Oak Ridge vicinity are shown in Fig. 3.10. Wells shown are those for which the Tennessee Department of Water Resources has well logs including well location, elevation, and depth to water. Additional wells exist within the regions shown, but they either have not been reported to the state or were incompletely reported.

Over one hundred wells and springs are located within 16 km (10 miles) of ORNL, and all are south of the Clinch River. Studies have indicated that the incised meander of the river in bedrock represents a major topographic feature that prevents any groundwater flow from passing beneath the river.[23]

Eight industrial groundwater supplies exist within about 32 km (20 miles) of ORNL,[23] as indicated by the data in Table 3.10. Three of these supplies are about 14.5 km (9 miles) from ORNL, and the nearest is at the Charles H. Bacon Company in Lenoir City, Tennessee. An estimated average of 320 m^3 (85,000 gal) is obtained daily from this supply,[23] which is located about 14.5 km (9 miles) south-southeast of ORNL. A daily average of about 38 m^3 (10,000 gal) is obtained from the well supplying the Lenoir City Car Works, which is about 14.9 km (9.3 miles) south of ORNL, as well as the one supplying the Ralph Rogers Company, which is approximately 15 km (9.4 miles) northeast of ORNL. The other five industrial groundwater supplies are farther from ORNL.

There are 16 public groundwater supplies located within a 32-km (20-mile) radius of ORNL, and a 17th supply, for the city of Rockwood, is about 34.6 km (21.5 miles) from ORNL. These 17 public groundwater supplies, their sources, and their distances from ORNL are given in Table 3.11. Of these sources, the closest to ORNL is the Allen Fine Spring supplying the Dixie-Lee Utility District in Loudon County. This groundwater source is about 10.9 km (6.8 miles) southeast of ORNL, and it serves approximately 6700 people with an average of about 1500 m^3 (400,000 gal) of water per day. The well that serves the Edgewood Center in Roane County is about 12.2 km (7.6 miles)

Table 3.9. Characteristics of some domestic wells and springs near the city of Oak Ridge and south of the Clinch River in the vicinity of ORNL

County	Distance to nearest post office (km)	Owner	Topographic position	Altitude (m)	Depth (m)	Geological material	Yield (m^3/s)
Anderson	Oak Ridge[a]						
	4.8 N	Braden	Valley	259[b]	S[c]	Shale	6.3E-4[b]
	2.4 NW	Henderson	Valley	258	31	Shale	U[d]
	3.2 NE	Coplin	Slope	308	92	Dolomite	U
	2.4 E	Preston	Slope	250	62	Limestone	U
	5.6 NE	Miller	Slope	259	16	Shale	U
	6.4 E	Fraker	Slope	259	16	Shale	U
	2.4 W	Owens	Valley	249	6	Shale	
Knox	Byington						
	6.4 W	Cobb	Slope	259	19	Shale	U
	6.4 W	Maddox	Valley	262	S	Dolomite	2.8E-2
	8.0 W	Houser	Slope	256	20	Dolomite	3.8E-4
	8.0 W	Raby	Valley	235	S	Dolomite	3.2E-2
	11.3 W	Peake	Valley	236	S	Dolomite	1.9E-2
	Martel						
	9.7 N	Blankenship	Slope	274	56	Dolomite	U
	Oak Ridge[a]						
	8.0 S	Cobb	Valley	256	18	Shale	U
Loudon	Martel						
	8.9 NW	Rutledge	Ridge	233	19	Dolomite	1.3E-4
	Lenoir City						
	10.5 NW	Coulter	Slope	294	31	Dolomite	U

Table 3.9. Characteristics of some domestic wells and springs near the city of Oak Ridge and south of the Clinch River in the vicinity of ORNL (continued)

County	Distance to nearest post office (km)	Owner	Topographic position	Altitude (m)	Depth (m)	Geological material	Yield (m^3/s)
Roane	Lenoir City						
	14.5 NW	Waller	Valley	236	7	Shale	U
	12.9 NW	Moore	Hilltop	348	79	Dolomite	U
	12.1 NW	Waller	Slope	247	20	Shale	U
	10.5 NW	McMahon	Slope	282	24	Dolomite	U
	10.5 NW	McMahon	Slope	252	4	Dolomite	U
	9.7 NW	Blue Spring	Valley	267	S	Dolomite	6.3E-2
	Kingston						
	11.3 E	Smith	Slope	235	13	Shale	U
	11.3 E	Hensley	Valley	261	6	Shale	U

[a]Jackson Square.

[b]Multiplier factors for converting International System of Units (SI) to English Units are located inside back cover.

[c]S = spring.

[d]U = unknown.

Source: G. D. Debuchananne and R. M. Richardson, "Groundwater Resources of East Tennessee," Tennessee Department of Conservation, Division of Geology, Bulletin 58, Part I, 1956.

ORNL–DWG 82-11900

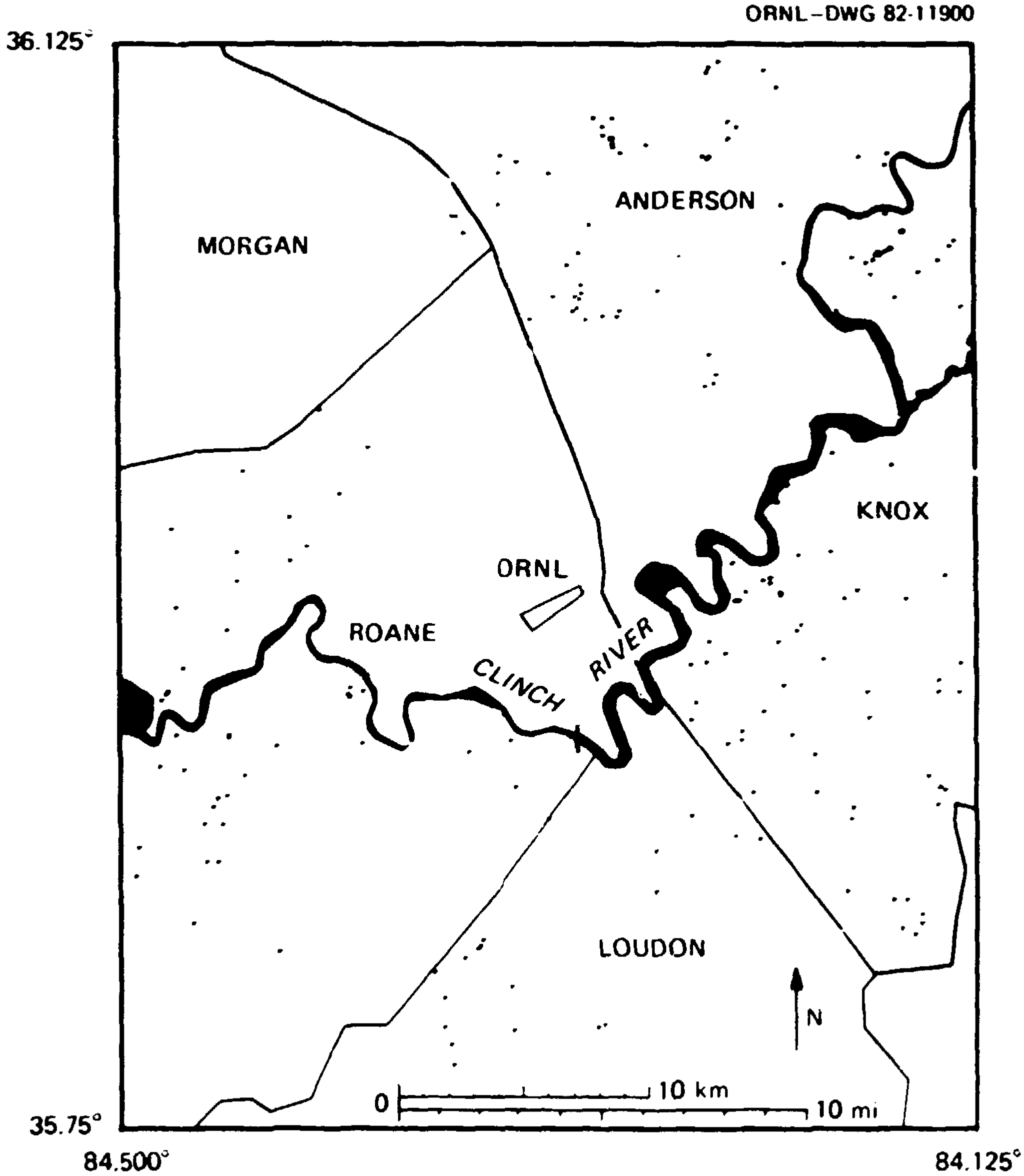

Fig. 3.10. Location of water wells in the Oak Ridge vicinity. Source: Tennessee Department of Conservation, Division of Water Resources, *Computerized Master File of Tennessee's Water Wells*, Nashville, Tenn., 1981.

southwest of ORNL, and the spring which supplies the Cumberland Utility District of Roane and Morgan counties is approximately 12.9 km (8 miles) west of ORNL.

Because of the stratigraphic and structural control of groundwater flow in the region, groundwater beneath the ORR is expected to migrate along strike and discharge to surface water bodies. There is a low probability of groundwater migration from the reservation to offsite wells.

The importance of the Knox group as a regional aquifer is apparent from its wide use among the public and industrial groundwater users. The mean Knox spring and well yield estimated from water use figures included in Tables 3.10 and 3.11 is about $1.7 \times 10^{-2} m^3/s$ (268 gpm). Reliable estimates of the mean yield to domestic wells in the Knox group are not available. Yields are expected to vary widely depending on the size and extent of cavity systems encountered by individual wells.

Table 3.10. Industrial groundwater supplies within about 32 km of Oak Ridge National Laboratory

Industrial water user	Yield (m^3/s)	Source	Probable water-bearing formation	Distance from ORNL (km)
Charles H. Bacon Co. (Lenoir City)	3.7E-3[a]	Well	Knox	14.5 SSE
Lenoir City Car Works	4.4E-4	Well	Chickamauga	15.0 S
Ralph Rogers Co.	4.4E-4	Well	Conasauga	15.1 NE
Charles H. Bacon Co. (Loudon)	1.5E-2	Spring[b]	Knox	20.4 S
Union Carbide Co. (Loudon)	1.4E-1	Spring[c]	Chickamauga	21.2 S
John J. Craig Co.	5.7E-4	Well Spring	Knox	24.9 SSE
Tennessee Forging Steel	1.1E-3	Well Pond	Knox	30.6 W
Morgan Apparel Co.	1.3E-4	Well		30.7 NW

[a]Multiplier factors for converting International System of Units (SI) to English Units are located inside back cover.
[b]Primary source.
[c]Secondary source.
Source: Exxon Nuclear Co., Inc., Nuclear Fuel Recovery and Recycling Center, Preliminary Safety Analysis Report, Report XN-FR-32, Docket No. 50-564, 1976.

3.2.3 Water Quality

In general, the waters of the Clinch River and most of its tributaries are moderately hard and slightly basic. Calcium and magnesium are the principal cations; anionic composition is dominated by bicarbonate and carbonate, presumably as a result of the abundance of limestone and dolomite bedrock underlying the river basin.[28] A different water chemistry is observed in Poplar Creek and other tributaries that drain the Cumberland Plateau. These streams contain substantial amounts of sulfate ions and trace elements resulting from oxidation and dissolution of sulfide minerals exposed through strip-mining of coal. Some streams in the Clinch River basin (e.g., Bear Creek and Melton Branch) are underlain mostly by shale, siltstone, or sandstone bedrock of the Rome and Conasauga formations. Water in these streams contains larger quantities of sodium, sulfate, and chloride than does water in streams originating in limestones. However, overall concentrations of dissolved solids are lower because of the lower solubility of silica and silicate minerals as compared with that of carbonate compounds.

3.2.3.1 Clinch River

At least four institutions routinely monitor water quality in the Clinch River. Both TVA and the USGS monitor water quality just below Melton Hill Dam. The Tennessee Department of Public Health maintains a monitoring station at CRK 16.3 [CRM 10.1, 3.2 km (2 miles) below the mouth of Poplar Creek and ORGDP]. Selected water quality constituents are monitored by Union Carbide

Table 3.11. Public groundwater supplies within about 32 km of Oak Ridge National Laboratory

Public water user	People served	Yield (m^3/s)	Source	Probable water-bearing formation	Distance from ORNL (km)
Oliver Springs	4,000	1.3E-2[a]	Spring	Knox	16.9 NNE
Dutch Valley Elementary School	140	1.2E-4	Well	Rome	22.5 NNE
First Utility District of Anderson County	3,600	1.2E-2	Spring	Conasauga	21.4 NE
West Knox Utility District	15,000	5.7E-2	Well[b]	Knox	22.5 E
Dixie-Lee Utility District	6,700[c]	1.8E-2	Spring	Knox	10.9 SE
Piney Utility District	2,000	3.3E-3	Spring	Knox	23.2 S
Loudon	5,200	2.5E-2	Spring[d]	Knox	23.5 SSW
Philadelphia	300	2.6E-4	Well	Knox	28.2 SSW
Edgewood SE Center	100	1.7E-4	Well	Knox	12.2 SW
Paint Rock Elementary School	250	2.2E-4	Well	Rome	26.9 SW
Midway High School	500	5.7E-4	Spring	Chickamauga	27.0 SW
Kingston	5,000	1.4E-2	Spring[e]	Conasauga	18.8 WSW
Rockwood	10,000	6.2E-2	Spring[e]	Knox	34.6 WSW
Cumberland Utility District of Roane & Morgan Cos.	4,300	7.8E-3	Spring[e]	Knox	12.9 W
Midtown	2,500	4.7E-3	Well	Rome	26.4 W
Brushy Mountain State Honor Farm	200	8.8E-6	Well		27.7 NW
Plateau Utility District	2,300	9.0E-3	Well		28.2 NW

[a]Multiplier factors for converting International System of Units (SI) to English Units are located inside back cover.
[b]Secondary source.
[c]Includes Martel Utility District.
[d]Half supply.
[e]Primary source.
Source: Exxon Nuclear Co., Inc., Nuclear Fuel Recovery and Recycling Center, Preliminary Safety Analysis Report, Report XN-FR-32, Docket No. 50-564, 1976.

Corporation, Nuclear Division (UCC-ND) at the above locations and at the Kingston water intake on the Tennessee River near the confluence with the Clinch River, CRK 18.5 (CRM 11.5, ORGDP cooling water intake), and CRK 23.3 (CRM 14.5, ORGDP process and potable water intake).

The Clinch River's water quality has also been analyzed by several special surveys in connection with ORGDP, the Clinch River Breeder Reactor (CRBR) Plant, and ORNL's discharge. Between 1960 and 1963, ORNL and the USGS cooperated in a major hydrologic survey that included sampling water from 29 streams in the Oak Ridge vicinity.[15,28] Water quality was sampled on the Clinch River at Center's Ferry at CRK 8.9 (CRM 5.5), at ORGDP potable water intake at CRK 23.3 (CRM 14.5), and at the major water intake serving the city of Oak Ridge, ORNL, and the Y-12 Plant at CRK 66.8 (CRM 41.5). Results are presented in Table 3.12.

Table 3.12. Chemical analyses of water at three sampling sites on the Clinch River near the Oak Ridge Reservation

Component or property	Concentration, mg/L								
	At CRK 66.8[a]			At CRK 23.3[b]			At CRK 8.9[c]		
	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average
Ca	36	18	27	27	17	21	43	17	27
HCO_3^-	130	105	117	141	87	110	135	57	112
Cr	0.19	0.00	0.02	NA[d]	NA	NA	0.18	0.00	0.01
Cl^-	11	1	5	4.5	1.0	1.6	8	1	3
Fe	9.2	0.3	3.4	0.37	0.01	0.06	7.1	0.1	1.7
Mg	18.0	5.1	9.4	10.0	4.5	7.7	22.6	4.1	9.4
Mn	1.1	0.0	0.4	NA	NA	NA	0.6	0.0	0.1
NO_3^-	2.4	0.2	1.0	19	0.3	2.7	12.7	0.0	1.5
PO_4^{3-}	0.4	0.1	0.2	0.75	0.05	0.22	0.6	0.0	0.1
K	3.1	0.8	1.7	2.3	1.1	1.3	3.5	0.6	1.6
Si	4.0	1.5	2.9	2.4	0.1	1.5	4.4	0.9	2.7
Na	5.2	1.0	2.3	4.7	1.8	2.4	9.5	0.0	2.4
Sr	0.086	0.058	0.073	0.080	0.040	0.07	0.080	0.043	0.069
SO_4^{2-}	23	2	12	29	1	10	29	0	12
Suspended solids	557	18	185	104	1.0	25.3	275	2	55
Dissolved solids	201	67	125	218	90	129	549	25	133
Total solids	677	140	310	231	127	154	601	112	188
Turbidity	68	6	28	NA	NA	NA	86	1	17
Hardness, as $CaCO_3$	148	78	107	NA	NA	NA	169	69	106
Specific conductance[e]	(263)	(119)	(195)	(282)	(190)	(216)	(312)	(105)	(196)
Acidity, as $CaCO_3$	10	0	3	NA	NA	NA	14	0	4
pH, standard units	(8.2)	(7.1)	NA	(8.1)	(7.0)	NA	(8.5)	(7.2)	NA

[a]Based on 104 weeks of samples from December 1960 through November 1962.
[b]Based on 58 weeks of samples from November 1960 through January 1962.
[c]Based on 104 weeks of samples from November 1960 through December 1962.
[d]NA denotes "data not available."
[e]In microsiemens at 25°C.

Source: R. J. Pickering, Composition of Water in Clinch River, Tennessee River and Whiteoak Creek as Related to Disposal of Low-level Radioactive Liquid Wastes, in Transport of Radionuclides by Streams, U.S.G.S. Professional Paper 433-J, 1970, Table 2.

More recently, water quality data for the lower Clinch River were compiled for analysis of environmental impacts of the proposed coal-to-gasoline synfuel facility.[13] These data (Table 3.13) were obtained from the Environmental Protection Agency (EPA) water quality data base, STORET, and values outside the 99.9% confidence limit were eliminated from the data set. The data are in close agreement with data collected in 1980 by UCC-ND.[29] However, UCC-ND's monthly monitoring at CRK 16.1 (CRM 10.0) indicated higher maximum values for nitrate (2.7 mg/L), total dissolved solids (219 mg/L), and zinc (0.06 mg/L). In addition, cyanide was consistently observed to be below the 2-μg/L detection limit. Table 3.13 also presents EPA's water quality criteria and drinking water standards and Tennessee's water quality criteria for the protection of aquatic life.

Overall water quality in the Clinch River below Melton Hill Dam is quite good. A pH of 5.0 measured on one occasion appears to be anomalous.[13] In the late 1960s and early 1970s, TVA recorded five measurements of dissolved oxygen below the 5.0-mg/L criterion. These conditions, measured in the tailrace of Melton Hill Dam, probably resulted from release of deeper, oxygen-depleted waters from the reservoir. Concentrations of fecal coliform bacteria have occasionally exceeded the criteria levels for swimming and drinking water. Concentrations of phosphorus and nitrogen are relatively high.

The EPA recommends that concentrations of carcinogens, such as arsenic and beryllium, be zero for the maximum protection of human health because of ingestion of water and organisms.[30] The observed concentrations of arsenic and beryllium exceed the EPA's recommended concentrations, which estimate a risk of cancer over a lifetime of 1 in 10 million (10^{-7}).

Trace element concentrations that have exceeded the EPA criteria for protection of aquatic life (Table 3.13) include Cd, Cu, Fe, Pb, Hg, Ni, Ag, and Zn. In most cases, it appears that the exceedences of criteria are not caused by point-source discharges from the Oak Ridge area because data from Norris Dam and Tazewell show most of the same exceedences.[13] For many samples

Table 3.13. Clinch River water quality

Pollutant	Units	Clinch River concentrations[a]: CRK 16.1 TPDH below Gallaher Bridge, Mean	Max	CRK 37.2 USGS Melton Hill tailwater, Mean	Max	CRK 37.2 TVA Melton Hill tailrace, Mean	Max	Water quality criteria & standards: Fresh water aquatic life	Human health	Drinking water	Standard violations or criteria exceedences
CONVENTIONAL POLLUTANTS											
BOD_5,	mg/L	1.2	3.3	1.5	2.6	1.2	2.6				
Chlorides,	mg/L	6.0	6.0	3.4	6.8	3.7	9.0		250[b]	250[b]	
COD,	mg/L	3.0	5.0	5.3	9.0	6.3	25.0				
Coliforms:[c]											
Total,	MF/ 100 ml	721	48,400			365	125,000				
Fecal,	MF/ 100 ml	28.2	7,955	7.7	21	13.5	110	1000[e] GM 5000[d] max	200[d] GM 1000[d] max (Swimming)	1000[d] GM 5000[d] max	e
Streptococci,	MF/ 100 mL	16.0	490	3.3	29						
Dissolved oxygen,	mg/L	8.9	5.1[f]	9.0	5.2[f]	8.8	2.5[f]	5.0[d,f]			
pH, std. units		7.37	5.0[g] 8.2	7.72	6.8[g] 8.2	7.66	7.0[g] 8.2	6.5[d,g] 8.5		6.0[d,g] 9.0	e
Solids:											
Total,	mg/L	143	225			133	150	500[b]			
Dissolved,	mg/L									500[d,h]	
-180°C				132	180	131	190				
-105°C		128	184			121	150				
Suspended,	mg/L	14	49	6	18	6	18				

Table 3.13. Clinch River water quality (continued)

Pollutant	Units	Clinch River concentrations[a]: CRK 16.1 TPDH below Gallaher Bridge, Mean	CRK 16.1 Max	CRK 37.2 USGS Melton Hill tailwater, Mean	CRK 37.2 USGS Max	CRK 37.2 TVA Melton Hill tailrace, Mean	CRK 37.2 TVA Max	Water quality criteria & standards: Fresh water aquatic life	Human health	Drinking water	Standard violations or criteria exceedences
Temperature, °C		14.9	24.0	14.5	24.0	14.7	25.0	30.5[d]	30.5[d]	30.5[d]	
UNCONVENTIONAL POLLUTANTS											
Nitrogen:											
Organic,	mg/L	0.84	1.2	0.16	0.84	0.15	0.84				
NH_4^+,	mg/L	0.05	0.21	0.046	0.37	0.05	0.37	1.2[i]			
NO_3^-,	mg/L	0.45	1.50	0.54	1.90	0.56	1.9		10.0	10.0[j]	
Total,	mg/L	1.05	2.30	0.72	1.30						
Color,	Pt-Co	18.4	130.0	6.6	17.0	7.2	20.0			15[h]	k
Phosphorus:											
Total,	mg/L	0.089	0.33	0.020	0.060	0.023	0.081				
Dissolved,	mg/L			0.009	0.030	0.013	0.023				
METALS AND OTHER POLLUTANTS											
Alkalinity:											
as $CaCO_3$,	mg/L	83	134	96	120	95	112	min 20[b]			
Aluminum,	µg/L	200[l]		513	2,600	618	2,600				
Antimony,	µg/L	26.5	100						146[m]		
Arsenic,	µg/L	3.0	33.0	3.7	6.0	4.9	6.0	440[m]	0.22E-3[n]	50[j]	o
Barium,	µg/L	34.6	100	88.5	100	<100	100		1,000[m]	1,000[j]	
Beryllium,	µg/L			<10	<10	<10	<10	1,000[p]	0.37E-3[n]		o
Boron,	µg/L			101	160	335	1,000				
Cadmium,	µg/L	1.8	20.0	0.88	3.0	1.3	4.0	0.026[m,q]	10[m]	10[j]	o,r

3-32

Table 3.13. Clinch River water quality (continued)

Pollutant	Units	Clinch River concentrations[a]						Water quality criteria & standards			Standard violations or criteria exceedences
		CRK 16.1 TPDH below Gallaher Bridge		CRK 37.2 USGS Melton Hill tailwater		CRK 37.2 TVA Melton Hill tailrace		Fresh water aquatic life	Human health	Drinking water	
		Mean	Max	Mean	Max	Mean	Max				
Chromium:											
Total,	µg/L	6.0	<40.0	10.6	30.0	5.3	10.0			50[j]	o
Hexavalent								21[m]	50[m]		
Trivalent								4,945[m]	170,000[m]		
Cobalt:											
Total,	µg/L			0.7	3.0	5.0[l]					
Dissolved,	µg/L	276[l]		0	<1.0						
Copper,	µg/L	5.7	14.0	21.6	80.0	24.1	80.0	5.6[m,q]	1,000[m]	1,000[h]	r
Cyanide,	µg/L					<10	<10	3.5[m]	200		
Fluoride, dissolved,	mg/L	0.13	0.50	0.10	0.10	0.11	0.41			1.4[b]	
Hardness, as $CaCO_3$,	mg/L	105	128	109	140						
Iron,	µg/L	538	2,600	333	1,000	381	1,000	1,000[b]		300[h]	k,r
Lithium,	µg/L			<10	10	<10	10				
Lead,	µg/L	12.4	50.0	9.4	33.0	12.1	33.0	4.3[m,q]	50[m]	50[j]	r
Manganese,	µg/L	70.5	280	47.6	130.0	53.5	200			50[h]	k
Mercury,	µg/L	0.33	1.00	0.36	2.3	0.37	2.3	0.20[m]	0.144[m]	2[j]	k,o,r
Nickel,	µg/L	19.6	100.0	35.6	50.0	44.4	100.0	99.2[m,q]	13.4[m]		o,r
PCB,	µg/L	0[l]						0.014	7.9E-6[n]		
Potassium,	mg/L	1.7	2.3	1.4	1.8	1.5	4.0				
Selenium,	µg/L	<1.0[l]		1.1	<2.0	1.6	2.0	35[m]	10[m]	10[j]	
Silica dissolved	mg/L	3.93[l]		4.2	6.8	4.1	6.2				
Silver,	µg/L			5.3	<10	<10	<10	4.4[m]	50	50[j]	r
Sodium,	mg/L	3.6	11.6	4.5	13.0	3.8	13.0				
Strotium,	µg/L					200[l]					
Sulfate,	mg/L	18.4	47.0	16.8	24.0	15.5	24.0			250[h]	

Table 3.13. Clinch River water quality (continued)

Pollutant	Units	Clinch River concentrations[a]						Water quality criteria & standards			Standard violations or criteria exceedences
		CRK 16.1 TPDH below Gallaher Bridge		CRK 37.2 USGS Melton Hill tailwater		CRK 37.2 TVA Melton Hill tailrace		Fresh water aquatic life	Human health	Drinking water	
		Mean	Max	Mean	Max	Mean	Max				
Titanium,	µg/L		<1,000	<1,000	<1,000	<1,000	<1,000				
Zinc,	µg/L	9.5	21.0	22.8	90.0	41.6	170	47[m,q]	5,000[m]	5,000[h]	r

[a]Data from EPA STORET, values greater than the mean plus 3.6 standard deviations (99.99 percent confidence level) have been excluded.

[b]"Red Book" criteria from: U.S. Environmental Protection Agency. Quality Criteria for Water. EPA-440/9-76-023. Washington, DC, 1976.

[c]Coliform means are geometric means.

[d]"Tennessee Water Quality Criteria." Tennessee Regulations Chap. 1200-4-3.01, Department of Health, Division of Water Quality, Adopted May 26, 1967; as amended through April 1980 (Bureau of National Affairs, Environment Reporter, 916:0541-5).

[e]Violates Tennessee Department of Health criteria.

[f]Minimum dissolved oxygen.

[g]Minimum/maximum pH.

[h]Secondary drinking water standrds, 42 FR G2 (1977).

[i]Ammonia criteria based on "Red Book" @pH = 7.5; T= 24°C.

[j]Primary Drinking Water Standards, 40 FR 248 (1975).

[k]Exceeds EPA drinking water standards.

[l]Single measurement.

[m]Water Quality Criteria for Toxic Substances, 45 FR 79318-79. Values given are 24-h average. Hardness dependent values based on hardness = 105 mg/L as $CaCO_3$.

[n]Zero concentration recommended, value shown is EPA 10^{-7} risk level.

[o]Exceeds EPA recommended criteria for human health effects.

[p]Based on hard water definition.

[q]Tennessee criteria (ref. d) are based on 0.1 of 96-h LC_{50}, but more stringent levels, (e.g. 0.01 of LC_{50}) may be established on a case-by-case basis for substances toxic due to cumulative characteristics.

[r]Exceeds EPA recommended criteria for aquatic life.

Source: Environmental Impact Report for the Coal-to-Gasoline Plant, Tennessee Synfuel Associates, Oak Ridge, Tennessee, December 1981, Table VIII-5 (modified).

during the period of record, the concentrations of trace elements were reported as below the detection limits. Mean concentrations are computed by assuming a concentration equal to the detection limit; the result is that the mean values presented may overestimate the actual average concentration.

At the Melton Hill Dam tailwaters and at CRK 16.1 (CRM 10.0), the average concentrations of Cd, Cu, Pb, Hg, and Ag exceed the EPA's 1980 toxic substances criteria for protection of freshwater aquatic life. It is not known whether the observed concentrations reflect human inputs or naturally occurring geochemical background levels. The average Clinch River concentrations (0.9–1.8 μg/L) of cadmium are similar to the median level of 1 μg/L for 726 water samples from U.S. lakes and rivers.[31] Average copper concentrations in the Clinch River (6–24 μg/L) are similar to the average of 14 μg/L for 87 samples from the southeastern United States.[32] Average values of lead in the Clinch River varied from 9–12 μg/L, similar to the 5-μg/L natural concentration reported for rivers[33] and the 8- and 17-μg/L means measured in southeastern rivers and in the Tennessee River respectively.[32] Mercury concentrations in the Clinch River appear to be significantly elevated above background. Levels up to 3 μg/L have been measured at CRK 16.3 (CRM 10.1),[22] and average concentrations are 0.3–0.4 μg/L (Table 3.13). Background concentrations in this area should not exceed 0.06 μg/L.[34] Although past practices at the Y-12 Plant have apparently introduced mercury into Bear Creek, East Fork Poplar Creek, and perhaps the Clinch River,[22,35] this does not explain the elevated mercury levels in tailwaters of Melton Hill Dam.

The average levels of iron and manganese in the Clinch River have exceeded drinking water standards. Drinking water standards are presented for comparative purposes, but they apply to water delivered to consumers rather than applying to raw water supplies.

3.2.3.2 White Oak Creek

Water quality in WOC is extensively monitored in connection with discharge of treated wastewater from ORNL and control of low-level radioactivity and other contaminants from solid waste disposal practices.

Routine monitoring of chromium, mercury, zinc, and nitrates is performed by UCC-ND each month at White Oak Dam. Data taken from 1976 through 1980 (Table 3.14) indicate that average concentrations of chromium, zinc, and nitrates are below the EPA criteria for protection of aquatic life (Table 3.13). The maximum concentrations of chromium and zinc appear to be declining, while the average and maximum concentrations of nitrates have increased and have exceeded the 10-mg/L drinking water standard at least once. Since 1978, levels of mercury have not been measured with sufficient analytical sensitivity to determine if they exceed the 0.14-μg/L criterion for protection of human health from ingestion of water and organisms.

At the three discharge points designated in the national pollutant discharge elimination system permit, ORNL performs routine monitoring to determine the extent of compliance with permit conditions. Two of these monitoring points are WOC and Melton Branch just upstream of their confluence. The effluent from the sanitary waste treatment facility is also monitored. (Data from these stations are summarized in Table 3.15 and discussed in Sect. 4.2.2.)

Sampling in the WOC watershed was conducted for 37 weeks between April 1979 and January 1980 with analyses performed for many trace elements.[36] Sampling stations were located along the length of WOC (Fig. 3.11). Data collected are summarized in Figs. 3.12 through 3.15, which present the mean concentrations with a ±1 standard deviation. These data are discussed in Sect. 4.2.2.

3.2.3.3 Oak Ridge Reservation streams

Water quality data from streams flowing through the ORR are presented in Table 3.16. Data were collected during the joint ORNL-USGS surveys from September 1961 through June 1964. Trace elements were sampled September 18–19, 1961.

Table 3.14. Water quality at White Oak Dam

Substance	(Concentration, µg/L)				
	1976[a]	1977[a]	1978[a]	1979[b]	1980[c]
Cr, average	20	3	<8	<5	<10
maximum	60	7	40	<5	<10
minimum	9	1	<5	<5	<10
Zn, average	30	5	<5	<20	<20
maximum	70	30	10	<20	<20
minimum	20	2	<5	<20	<20
NO_3^-(N), average	700	800	1600	2700	4600
maximum	1200	2000	13700	4300	9800
minimum	90	40	60	200	10
Hg, average	0.2	0.3	<0.5	<1	<1
maximum	0.2	2	<0.5	<1	<1
minimum	0.1	0.06	<0.5	<1	<1

[a]Results of monthly sampling, n = 12.
[b]Only 11 months sampled, n = 11.
[c]Only 10 months sampled, n = 10.
Source: Environmental Monitoring Reports, U.S. Department of Energy, Oak Ridge Facilities, Calendar Years 1976-1980, Y/UB-6, -8, -10, -13, and -15, Union Carbide Corporation-Nuclear Division, Oak Ridge, Tenn., 1977-81.

3.2.3.4 Regional groundwater

A previous study conducted by the USGS[37] presented summary appraisals of the groundwater resources in the Tennessee Valley Region. The region lies mainly in Tennessee, Alabama, and North Carolina but includes small parts of Virginia, Georgia, Kentucky, and Mississippi. The six distinctive physiographic provinces identified in the Tennessee Valley Region include Coastal Plain, Highland Rim, Central Basin, Cumberland Plateau, Valley and Ridge (within which the ORNL site is located), and Blue Ridge. The natural quality of groundwater in the Tennessee Valley Region depends on many factors but mainly on the chemical composition of the rock in which the water occurs. A summary of the median chemical quality of the groundwater in the Valley and Ridge Physiographic Province is presented in Table 3.17.

In the Tennessee Valley Region, the quality of groundwater from a particular aquifer at any one place tends to be relatively constant with time. Most of the groundwater in the region is chemically suitable for public drinking water supplies. As shown in Table 3.17, median values for iron, sulfate, fluoride, chloride, and nitrate concentrations observed in the Valley and Ridge Physiographic Province are well below the maximum concentrations for drinking water recommended by the EPA. However, well-developed openings and highly porous material when less than about 30 m (100 ft) below land surface are very susceptible to pollution, and strong protective measures are needed to ensure that the groundwater quality will remain unimpaired.

Table 3.15 National pollutant discharge elimination system (NPDES) experience at ORNL, 1976–80

Discharge point	Effluent parameters	Daily effluent limits Average	Daily effluent limits Maximum	Percentage of measurements in compliance
001				
(White Oak Creek)	Dissolved oxygen (min), mg/L	5		94
	Dissolved solids, mg/L		2000	99
	Oil and grease, mg/L	10	15	98
	Chromium (total), mg/L		0.05	98
	pH, standard units		6.0 - 9.0	95
002				
(Melton Branch)	Chromium (total), mg/L		0.05	99.6
	Dissolved solids, mg/L		2000	98
	Oil and grease, mg/L	10	15	100
	pH, standard units		6.0 - 9.0	100
003				
(Main sanitary treatment facility)	Ammonia (N), mg/L		5	33
	BOD, mg/L		20	78
	Chlorine residual, mg/L		0.5 - 2.0	97
	Fecal coliform bacteria, No./100mL	200[a]	400[b]	96
	pH, standard units		6.0 - 9.0	100
	Suspended solids[c], mg/L		30	90
	Settleable solids[c], mL/L		0.5	94
004				
(7900 area sanitary treatment facility)	BOD, mg/L		30	No discharges from this facility
	Chlorine residual, mg/L		0.5 - 2.0	
	Fecal coliform bacteria, No./100mL	200[a]	400[b]	
	pH, standard units		6.0 - 9.0	
	Suspended solids[c], mg/L		30	
	Settleable solids[c], mL/L		0.5	

[a]Monthly average.
[b]Weekly average.
[c]Limit applicable only during normal operations. Not applicable during periods of increased discharge due to surface run-off resulting from precipitation.

Source: Table 24, Environmental Monitoring Report, U.S. Department of Energy, Oak Ridge Facilities, Calendar Year 1976-1980, Y/UB-6, -8, -10, -13, and -15, Union Carbide Corporation-Nuclear Division, Oak Ridge, Tenn., June 1981.

ORNL-DWG 80-15923R3

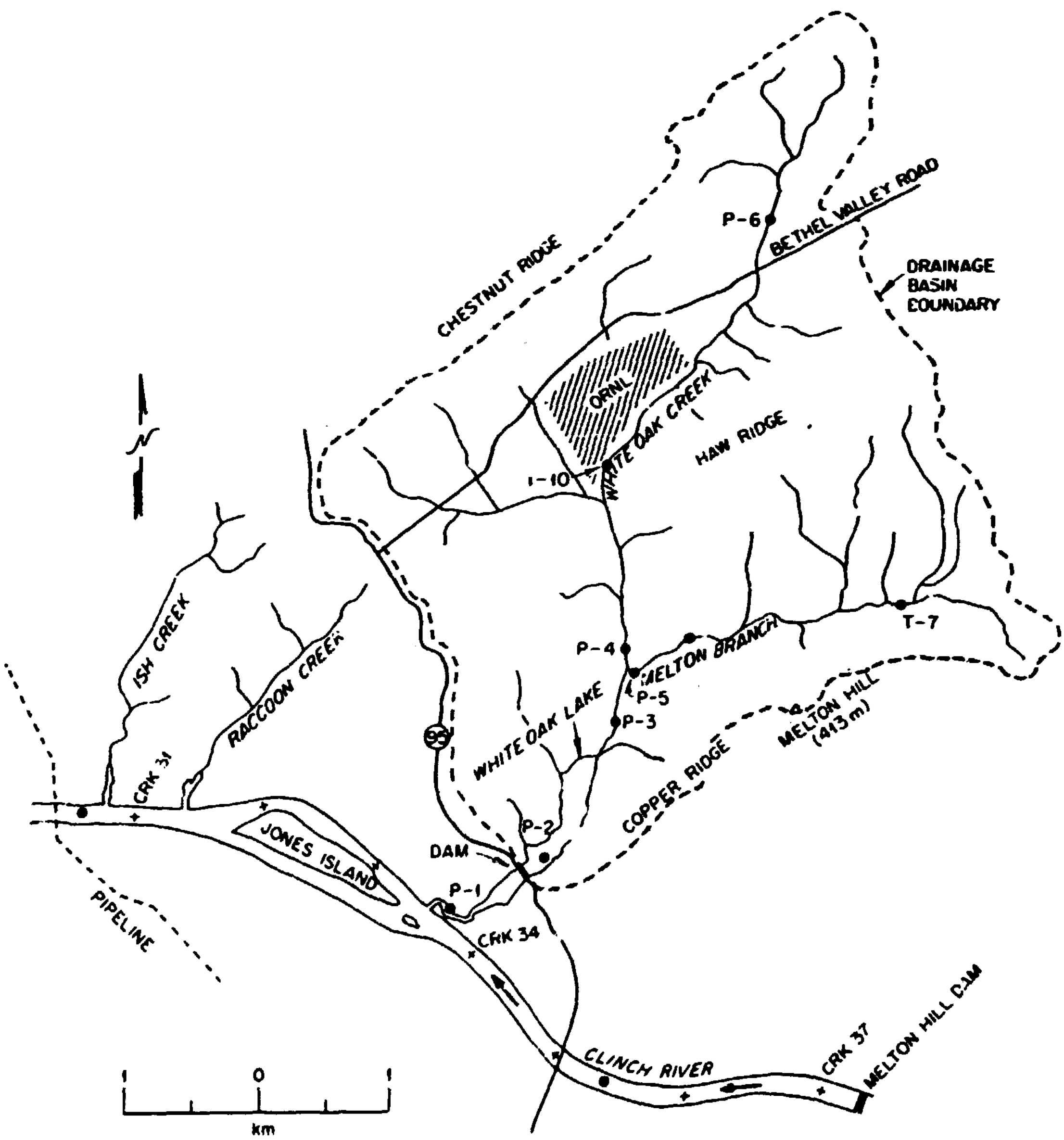

Fig. 3.11. Water-sampling stations in the White Oak Creek basin. Source: J. M. Loar, J. A. Solomon, and G. F. Cada, *Technical Background Information for the ORNL Environmental and Safety Report. Vol. 2. A Description of the Aquatic Ecology of White Oak Creek Watershed and the Clinch River Below Melton Hill Dam.* ORNL/TM-7509/V2, Oak Ridge National Laboratory, Oak Ridge, Tenn., October 1981, modified Fig. 2.1.

ORNL-DWG 82-14591

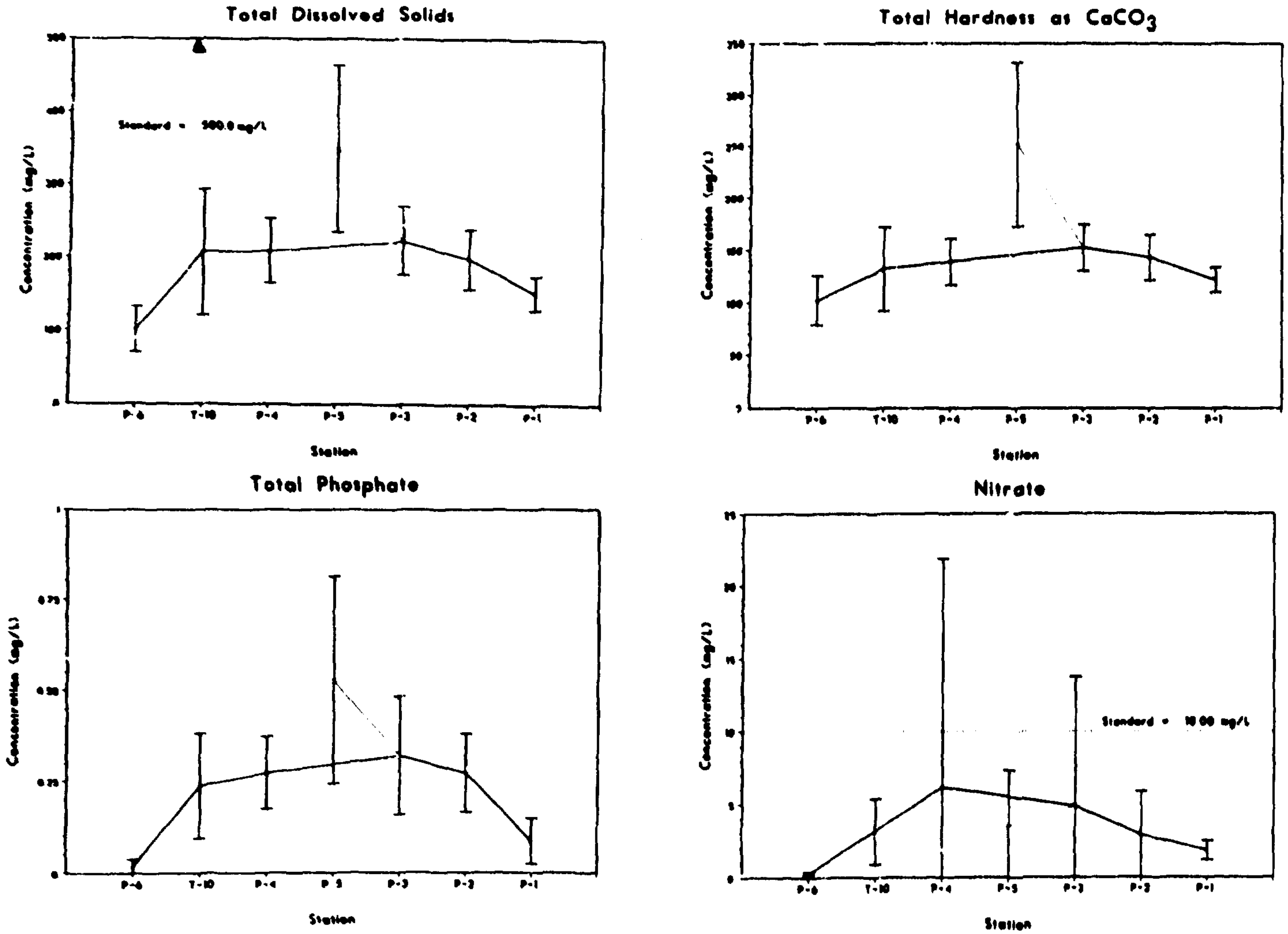

Fig. 3.12. Mean concentrations of total dissolved solids, total hardness, nitrate, and phosphate between April 1979 and January 1980 at sampling stations in the White Oak Creek basin (see Fig. 3.11). Source: M. Montford et al., *Water Quality in White Oak Creek and Melton Branch*, ORNL/TM-8131, Oak Ridge National Laboratory, Oak Ridge, Tenn., in press, 1982.

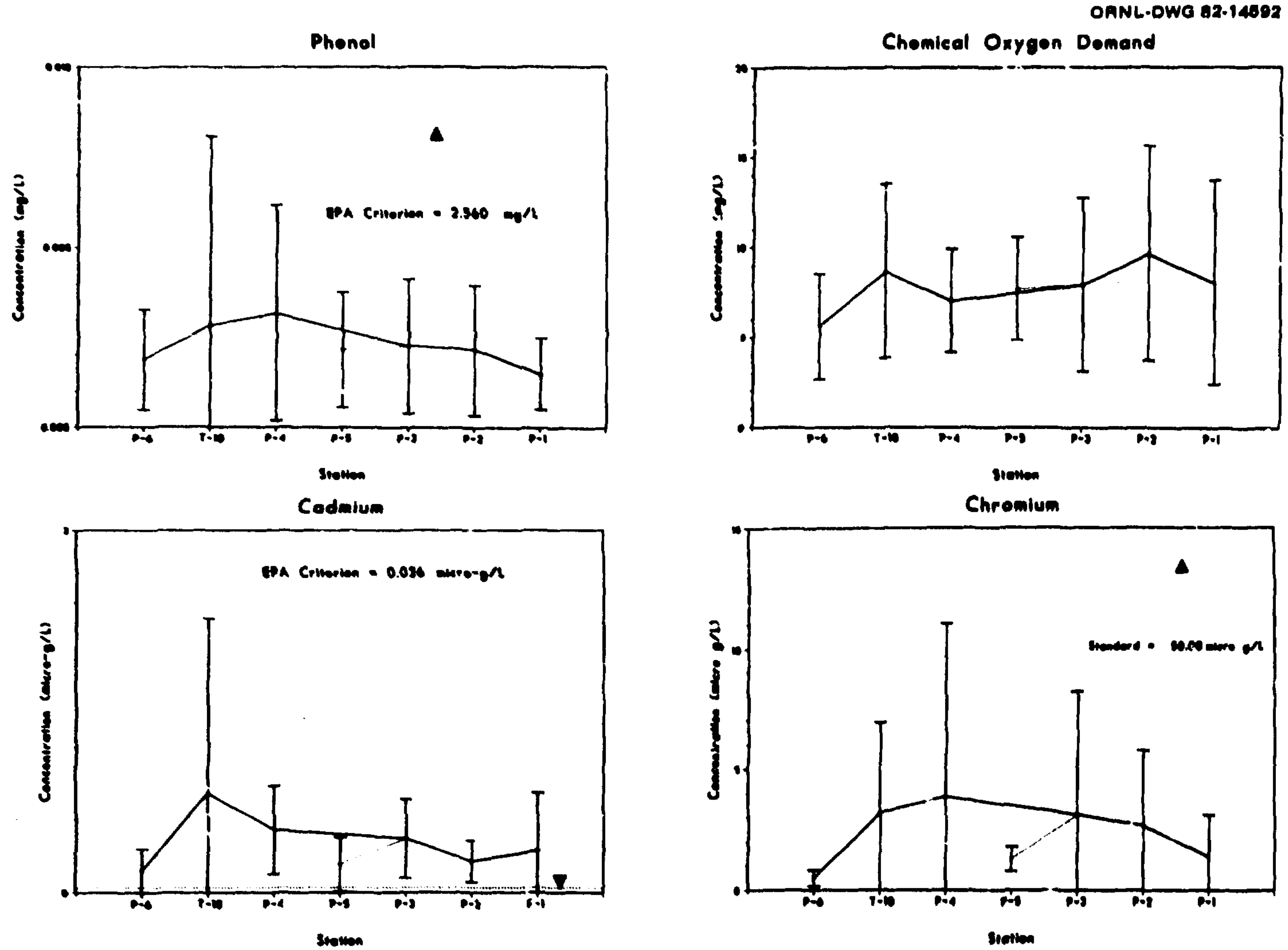

Fig. 3.13. Mean concentrations of chemical oxygen demand, phenol, cadmium, and chromium between April 1979 and January 1980 at sampling stations in the White Oak Creek basin (see Fig. 3.11). Source: M. Montford et al., *Water Quality in White Oak Creek and Melton Branch*, ORNL/TM-8131, Oak Ridge National Laboratory, Oak Ridge, Tenn., in press, 1982.

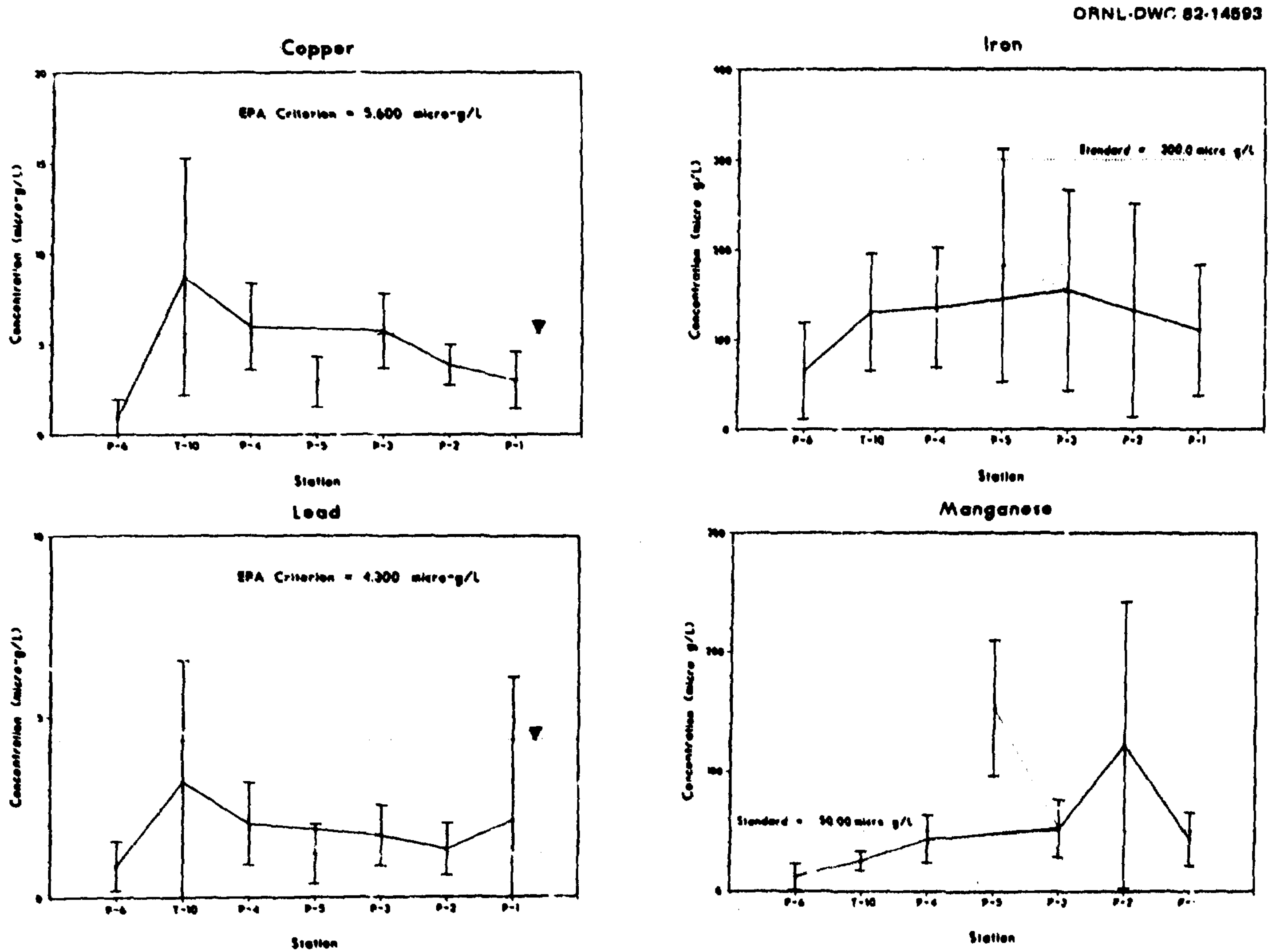

Fig. 3.14. Mean concentrations of copper, iron, lead, and manganese between April 1979 and January 1980 at sampling stations in the White Oak Creek basin (see Fig. 3.11). Source: M. Montford et al., *Water Quality in White Oak Creek and Melton Branch*, ORNL/TM-8131, Oak Ridge National Laboratory, Oak Ridge Tenn., in press, 1982.

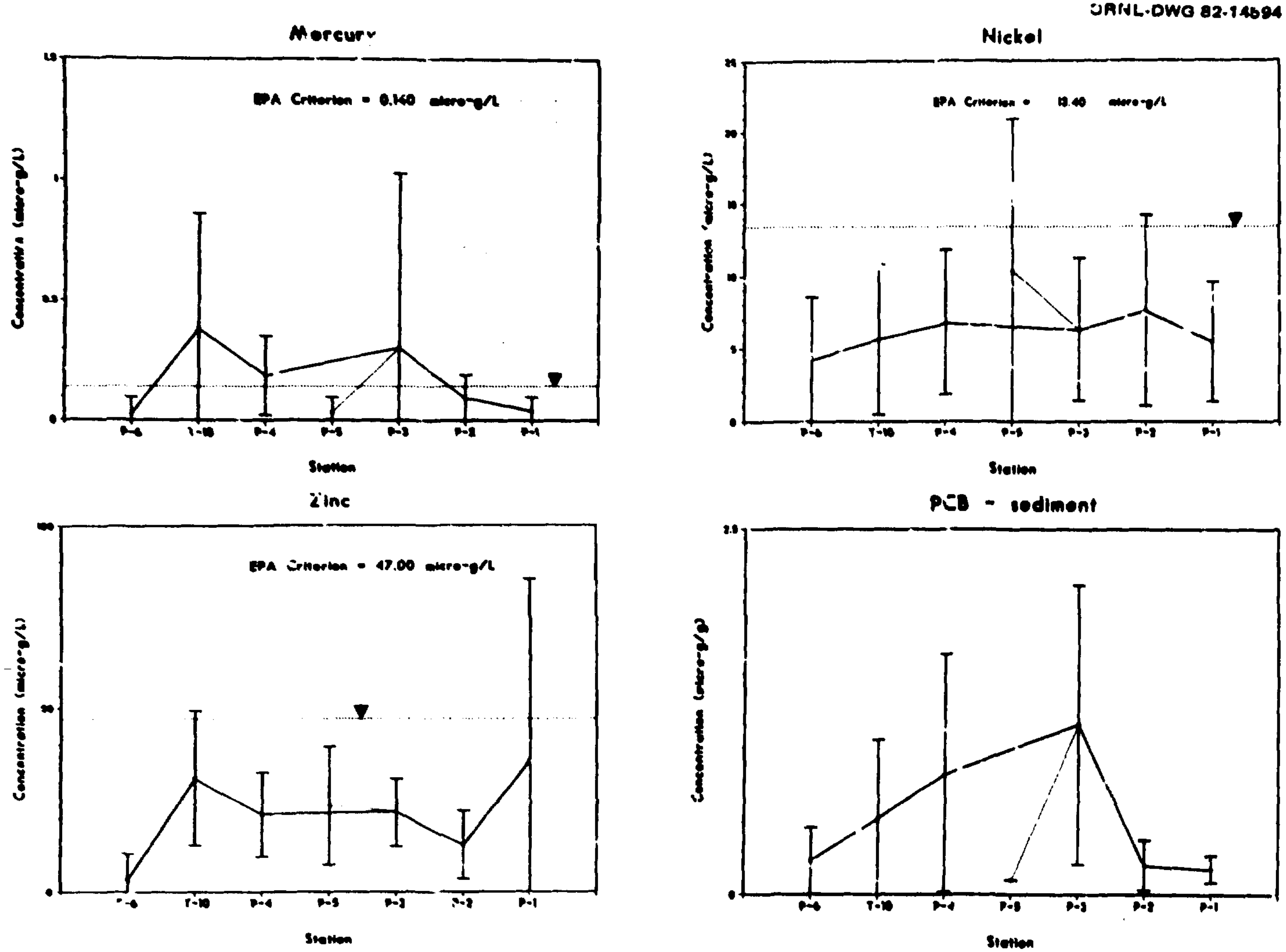

Fig. 3.15. Mean concentrations of mercury, nickel, zinc, and PCBs (sediment) between April 1979 and January 1980 at sampling stations in the White Oak Creek basin (see Fig. 3.11). Source: M. Montford et al., *Water Quality in White Oak Creek and Melton Branch*, ORNL/TM-8131, Oak Ridge National Laboratory, Oak Ridge, Tenn., in press, 1982.

Table 3.16 Chemical analyses and spectrographic trace element analyses of water samples from some tributaries of the Clinch River that flow through the Oak Ridge Reservation

Component or property	Scarboro Creek	East Fork Poplar Creek near its mouth	Mill Branch	Gum Hollow	East Fork Poplar Creek near Oak Ridge	Bear Creek near Oak Ridge	Poplar Creek near Oak Ridge	White Oak Creek above ORNL	Melton Branch	White Oak Creek near White Oak Dam
					Concentration (ppm)					
Al	0.05	0.2	0.06	0.1	0.06	0.06	0.1	0.06	0.03	0.07
Ca	[illegible]	33	40	34	39	46	29	26	39	36
HCO_3^-	[illegible]	111	148	120	136	156	102	132	143	166
CO_3^{2-}	0	16	0	0	0	0	0	0	0	0
Cl^-	1.6	32	4.4	0.9	26.2	1.9	1.9	0.9	4.2	7.6
F^-	0.06	1.3	0.1	0.1	0.9	0.2	0.1	0.1	0.4	0.7
Fe	0.01	0.01	0.02	0.02	0.02	0.01	0.05	0.01	0.01	0.06
Li	0.05	0.4	0.06	0.06	0.3	0.05	0.01	0.02	0.1	0.2
Mg	17	8.0	9.0	6.1	10.0	16.2	8.8	12.6	8.1	8.4
Mn	0.01	0.01	0.01	[illegible]	0.01	0	0.01	0.01	0.01	0.01
NO_3^-	0.6	35	0.8	0.2	20.6	14.0	0.5	0.3	1.2	7.6
PO_4^{3-}	0	0.6	0	0	2.3	0	0	0.02	0.06	0.35
K	0.8	2.4	2.6	[illegible]	2.7	1.4	1.3	0.6	1.4	1.7
SiO_2	7.6	4.7	11.2	9.2	6.5	8.5	7.2	[illegible]	5.2	5.4
Na	0.8	48	4.2	1.8	26.0	2.5	[illegible]	0.6	5.1	20
SO_4^{2-}	3.5	29	16.3	12.5	27	29	26	2.7	15.9	29
Dissolved solids	155	273	162	126	232	162	129	112	152	189
Detergent	0.03	0.5	0.05	0.06	0.7	0.1	0.06	0.05	0.08	[illegible]
Ca-Mg hardness, total	158	116	136	110	139	166	108	112	130	124
Ca-Mg hardness, noncarbonate	7	12	14	11	27	40	26	4	13	7
Specific conductance[a]	(285)	(452)	(273)	(215)	(393)	(322)	(224)	(209)	(267)	(325)
pH, standard units	(7.8)	(8.3)	(7.7)	(7.7)	(7.1)	(7.8)	(7.4)	(7.9)	(7.8)	[illegible]
					Concentration (ppb)[b]					
B	26	34	49	22	110	34	31	8.0	27	32
Ba	63	68	59	48	140	120	68	120	100	100
Cr	0.44	3.0	<0.31	0.30	2.4	<0.34	<0.21	<0.24	1.0	120
Co	<3.1	ND[c]	ND	ND	ND	ND	<2.1	ND	ND	ND
Cu	4.1	5.4	7.1	9.3	51	2.8	3.7	2.4	8.0	17
Pb	9.1	<5.7	3.4	6.7	12	4.0	2.7	3.4	3.9	6.8
Li	6.47	130	2.4	1.3	130	10	0.58	0.24	1.3	2.7
Mo	ND	<1.7	ND	ND	4.3	ND	ND	ND	ND	26
Ni	3.5	<5.7	4.3	8.0	71	6.1	6.6	<2.4	6.0	22
Rb	ND	5.7	3.1	ND	<5.1	ND	<2.1	2.4	ND	<3.0
Ag	<0.31	1.8	0.31	ND	<0.51	ND	<0.21	ND	0.23	<0.30
Sr	[illegible]	97	100	61	130	130	37	21	4	130
Ti	5.3	<5.7	<3.1	2.6	51	3.4	3.5	<2.6	3.7	5.0
V	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Yb	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Y	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zn	<310	ND	<310	ND	ND	ND	ND	ND	<230	ND
Zr	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

[a] microsiemens (μmho) at 25°C.
[b] Trace elements sampled Sept. 18-19, 1961.
[c] ND denotes "not detectable."
Source: R. J. Pickering, "Quality of Surface Water and Geochemical Relationships," in W. M. McMaster, Hydrologic Data for the Oak Ridge Area, Tennessee, U.S.G.S. Water-Supply Paper 1839-N, 1967, pp. 50-60.

Groundwater quality data obtained by the USGS at sampling stations in Anderson and Roane counties and analyses of water samples obtained on the CRBR site are presented in Appendix C.

In general, the groundwater quality at the CRBR site is comparable with the regional groundwater quality with the exception of total hardness, conductivity, bicarbonate, and iron concentrations, which have proven to be somewhat higher at the site than is typical of the region. Groundwater at the CRBR site is chemically suitable for human consumption, although the hardness of the water may be troublesome for some uses.

3.2.3.5 Site groundwater

In general, groundwater quality on the ORR is similar to the groundwater quality of other parts of the Valley and Ridge Physiographic Province. The water quality of surface streams in

Table 3.17. Groundwater quality in the Valley and Ridge Physiographic Province in the Tennessee Valley Region

Constituent	Concentration (mg/L)
Silica	10.0
Iron	0.09
Calcium	38.0
Magnesium	12.0
Sodium	4.5
Potassium	4.5
Bicarbonate	178.0
Sulfate	5.0
Chloride	3.5
Fluoride	0.0
Nitrate	3.9

Source: A. Zurawski, "Summary Appraisals of the Nation's Ground Water Resources - Tennessee Region," Geological Survey Professional Paper 813-L, 1978.

relatively undisturbed watersheds under low-flow conditions usually reflects the quality of groundwater within the watershed. Results of chemical analyses of samples from eight area streams are reported in Table 3.16. The data show some variations in water quality which may be attributable partly to groundwater quality variations and partly to contaminant sources within some of the watersheds.

A study conducted by ORNL in 1961 analyzed the water quality of 19 auger wells drilled in the vicinity of SWDA No. 5 (see Fig. 2.11), which is located about 1500 m (5000 ft) south of the ORNL central site.[38] These auger wells, relatively shallow borings cased with perforated pipes surrounded by gravel, are used to monitor groundwater quality where the depth to water does not exceed 4.6 to 6.1 m (15 to 20 ft). The results of the chemical analysis of samples from these wells are presented in Appendix C, Table C.3. As shown, the water is a calcium bicarbonate type of low dissolved solids. Calcium and magnesium are the principal cations, and bicarbonate is the predominant anion. The values of the ratio of calcium to magnesium suggest that the water obtained calcium from limestone containing very little magnesium. Because the bicarbonate ion is formed in the dissolution of carbonate rocks, the high bicarbonate ion concentration is to be expected. Dispersed sulfide minerals in the rock probably account for the sulfate ion concentration. These water samples were taken prior to the beginning of waste burial operations in the area during December 1958.

Since groundwater movement is the mechanism by which contaminants are transported from burial sites, investigations have been directed toward determination of the direction and rate of groundwater movement in the disposal areas. Groundwater tracer tests were initiated in July 1977 in two radioactive waste disposal areas in Melton Valley. One area is adjacent to SWDA No. 4; the other is in an undisturbed part of SWDA No. 6. Tritiated water was used as the tracer, and water samples were taken from surrounding observation wells.[21] Data collected through 1979 indicate that the weathered zones in the shallow portions of the Conasauga shale formation underlying these areas permit horizontal movement of groundwater.

Tritium and ^{90}Sr have been observed at the mouth of WOC for many years. A program of surface water sampling was initiated to determine the relative contribution of various areas of the watershed to the total activity being released to the Clinch River. Water samples were collected and discharges were measured at different points (stations) along the primary streams. The annual quantities discharged to the creek between 1964 and 1976 are shown in Table 3.18. Starting in 1967, a dramatic increase in the quantity of tritium was observed in the creek. This increase was investigated, and the evidence indicated that the tritium originated in shipments of material received from Mound Laboratory prior to 1967. This waste material was disposed of in SWDA No. 5.[39]

Table 3.18. Tritium and ^{90}Sr discharges to White Oak Lake attributed to seepage from solid waste disposal areas, 1964–1976

Year	Quantity (TBq/year)	
	$^{3}H^{a}$	$^{90}Sr^{b}$
1964	71	0.12
1965	43	0.13
1966	110	0.071
1967	490	0.10
1968	360	0.071
1969	450	0.049
1970	350	0.050
1971	330	0.044
1972	390 (59)[c]	0.073
1973	560 (28)[c]	0.081
1974	320	0.20
1975	410	0.14
1976	270	0.16

[a]Total entering White Oak Lake from all sources.
[b]Difference between sampling points 1 and 3 (Fig. 2.11).
[c]Numbers in parentheses represent contribution from main branch of Whiteoak Creek.
Source: J. O. Duguid, D. E. Edgar, J. R. Gissel, and R. A. Robinson, Operations Division, ORNL unpublished data, 1977.

A recent investigation indicates that this is indeed the case. Samples taken in Melton Branch at sampling point 4 and at sampling point 2 on WOC (Fig. 2.11) indicate that 90% of the tritium is coming from Melton Branch and that the quantity in WOC upstream from the junction of the two creeks is of about the same order of magnitude as that observed for the total prior to 1967. Thus the bulk of the tritium entering White Oak Lake is discharged to Melton Branch from SWDA No. 5 with lesser amounts coming from other waste disposal areas (seepage pits, trenches, and SWDA No. 4) in the drainage area.[39]

The difference between ^{90}Sr concentrations at sampling points 1 and 3 (Fig. 2.11) can be attributed to groundwater discharges from SWDA No. 4. These discharges for the years 1963 through 1975 are shown in Table 3.19. The leaching and discharge is believed to be enhanced by

Table 3.19. Precipitation data and ^{90}Sr discharges from SWDA No. 4, 1963–1975

Water[a] year	Precipitation (cm)	Total ^{90}Sr discharge (GBq)	Discharge of ^{90}Sr (GBq/cm)
1963	140.5	178	1.27
1964	106.9	100	0.935
1965	132.0	115	0.871
1966	103.8	93.2	0.898
1967	153.8	101	0.657
1968	114.3	75.5	0.661
1969	101.8	77.0	0.756
1970	121.7	59.2	0.486
1971	122.6	43.7	0.356
1972	120.4	87.3	0.725
1973	181.0	58.5	0.323
1974	174.6	193	1.11
1975	146.6	119	0.812

[a]Water year is September 1 through August 31.

Source: J. O. Duguid, D. E. Edgar, J. K. Gissel, and R. A. Robinson, Operations Division, ORNL, unpublished data, 1977.

high water table conditions in the burial ground. A comparison of SWDA No. 4 with selected burial sites at the Savannah River Plant, South Carolina, Idaho National Energy Laboratory, Idaho, Hanford Operations, Washington, and Los Alamos Scientific Laboratory, New Mexico, indicates that, of the burial grounds studied, SWDA No. 4 had the greatest possibility for groundwater contamination.[39]

Discharge data shown in Table 3.19 indicate a definite relationship between precipitation and ^{90}Sr discharge from SWDA No. 4. The data also suggest a strong relationship between total discharge and the amount of precipitation. This observation has been substantiated through studies of ^{90}Sr sorption and leaching, using soils collected below SWDA No. 4.[39] Thus the primary methods of controlling ^{90}Sr discharge from the burial ground must rely on reduction of water passing through the buried waste. This reduction can be achieved through near-surface sealing of the area, which will provide a barrier to infiltration of precipitation.

In addition to ^{90}Sr discharges from burial sites, other radionuclides are known to be in the groundwater and to migrate to the surface environment. Alpha and beta activity were observed in water collected in 1959 and 1960 from two seeps in SWDA No. 4 and in the intermittent stream bordering the site on the south.[26] An analysis of seep water indicated that ^{90}Sr, ^{137}Cs, ^{95}Zr, ^{95}Nb, ^{60}Co, and rare earths were present and that ^{106}Ru, ^{3}H, and trivalent rare earths were the principal contaminants. At about the same time, ^{106}Ru, ^{137}Cs, and ^{60}Co were found in cores obtained from several new wells. In 1974, seeps and surface drainage contained primarily ^{90}Sr, ^{3}H, ^{125}Sb, and ^{244}Cm.[39]

The radioactive discharges from the seepage pits and trenches comprise a small fraction of the total discharge at White Oak Dam. The radionuclides contained in groundwater discharges from the seepage pits and trenches are ^{106}Ru, ^{125}Sb, and ^{60}Co. Tritium is also present in groundwater near these disposal areas. The ^{60}Co found in the groundwater was attributed to complex formation with ethylenediaminetetraacetic acid. This complexing agent may be responsible for mobilization of

^{60}Co in the vicinity of the pits and trenches and is possibly responsible for mobilization of other radionuclides as well.[39]

The discharge of ^{90}Sr from SWDA No. 5 is monitored at sampling station 4 on Melton Branch. The bulk of the ^{90}Sr passing this point (about 90%) is estimated to come from the burial ground, while about 10% is estimated to come from the Homogeneous Reactor Test settling basin and the contaminated area below it.[39] The ^{90}Sr discharge from SWDA No. 5 for the water years 1967 through 1976 is given in Table 3.20. The highest discharge (1968) originated from a source other than buried waste. These data do not demonstrate the uniformity in discharge that was observed at SWDA No. 4. It is believed that the difference in the discharges from the two disposal areas arises from differences in the time elapsed since completion of burial.[39] SWDA No. 5 has not yet begun to discharge ^{90}Sr uniformly, while SWDA No. 4 has been demonstrating uniform discharge since 1963 (and perhaps earlier). From SWDA No. 5, the discharge currently arises from trench overflow during the wetter winter months.

Table 3.20. Precipitation data and ^{90}Sr discharges from SWDA No. 5, 1967-1976

Water[a] year	Precipitation (cm)	Total ^{90}Sr discharge (GBq)	Discharge of ^{90}Sr (GBq/cm)
1967	153.8	32.9	0.213
1968	114.3	105	0.919
1969	101.8	32.6	0.320
1970	121.7	34.4	0.283
1971	122.6	21.5	0.175
1972	120.4	30.0	0.249
1973	181.0	52.9	0.292
1974	174.6	51.4	0.294
1975	146.6	27.8	0.190
1976	130.0	27.8	0.214

[a]Water year is September 1 through August 31.

Source: J. O. Duguid, D. F. Edgar, J. R. Gissel, and R. A. Robinson, Operations Division, ORNL, unpublished data, 1977.

3.2.4. Characterization of Sediments

Concentrations of trace elements in Clinch River sediments have been monitored at two stations by UCC-ND. Data collected for the years 1976 through 1980 (Table 3.21) are similar to results of sediment sampling conducted near the CRBR Project site (CRK 24.3–28.8) in March 1974 and April 1975.[14] Many of these levels exceed the background concentrations for pristine streams but do not indicate serious chronic contamination of sediments. The levels of mercury and chromium are somewhat elevated in comparison with usual background concentrations.[40]

Levels of polychlorinated biphenyls (PCBs) in Clinch River sediments have been monitored occasionally. Levels measured in April 1975 for the CRBR Project were 0.00064 μg/g at CRK 28.8 (CRM 17.9), 0.016 μg/g at CRK 25.6 (CRM 15.9) (mean of two analyses), and 0.00028 μg/g at CRK 24.3 (CRM 15.1).[14] These concentrations suggest that PCB contamination is not a serious problem in the Clinch River between Melton Hill Dam and the mouth of Poplar Creek.

Table 3.21. Sediment quality in the Clinch River

Element	Concentration[a] (µg/g dry weight basis)										
	CRK 20.3 (CRM 12.6) Upstream of mouth of Poplar Creek					CRK 15.8 (CRM 9.8) Brasher Island					
	1977	1978	1979	1980	Mean	1976	1977	1978	1979	1980	Mean
Al	45,000	59,000	26,500	15,000	36,200	32,000	36,000	34,000	26,000	43,000	34,200
Cd	<5	<5	<5	1	<4	<5	<5	<5	<5	2	<4.4
Cr	87	57	244	14	101	38	44	43	25	35	37
Cu	16	40	65	11	33	20	27	20	15	34	23
Hg	0.4	<0.2	<0.2	1	<0.45	<0.5	0.3	<0.2	<0.2	4	<1.0
Mn	406	1105	386	391	572	1320	1260	1875	985	2409	1570
Ni	55	50	26	14	36	325	33	30	30	37	91
Pb	38	35	37	<12	31	15	56	30	33	38	34
U	1.4	8	1	1	2.8	0.4	2.1	16	2	1	4.3
Th	<20	<40	<40	<20	<30	<0.1	<20	<40	<40	<20	<24
Zn	45	90	47	32	54	75	74	60	46	83	68

[a]Samples collected by coring device in July and November. Analyses performed on bulk (unsieved) samples by atomic absorption spectraphotometry. Concentrations reported for each year are an average of two samples.

Source: Environmental Monitoring Report, U.S. Department of Energy, Oak Ridge Facilities Reports for Calendar Years 1976–1980, Y/UB-6, -8, -10, -13, -15, Union Carbide Corporation — Nuclear Division, Oak Ridge, Tenn., 1977–1981.

Although the sediments of White Oak Creek basin[17] (and the Clinch River[41]) have been extensively analyzed for their radiological composition, systematic analysis of sediment composition has not been performed for stable (nonradiological) substances other than chromium and PCBs. Chromium levels in sediment were measured in 1976 in connection with a study of chromium levels in fish.[42] White Oak Lake surface sediments (0–5 cm) of less than 53 μm in diameter had an average concentration of 670 ± 170 μg/g (±2 std dev), with a range of 118 to 1100 μg/g. By comparison, the same size fraction of surface sediments collected from a control area in Melton Hill Reservoir contained an average chromium concentration of 44 ± 30 μg/g.

White Oak Creek also appears to have elevated levels of PCBs in sediment (Fig. 3.15). Average concentrations less than 0.3 μg/g were measured from sediments above ORNL, at White Oak Dam, and at the mouth of WOC. White Oak Creek below ORNL showed higher concentrations, with maximum highest levels (average = 1.1 μg/g) occurring below the confluence of WOC and Melton Branch.

The bottom sediments in the Clinch and Tennessee rivers below the entry of ORNL liquid effluents have been studied extensively and reported in the Clinch River Study series.[41] The inventory, retention, and distribution of radionuclides in the bottom sediment of the Clinch River[43] was investigated experimentally as part of the study over a 34-km (21-mile) reach of the stream from just upstream from the mouth of WOC [CRK 36.7 (CRM 22.8)] and downstream to the mouth of the Emory River [CRK 2.1 (CRM 1.3)]. At the time of the sampling (July 1962) the total becquerels in this stretch of the river was 5.6 TBq (150 Ci) of ^{137}Cs, 670 GBq (18 Ci) of ^{60}Co, 590 GBq (16 Ci) of ^{106}Ru, 110 GBq (2.9 Ci) of ^{90}Sr, and 370 GBq (10 Ci) of rare earths. Through comparison of the inventory with the release of each radionuclide to the Clinch River in the 1943–1962 liquid effluent and adjusting for radioactive decay, the percentage of retention was computed to be 21% for ^{137}Cs, 9% for ^{60}Co, 0.4% for ^{106}Ru, 0.2% for ^{90}Sr, and about 25% for the rare earths.[43] Based on the above computations and correcting for decay of the radionuclides retained in the sediment up to 1962, the inventory of radionuclides in the river through 1981 has been estimated and is shown in Table 3.22.

Table 3.22. Inventory of radionuclides in the bottom sediment in the Clinch River for various periods

	Activity (Bq)[a]		
Radionuclide	1943–1961[b]	1962–1981[c]	1943–1981[d]
^{60}Co	6.7E11	2.1E11	2.7E11
^{90}Sr	1.1E11	5.9E9	7.3E10
^{106}Ru	5.9E11	1.1E11	1.1E11
^{137}Cs	5.6E12	2.3E11	3.8E12
^{144}Ce[e]	3.7E11	6.2E11	6.2E11

[a]To convert Bq to Ci multiply by 2.7E-11.

[b]Inventory at the end of 1961, representing the accumulation over the first 19 years of operation (see Ref. 43).

[c]Inventory accumulated from 1962–1981 based on releases of radionuclides over the period shown in Table 2.10.

[d]Estimated total inventory accumulated over the 39 years of plant operation adjusting for radioactive decay only. Reduction by downstream scouring was not considered.

[e]All unidentified rare earths were considered as ^{144}Ce.

Ninety-five percent of the total amount of radionuclides in the sediment was found in the section of the channel of the Clinch River near the Gallaher Bridge [CRK 22.5 (CRM 14)] and confluence with the Tennessee River. While the highest concentration of radionuclides occurs at the mouth of the WOC [CRK 33.5 (CRM 20.8)], the smallest sectional volume of radioactive sediment was found in this part of the study reach. There was more or less regular sediment deposition along the river bottom; however, there were parts of each sampling section in which either no sediment deposits were found or the sediment present was not radioactive.

Estimates of exposure to external gamma radiation were measured by use of a device called the "flounder" described in ref. 44. Based on calculations and measurements made from 1954 to 1961 of the dose rates from contaminated sediments in the Clinch and Tennessee rivers[44] [and allowing for attenuation of about 1 m (3 ft) of water], an average dose from swimming in the streams for 1% of the year is shown in Table 3.23. It is felt these doses represent the upper values over the 38 years of plant operation. Allowing for decay of radionuclides deposited before 1961 and the reduced releases of radioactivity to the Clinch River since 1961, it is likely that the present comparable doses would be no higher, and most probably less, than those for the 1954–1961 period.

3.3 METEOROLOGY

3.3.1 Descriptive Regional Climatology

Oak Ridge is located within the broad valley of the upper Tennessee River between the Cumberland Mountains and Cumberland Plateau to the northwest and west, with elevations generally from 600 to 1000 m (2000 to 3200 ft), and the Great Smoky Mountains to the southeast, with elevations ranging from 1200 m to over 1900 m (4000 to 6200 ft).[45] The weather and climate of the Oak Ridge vicinity are greatly influenced by local and regional terrain (see Sect. 3.1).

Table 3.23. Annual dose received from external gamma from radioactive sediment while swimming[a] in the Clinch and Tennessee rivers[b]

River	Doses (mSv/year)[c] Measured values[d]	Calculated values[e]
Clinch	2.1E-3	8.0E-3
Tennessee	6.0E-4	1.4E-3

[a]Assumed swimming in the streams for 1% of the year.

[b]Assumed attenuation through approximately 1 meter of water.

[c]Average dose over the study period of 1954-1962 (Ref. 43). To convert mSv to mrem multiply by 100.

[d]Measured river bottom sediment with use of gamma detective device called a "flounder."

[e]Calculations based on the average radionuclide composition of the sediment.

The prevailing surface winds usually blow up valley from the southwest or down valley from the northeast. Under light wind regimes, local wind patterns tend to blow up valley during the day and down valley at night. Besides influencing wind direction, regional and local terrain also act to reduce surface wind speeds substantially. Because of their position north and west of Oak Ridge, the Cumberland Mountains tend to moderate temperat[illegible] retarding the southward progress of polar air masses, which are most frequent during [illegible] Extratropical cyclones, which are frequently retarded and weakened by the combi[illegible] the Cumberland Mountains and Plateau, show a tendency to travel either north or [illegible] of the region during their eastward migration.

Although precipitation is plentiful across the area, precipitation amounts tend to be enhanced near the Cumberland Mountains and to decrease from northwest to southeast across the province to a relative minimum near the foot of the Great Smoky Mountains.[46] Severe wind storms, tornadoes, and hail are rare in the upper Tennessee River basin. However, periods of air stagnation, which have a high potential for being air pollution episodes, occur relatively frequently in eastern Tennessee for a total of about one week per year.[47] High relative humidities and the heavy loading of the atmosphere with aerosols are endemic to this region and lead to poor visibility from haze much of the year. On the average, summer is the season with the poorest visibility,[48] although early morning fog, which can occur throughout the year, is most common during the late summer and early autumn (see Appendix D, Table D.1).

3.3.2 Meteorological Reporting Station

The meteorological observations made in the city of Oak Ridge, approximately 11 km (7 miles) northeast of the ORNL site, have been used to quantify the climate of the Oak Ridge vicinity. Meteorological observations at Oak Ridge have been made by the U.S. Weather Bureau and National Weather Service or by cooperative observers since May 1947.[49] These records constitute the longest record of meteorological data in the Oak Ridge area. The next nearest comparable observation station is located about 32 km (20 miles) southeast of the ORNL site at the McGhee-Tyson Airport south of Knoxville, Tennessee. Although the observations of the Oak Ridge station are no longer as comprehensive as those at Knoxville (e.g., wind observations have been discontinued), the Oak Ridge record provides a sufficient basis for describing the climate in the Oak Ridge vicinity.

Construction of a network of meteorological observation towers at or near the ORNL site is expected to be completed during the summer of 1982. This network will consist of two new 30-m (100-ft) towers and one new 100-m (330-ft) tower, to which it is hoped that a currently inoperative tower [roughly 30 m (98 ft) in height] already on the ORNL site will be added at some future date. All four towers will be equipped eventually with the same instrumentation to monitor wind speed and direction, temperature, and humidity. Each tower will be fitted with instruments at heights of 10 and 30 m (33 and 100 ft), with additional wind and vertical temperature gradient instrumentation at the top of the 100-m (328-ft) tower. The new meteorological observation network will provide excellent meteorological support for ongoing activities at ORNL as well as a greatly enhanced capability for research in the atmospheric sciences.

3.3.3 Temperature

The moderating influence of the Cumberland and Great Smoky mountains on an otherwise humid continental climate is noticeable in the temperatures observed at Oak Ridge. Seldom do temperatures rise above 38°C (100°F) or drop below −18°C (0°F). The annual mean temperature at Oak Ridge is 20.3°C (68.6°F); monthly means range from 3.4°C (38.1°F) in January to 25°C (77°F) in July.[49] Although large day-to-day temperature fluctuations are possible during the winter because of the occasional passage of polar cold fronts, daily temperatures tend to change gradually with the passing seasons. The average diurnal temperature range is about 12°C (22°F).[49] A more complete summary of the Oak Ridge temperature record is provided in Appendix D, Table D.2.

3.3.4 Precipitation

Eastern Tennessee typically receives substantial amounts of precipitation throughout the year, with peak amounts at Oak Ridge falling from December through March and a secondary peak during July.[49] Precipitation during the winter and early spring usually is caused by extratropical cyclones and their attendant fronts and falls quite uniformly over wide areas. These periods of precipitation can last for many hours at fall rates considered light to moderate. Warm weather precipitation typically falls from brief but very intense local showers and thunderstorms, which most often form during the heat of the afternoon and evening and dissipate soon after sundown. Local topographic features in the Cumberland Mountains tend to enhance this summer shower activity, leading to areal differences of precipitation amounts not usually observed during the winter. Autumn precipitation tends to be light, and extended dry periods of a week or more are not uncommon.

The vast majority of the precipitation [139.7 cm (55.0 in.) of water equivalent annually] observed in Oak Ridge falls as rain. A trace or more of snow has been reported each winter on record, with the annual average snowfall of 26.4 cm (10.4 in.).[49] Snowfall is frequently elevation dependent: higher elevations in the Cumberland Mountains and on the Cumberland Plateau receive greater quantities than locations in the valley. Periods of freezing rain are not uncommon during the winter in the Valley and Ridge Physiographic Province. Cold air is frequently trapped in the lowlands as the warmer and more moist air associated with extratropical cyclones advects in at greater elevations. Thus, while rain may fall on the Cumberland Plateau and in the Cumberland and Great Smoky mountains, freezing rain can occur in the valley between. However, freezing temperatures seldom persist for more than a few days, permitting whatever snow and ice that does accumulate to thaw rapidly. A quantitative summary of the precipitation record for Oak Ridge is presented in Appendix D, Table D.3.

3.3.5 Wind

The wind climatology of Oak Ridge and vicinity is caused by the combined influences of synoptic weather systems and the region's complex terrain. While the synoptic scale atmospheric pressure differences are the driving forces behind the region's overall wind field, this wind field is shaped by the physical channeling effect of the region's mountains and ridges, resulting in reduced wind speeds and predominantly up or down valley winds.

In addition to the influence of regional topography on the wind, local relief plays an important part in the local wind field during frequent relatively calm periods. Under near calm conditions, the diurnal wind cycle tends to have winds blowing up valley during the day and down valley at night, which leads to possible differences of wind direction from one valley to the next. An example of such a direction difference is the prevailing southwesterly wind observed at Oak Ridge[49] and the prevailing northeasterly wind at nearby Knoxville.[50]

However, even within an area the size of the ORR, the wind can vary considerably. The wind records for the ORNL, Y-12, and ORGDP sites during the 5-year period 1956–1960 indicate a much higher frequency of northeast wind at ORGDP than at either ORNL or the Y-12 Plant.[51] The wind roses (figures showing frequency of occurrence of wind direction sectors and wind speed classes) for ORNL during this 5-year period (for both lapse and inversion conditions) are shown in Figs. 3.16 and 3.17.[51] These figures graphically show the predominance of the southwest and northeast winds under both atmospheric stability conditions. The observation site for these data was a meterological tower approximately 45 m (150 ft) northeast of the 2001 building on a rise roughly 27 m (90 ft) above the floor of Bethel Valley.[51] A more comprehensive summary of the wind record at Oak Ridge is presented in Appendix D, Table D.4.

3.3.6 Air Quality

Oak Ridge National Laboratory is located within Air Quality Control Region 207, which includes most of eastern Tennessee and part of southwestern Virginia.[52] Ambient air quality

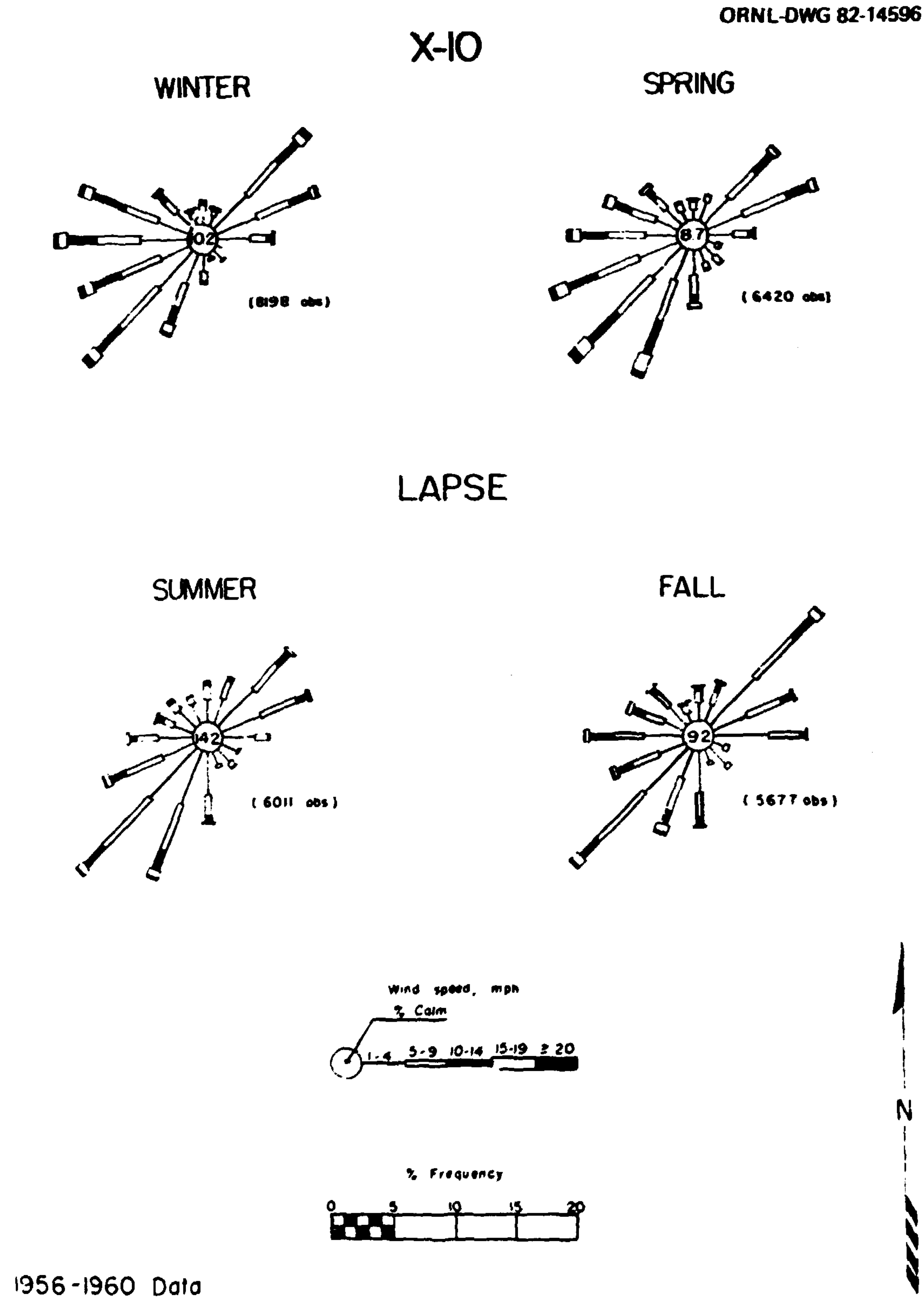

Fig. 3.16. Wind roses for ORNL site under lapse conditions for each season, 1956–1960. Source: W. F. Hilsmeier, *Supplementary Meteorological Data for Oak Ridge*, ORO-199, U.S. Atomic Energy Commission, 1963, pp. 35 36.

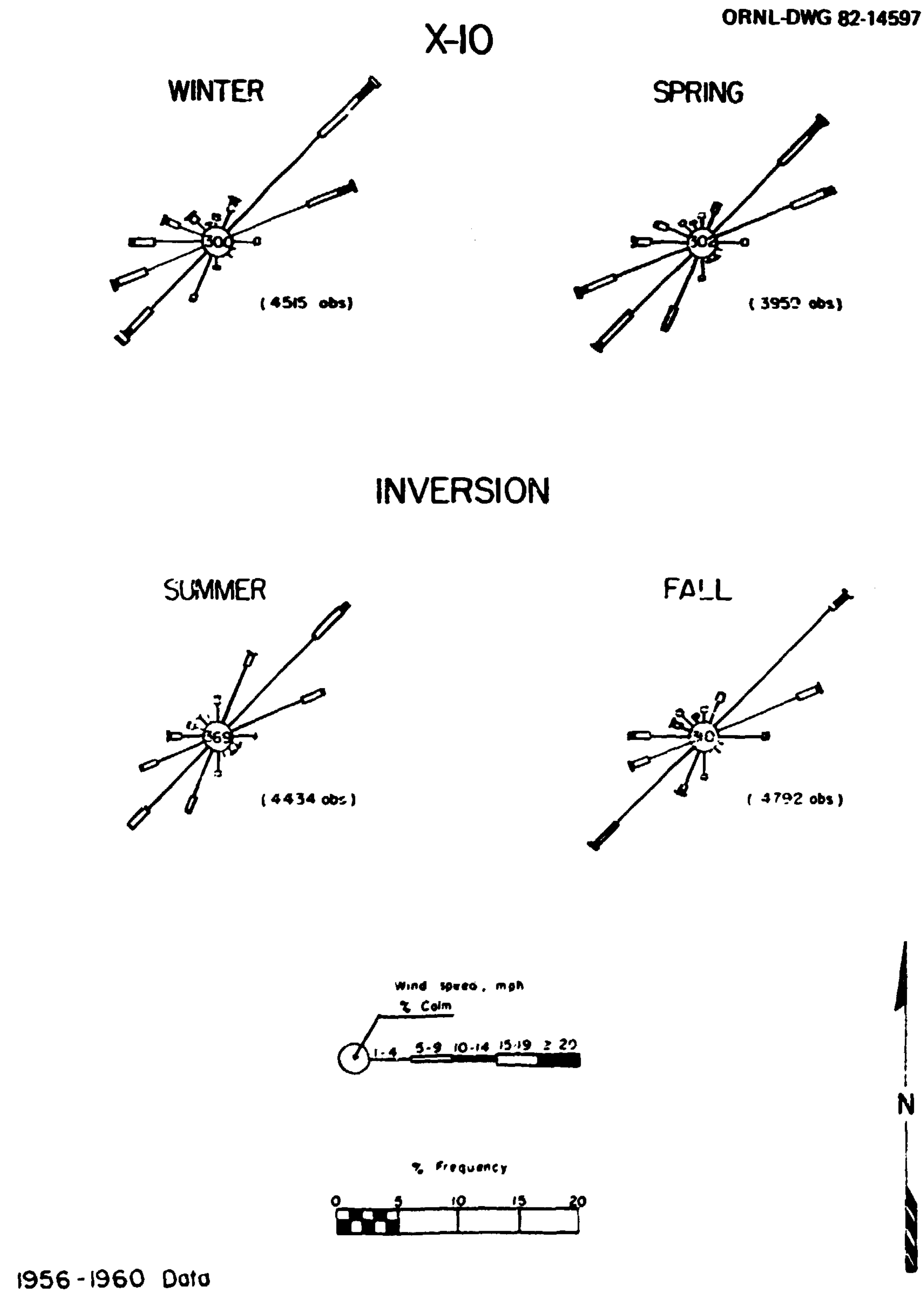

Fig. 3.17. Wind roses for ORNL site under inversion conditions for each season, 1956–1960. Source: W. F. Hilsmeier, *Supplementary Meteorological Data for Oak Ridge*, ORO-199, U.S. Atomic Energy Commission, 1963, pp. 35–36.

standards have been promulgated by EPA for total suspended particulates (TSPs), sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), and ozone. Of these five criteria pollutants, all but CO have been subject to ambient concentration monitoring within a roughly 20-km (13-mile) radius of ORNL during the period 1976 through 1980, with these data compiled by the Tennessee Division of Air Pollution Control. A representative selection of available monitoring data from the Oak Ridge area is presented in Tables 3.24 through 3.27.

Table 3.24. Total suspended particulate (TSP) concentrations ($\mu g/m^3$) in Oak Ridge, Tennessee vicinity[a]

Monitor location	Highest 24 h					Second highest 24 h					Annual average[b]				
	1976	1977	1978	1979	1980	1976	1977	1978	1979	1980	1976	1977	1978	1979	1980
Oak Ridge	106	171	152	134	145	103	128	123	96	141	63	69	68	52	75
TVA Bull Run			266	173	142			104	95	128			46	43	51
Clinton	117	157				114	124				66	62			
TVA Anderson County			99	108	106			82	102	88			44	43	49
TVA Roane County			109	136	97			104	122	90			50	47	49
Kingston sewage treatment plant	162	138	167	108	137	147	126	105	97	107	65	50	52	41	58
Harriman	114	178	165	133	106	113	141	137	130	98	65	62	58	51	55

[a]The primary ambient air quality standard is 75 $\mu g/m^3$, annual geometric mean, and a maximum of 260 $\mu g/m^3$ averaged over a 24-h period and not to be exceeded more than once per year. The secondary standard is 150 $\mu g/m^3$, a 24-h maximum not to be exceeded more than once per year.

[b]Annual geometric mean.

Source: Tennessee Division of Air Pollution Control, "Comparison of Air Quality Data With the NAAQS," State of Tennessee, 1982.

The annual TSP concentration monitored at Oak Ridge during 1980 exceeded the federal secondary standard and equaled the federal primary TSP standard. Although a high annual average TSP concentration was observed, the recent trend at this receptor has been to be within acceptable concentration limits. Since the other monitors in this area registered TSP concentrations well below the secondary TSP standard, the Oak Ridge monitor may have been subject to unusual conditions, such as nearby construction, as well as the possible enhancement of natural dust sources by the unusually hot and dry weather of 1980.

Based upon the 1980 monitoring data and the appropriate federal standards, the air quality in the ORNL vicinity was within federal primary ambient air quality standards for SO_2 and TSP and had been within standards for NO_2 and ozone when last monitored. However, EPA has designated the area around Oak Ridge to be a nonattainment area for NO_2 and ozone, to be unclassified for CO, and to be in attainment for SO_2 and TSP.[53] Thus, while the air quality in the ORNL vicinity has recently met federal air quality standards, these standards have not been met for enough consecutive years to allow reclassification of the area to attainment for NO_2 and ozone.

The Local Air Monitoring (LAM) network at ORNL consists of 23 monitoring sites within the ORNL complex in Bethel and Melton valleys (see Fig. 3.18).[54] Five of these LAM sites have been used to collect TSP samples during 1980. The results of this local TSP monitoring and the federal standards are shown in Table 3.28. The 1980 annual average TSP concentrations at these five sites were well below the secondary federal TSP standards and thus within acceptable limits.

Table 3.25. Sulfur dioxide (SO_2) concentrations ($\mu g/m^3$) in Oak Ridge, Tennessee vicinity[a]

Monitor location	Highest 3 h					Second highest 3 hr					Highest 24 h					Second highest 24 h					Annual average[b]				
	1976	1977	1978	1979	1980	1976	1977	1978	1979	1980	1976	1977	1978	1979	1980	1976	1977	1978	1979	1980	1976	1977	1978	1979	1980
DOE No. 4		476	306		252		419	239		220		192	73		110		169	68		108		30	22		22
DOE No. 5	528	572	1070			485	467	796			207	235	319			166	174	270			30	35	56		
TVA Bull Run			402	664	245			314	349	201			130	149	72			80	116	60			13	11	7
TVA Anderson County				594	183				472	131				126	93				92	76				10	12
Kingston sewage treatment plant	1891	432	769		452	1565	293	153		348	648	126	134		111	550	98	13		98	40	19	15		22
TVA Kingston			410	332	437			376	314	419			80	130	101			75	114	80			17	16	12
TVA Roane County			952	515	297			428	428	297			147	159	97			130	138	85			22	19	19

[a]The air quality standards for SO_2 are 80 $\mu g/m^3$, annual arithmetic mean; the maximum 24-h concentration is 365 $\mu g/m^3$ not to be exceeded more than once per year; the maximum 3-h standard is 1300 $\mu g/m^3$ not to be exceeded more than once per year.

[b]Arithmetic mean.

Source: Tennessee Division of Air Pollution Control, "Comparison of Air Quality Data With the NAAQS," State of Tennessee, 1982.

Table 3.26. Nitrogen oxides (NO_x) concentrations ($\mu g/m^3$) in Oak Ridge Tennessee vicinity[a]

Monitor location	Annual mean[b] 1976	1977	1978	1979
Clinton	33	30		
Kingston (1st and Lovelace Street)		45	31	
Rockwood (Telephone Company)	39	36	37	32

[a]The air quality standard for oxides of nitrogen, expressed as nitrogen dioxide, is 100 $\mu g/m^3$ annual arithmetric mean.

[b]Arithmetic mean.

Source: Tennessee Division of Air Pollution Control, "Comparison of Air Quality Data With the NAAQS," State of Tennessee, 1982.

Table 3.27. Daily maximum ozone (O_3) concentration ($\mu g/m^3$) in Oak Ridge, Tennessee vicinity[a]

Monitor location	Highest		Second highest		Third highest	
	1977	1978	1977	1978	1977	1978
Kingston (1st and Lovelace Street)	345	227	317	217	309	215

[a]The air quality standard for ozone is 0.120 ppm (235 $\mu g/m^3$). The standard is attained when the number of calendar days with exceedances is not greater than one. See 40 CFR 50.9.

Source: Tennessee Division of Air Pollution Control, "Comparison of Air Quality Data With the NAAQS," State of Tennessee, 1982.

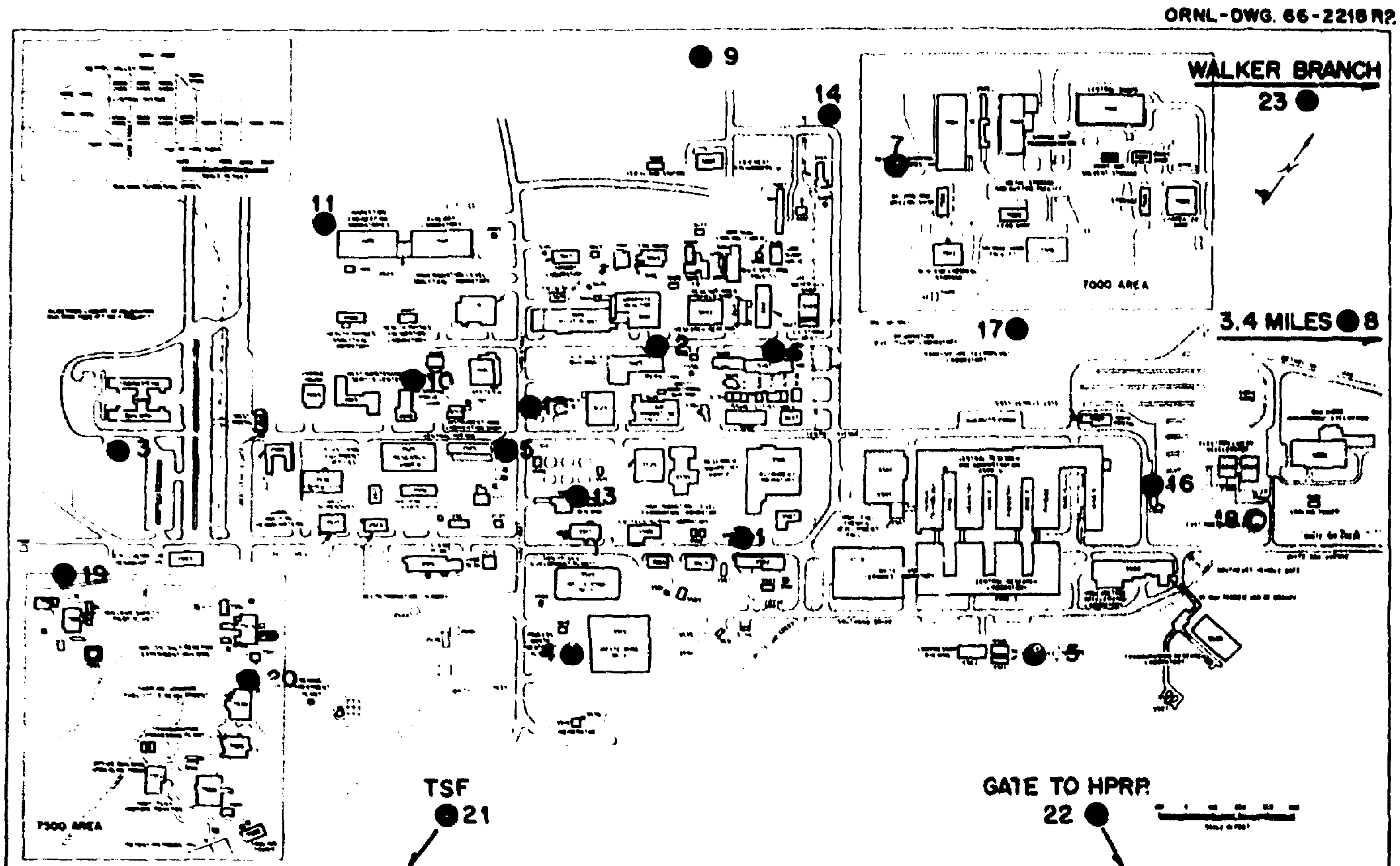

Fig. 3.18. Local air-monitoring (LAM) network. Source: J. A. Auxier and D. M. Davis, *Industrial Safety and Applied Health Physics Annual Report for 1980*, ORNL-5821, Oak Ridge National Laboratory, Oak Ridge, Tenn., modified Fig. 4.1.1.

Table 3.28. Annual average suspended particulate (TSP) concentrations observed at ORNL Local Air Monitoring (LAM) network sites, 1980[a]

Site	(μg/m³)
LAM-1	44
LAM-2	40
LAM-6	42
LAM-7	44
LAM-15	38

[a]The primary ambient air quality standard is 75 μg/m³, annual geometric mean.

Source: J. A. Auxier and D. M. Davis, Industrial Safety and Applied Health Physics Annual Report for 1980, ORNL-5821, November 1981, p. 52.

In addition to the LAM network used to monitor TSP, a program to monitor fluorides and radiological materials has been established on the ORR and in the surrounding countryside.[55] The release of fluorides within the ORR is almost entirely caused by the operations at ORGDP and thus is not germane to this analysis. The results of the radiological monitoring are discussed in Sect. 3.5.

3.4 ECOLOGY

3.4.1 Terrestrial Ecology

3.4.1.1 Overview

The ORR consists of approximately 15,000 ha (37,000 acres) within the Valley and Ridge Physiographic Province of eastern Tennessee. The reservation was predominantly agricultural land before federal acquisition in 1942 for use in the wartime Manhattan Project. The land was withdrawn from public access, allowing much of it to revert to natural plant cover. About 10,500 ha (25,950 acres) currently are managed for environmental research, wood-fiber production, or both (Sect. 2.3.3 and 2.8.5).

3.4.1.2 Vegetation

The vegetation of the undeveloped portions of the ORNL site is similar to the vegetation of the ORR as a whole, which is described in a number of publications.[56–58] The following description of vegetation was obtained from these references and should be representative of the ORNL site.

Plant communities on the ORR are characteristic of those found in the intermountain regions of Appalachia from the Allegheny Mountains in southern Pennsylvania to the southern extension of the Cumberland Mountains in northern Alabama. The dominant association on the reservation is oak-hickory (*Quercus-Carya*) forest, although elements of the mixed mesophytic forest commonly found in the Cumberland Mountains are also present in scattered areas.

The reservation's oak-hickory forest is typified by extensive stands of oak, hickory, and other hardwood species. Within the hardwood forest, scattered pines and small natural stands dominated by pines are also present. Yellow-popular (*Liriodendron tulipifera*) often forms nearly pure stands on well-drained bottomlands and lower slopes; willow (*Salix discolor*), sycamore (*Platanus occidentalis*), and box elder (*Acer negundo*) border streams and are dominant on poorly drained floodplains. Species more commonly found in the mixed mesophytic association, such as beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), magnolia (*Magnolia acuminata*), buckeye (*Aesculus* spp.), and basswood (*Tilia americana*), often occur in the coves and on the sheltered slopes. In addition, approximately 1740 ha (4300 acres) of the reservation were planted in loblolly pine (*Pinus taeda*) between 1947 and 1956; smaller areas have since been planted in loblolly pine, black walnut (*Juglans nigra*), river birch (*Betula nigra*), sycamore, and yellow poplar.

The vegetation of the ORR has been categorized into the following seven types: pine, hemlock and/or white pine, cedar, bottomland, upland and northern hardwoods, and nonforest.[59] A total of 1370 plant species have been identified on the reservation. The abundance of various habitats on the reservation is presented in Table 3.29. The major plant communities and principal dominant species are described in the following paragraphs (see vegetation map in ref. 57).

Pine and pine-hardwood. This forest type includes pine plantations and natural forest stands dominated by pines. Large tracts of loblolly pine (*Pinus taeda*) were planted in the 1940s and 1950s and are still managed for pine. The plantations are monocultures, whereas the natural pine-dominated forests include oaks (*Quercus* spp.), hickories (*Carya* spp.), and yellow poplar. Once the

Table 3.29. Rough estimates of the abundance of various habitats on the Oak Ridge Reservation[a]

Habitat	Percent of the reservation	
Pine	29.8	
Pine plantations		14.8
Natural		15.0
Cedar and open scrub	3.7	
Hardwoods	51.0	
Upland hardwoods		48.1
Bottomland hardwoods		2.5
Scrub hardwoods		0.4
Swamp or marsh	0.1	
Fields, old field, pasture, lawns	7.6	
Roads	2.6	
Rights-of-way	5.3	

[a]Facility areas within fences not included.

Source: R. L. Kroodsma and L. K. Mann, Environmental Sciences Division of the Oak Ridge National Laboratory.

natural pine-dominated stands were very extensive on the reservation and occupied large areas of all sectors (see the vegetation map in ref. 57). However, because of natural succession and selective harvesting of pine in this original forest, most areas are now dominated by hardwood species with small stands of natural pine scattered among the hardwoods. Also, some of the original forest was cleared and converted to pine plantations during the 1960s and 1970s. Before the pine harvests, the original forest was dominated by shortleaf pine (*Pinus echinata*) and Virginia pine (*Pinus virginiana*).

Hemlock, white pine, and hardwood. This type, representing a Southern Appalachian extension of a northern (and higher elevation) forest, is rare on the reservation. Small areas on Pine Ridge, Black Oak Ridge, Haw Ridge, and north of Melton Hill Dam—all in the western one-half of the reservation—are virtually all that remain. Total area is estimated to be no more than 40 ha (100 acres). Dominant species are hemlock (*Tsuga canadensis*) and white pine (*Pinus strobus*).

Cedar, cedar-pine, and cedar-hardwood. This type is extensive on the reservation and predominates in Bethel Valley and in southern areas near the Clinch River and Melton Hill Reservoir. It is markedly less abundant north of Bear Creek Road. It is best developed on shallow limestone (or dolomite) and appears rapidly following disturbance. Thus the present pattern reflects both substrate and the history of land use. The dominant species is eastern red cedar (*Juniperus virginiana*), associated with shortleaf and Virginia pine, yellow poplar, oaks, hickories, redbud (*Cercis canadensis*), sassafras (*Sassafras albidum*), and other hardwoods.

Bottomland hardwood. This type, restricted to narrow floodplains along creek bottoms, comprises a small portion of forest communities of the ORR. Small stands occur along Gum Hollow Creek, Bear Creek, and Grassy Creek; larger stands appear along WOC and East Fork Poplar Creek. Virtually all of the bottomland hardwoods are located in the western two-thirds of the reservation. Dominant species are cottonwood (*Populus deltoides*), sycamore willow (*Salix* spp.), silver maple (*Acer saccharinum*), and river birch.

Upland hardwood. This type originally occupied roughly 20% of the reservation's land area (see vegetation map in ref. 57). The largest concentrations occurred on Black Oak, East Fork, Pine, Chestnut, and Copper ridges. Scattered patches occurred throughout the reservation area. Subsequent to harvesting of pines in the original pine-hardwood forests, upland forests dominated by hardwoods now occupy about 48% of the reservation area. This forest is essentially an oak-hickory complex representative of the terminal type in this region of the eastern United States. Important species include chestnut oak (*Quercus prinus*), white oak (*Quercus alba*), black oak (*Quercus velutina*), northern red oak (*Quercus rubra*), scarlet oak (*Quercus coccinea*), post oak (*Quercus stellata*), various hickories, ash (*Fraxinus* spp.), yellow poplar, red maple (*Acer rubrum*), black gum (*Nyssa sylvatica*), dogwood (*Cornus florida*), beech, and others. A showy vernal flora is characteristic of this type, and many common wildflowers in East Tennessee are virtually restricted to upland hardwood forests.

Northern hardwood. Northern hardwood forest is rare on the ORR; it occurs in small areas only on Black Oak Ridge and on Copper Ridge in the western part of the reservation. Composition is similar to the upland hardwood forest with a mixture of sugar maple, hemlock, basswood, and buckeye.

Nonforest. This is a diverse category that includes primarily grasslands, devegetated areas, and cultural features. The grasslands are of two types. One type is native or seminative grassland that is either maintained (e.g., under power transmission lines) or is reverting to forest. Dominants include species of bluestem (*Andropogon* spp.), fescue (*Festuca* spp.), and bluegrass (*Poa* spp.). The second type is cultivated grassland (lawns and pastures). These predominate in and around the three plant areas (ORNL, Y-12, and ORGDP) and on CARL lands at the eastern extremity of the reservation. Grasses include fescues, bluegrass, orchard grass (*Dactylis glomerata*) and a number of other species.

3.4.1.3 Fauna

The plant communities on the reservation provide habitat for a large number of animal species. About 60 species of reptiles and amphibians, more than 120 species of terrestrial birds (excluding 32 species of waterfowl, wading birds, and shorebirds), and about 40 species of mammals have been recorded.[56] Species characteristic of the reservation's habitats are listed in Table 3.30.

Habitats supporting the greatest number of species are those dominated by hardwood tree species, followed by wetlands, then old fields, fields (e.g., pastures, cultivated fields), and pine plantations. Hardwoods are required by most species occurring in hardwood-dominated or pine-dominated forests. Of all the herptile, bird, and mammal species that breed on the reservation, only the pine warbler requires pine. Bird species characteristic of old fields require the presence of brushy vegetation such as shrubs, saplings, and blackberry (*Rubus*).

Most of the species (e.g., wild turkey, red-tailed hawk, red fox, bobcat, white-tailed deer) that use more than one habitat type (e.g., forest and fields, Table 3.29) are more dependent on the presence of trees, forest, or brush than on the presence of fields. However, limited amounts of cultivated or old fields are beneficial to several of these species. Populations of such species are often densest in predominantly forested areas with small fields interspersed among the forest.

In contrast to the reservation, the surrounding countryside consists of a much greater proportion of cultivated fields, pastures, and residential areas. In this area the forests are much more fragmented than on the reservation, and the rate of species turnover (loss) may be high because of the small size of the forested tracts.[60] Because of the greater continuity of forests on the reservation and because of a lack of human disturbance over much of the area, many forest wildlife species that are disproportionately affected by forest fragmentation[60] may find an abundance of suitable habitat on the reservation. Thus, the reservation may serve as a refuge for wildlife and as a source of colonizing immigrants into surrounding areas. In other words, the reservation may serve outlying areas by providing a continual source of forest wildlife.

3.4.1.4 Rare and endangered species

Plants. Two plant species on the federal list of endangered plants[59] have been recorded in Tennessee. The Tennessee purple coneflower (*Echinacea tennesseensis*) was found in Davidson and Rutherford counties, and the green pitcherplant (*Sarracenia oreophila*) was recorded in Fentress County.[61] The county closer to the ORR is Fentress County, approximately 65 km (40 miles) northwest. These two species are not likely to occur on the reservation. They were not included on a list of plant species likely to be present in the area but not yet found.[62]

A list of rare and endangered plant species was prepared for the state of Tennessee,[61] but the list does not yet have the state's official legal recognition. None of the plant species listed as endangered has been found on the reservation, although searches are conducted periodically to locate rare species.[62] Nine species listed as threatened, rare, or of special concern are present on the reservation;[62] they primarily are in areas designated as natural areas.[56] Several other species on the state list were recently located in a cedar barren across the Clinch River from the ORGDP. These have not been found on the ORNL site.

Animals. The geographic ranges of seven animal species listed as endangered on the federal list[63] encompass the ORNL site. The gray bat (*Myotis grisescens*) hibernates and raises its young in caves and is almost unknown outside of caves.[64,65] Although there are several caves on the reservation that were checked for bats, no bats of any species were found.

The Indiana bat (*Myotis sodalis*) hibernates in caves during the winter and raises the young in maternal colonies located primarily in hardwood forests along streams.[64,66] Several caves have been designated as critical habitat for Indiana bats. One such cave is in Blount County, Tennessee, located more than 30 km (19 miles) from the reservation.[67] Indiana bats have also been observed at a cave in Campbell County 90 km (55 miles) from the reservation.[56] Although no surveys have been conducted to locate Indiana bats on the reservation during the spring and summer, it is possible that maternity colonies are located in the area.

Table 3.30 Amphibians, reptiles, birds, and mammals characteristic of or dependent on various habitats of the Oak Ridge Reservation

	Field	Old field[a]	Pine plantations	Hardwood and hardwood-pine forest	Water and wetlands	Combination of two or more habitats
Number of bird species	10	13	3	53	39	32
Number of mammal species	2	3	0	7	4	19
Number of reptile and amphibian species	0	0	0	7	21	32
Representative species	Grasshopper sparrow Eastern meadowlark Least shrew Eastern mole	Prairie warbler Yellowthroat Blue grosbeak Yellow-breasted chat Indigo bunting Field sparrow Towhee Eastern harvest mouse Hispid cotton rat Eastern cottontail	Pine warbler Pine siskin Red crossbill	Cooper's hawk Yellow-billed cuckoo Red-bellied woodpecker Downy woodpecker Wood pewee Acadian flycatcher Worm-eating warbler Black and white warbler Kentucky warbler Tufted titmouse Scarlet tanager Ovenbird White-breasted nuthatch Indiana bat Red bat Hoary bat Eastern chipmunk Gray squirrel Flying squirrel White-footed mouse Box turtle Broad-headed skink Northern ringneck snake	Wood duck Scaup Ring-necked duck Green heron Great blue heron Belted kingfisher Mink Beaver Rice rat Muskrat Snapping turtle Map turtle Eastern painted turtle Northern water snake Queen snake Red-spotted newt Two-lined salamander Bullfrog	Bobwhite Red-tailed hawk Turkey vulture Common crow Barn swallow Cardinal Opossum Southeastern shrew Short-tailed shrew Big brown bat Little brown bat Keen's myotis Silver-haired bat Eastern pipistrel Evening bat Raccoon Long-tailed weasel Striped skunk Red fox Gray fox Bobcat Woodchuck Golden mouse Pine vole White-tailed deer Green anole Northern brown snake Northern black racer Northern copperhead Slimy salamander Cave salamander Upland chorus frog Pickerel frog

[a]The "o   ield" category includes young pine plantations prior to canopy closure as well as broad-leaved vegetation types.
Source: R. L. Kroodsma, Environmental Sciences Division of the Oak Ridge National Laboratory.

The eastern cougar (*Felis concolor cougar*) may be extirpated in the eastern United States. Although numerous sightings of cougars have occurred during the last decade (including sightings on the ORR), a concerted search for cougar by the U.S. Fish and Wildlife Service has failed to show conclusive evidence of a cougar population.[68] Therefore, the numerous, apparently valid sightings were probably of individuals of the western cougar races that escaped or were released from captivity. Thus, a resident population of eastern cougars probably does not exist in the Oak Ridge area. The reservation may provide suitable habitat for cougars because of a lack of human disturbance and a growing deer herd that provides suitable prey.

The bald eagle (*Haliaeetus leucocephalus*) occurs fairly regularly in the Oak Ridge area, primarily on the numerous reservoirs of the Tennessee River system. The eagles are more frequent during the winter than during the summer. The winter eagles are probably mostly of the northern race, originating from several northern states and Canada. The populations of eagles from these areas are listed as threatened rather than as endangered. Eagles occurring in the summer may originate from the endangered breeding population in Florida, where nesting occurs in the winter.[69] No eagles are known to nest in the area around the ORR, although the area apparently provides suitable habitat. An attempt is currently being made to develop a breeding population of eagles in western Tennessee in the Land-Between-the-Lakes area.

The peregrine falcon (*Falco peregrinus*) has not been recorded on the ORR. However, it may occur in the area as an extremely rare migrant or winter visitor. No peregrine falcons are known to breed anywhere in the Tennessee region.

The Bachman's warbler (*Vermivora bachmanii*) is the rarest woodland warbler and may be extinct. It has been known to breed very locally in moist deciduous woodlands in the southeastern United States. Recent searches conducted by the U.S. Fish and Wildlife Service and the U.S. Forest Service have failed to locate this species.[68] It has not been recorded on the ORR.

The red-cockaded woodpecker (*Picoides borealis*) is a resident species of pine forests in the southeastern United States. It nests in mature to old-age pine trees infected with the fungal red heart disease (*Fomes pini*).[70,71] In Tennessee the population is at the northern limits of its range and as of 1977 may have numbered from 6 to 25 birds.[70] Since 1971, red-cockaded woodpeckers have been found at four separate locations in Tennessee, all in eastern Tennessee. These are Pickett State Park, Pickett County; Great Smoky Mountains National Park, Blount County; Campbell County; and Catoosa Wildlife Management Area in Cumberland and Morgan counties.[70] The ORR is centrally located with respect to these locations and is only about 25 km (15 miles) from the Catoosa Wildlife Management Area. Therefore, the reservation is located in an area that could potentially be colonized by these East Tennessee birds. Suitable habitat for the red-cockaded woodpecker is currently lacking on the reservation, although with time and with proper management, the reservation's numerous pine plantations could develop into suitable habitat.

In addition to these federally listed endangered species, the state of Tennessee lists five other animal species as endangered within the state.[72] This list does not have legal status. The Mississippi kite (*Ictinia mississippiensis*) breeds in western Tennessee, and the golden eagle (*Aquila chrysaetos*) and common raven (*Corvus corax*) occur in the Appalachian Mountains of eastern Tennessee. Their geographic distributions indicate that these species do not occur with any regularity on the ORR. The osprey (*Pandion haliaetus*) is becoming increasingly common in the Oak Ridge area, where it occurs regularly on the rivers and lakes during migration. It also nests on Watts Bar Lake and may at some time begin nesting along Melton Hill Lake, which adjoins the reservation.

The Bachman's sparrow (*Aimophila bachmanii*) typically occurs in open pine woods with a heavy ground cover of grasses, shrubs, and brush; in weedy abandoned fields; in open wooded pastures; and in very young pine plantations.[73] This species formerly occurred throughout Tennessee but recently has been very rare and locally distributed. Because apparently suitable habitat is plentiful, the reason for this species' decline is unknown. As of 1976, evidence of breeding (i.e., nests or juvenile birds) in Tennessee had been recorded on only four occasions during the previous 30 years.[73] Prior to 1982, the last record in the Oak Ridge area was of a pair of adult birds on the

ORR at Bear Creek Road and Highway 95 on June 20, 1975.[73] In late May 1982, two singing territorial males were observed several times over about a 2-week period 1 km (0.6 mile) northwest of the ORNL central facilities area. Both were in very young pine plantations with a dense growth of tall grasses. Habitats that appear to be suitable for this species occur in several areas on the ORR (old weedy fields and very young pine plantations).

3.4.2 Aquatic Ecology

The aquatic communities potentially affected by ORNL include WOC, Melton Branch, White Oak Lake, WOC embayment, and the Clinch River CRK 30.5 (CRM 19) downstream from the mouth of WOC. The aquatic biota of these communities have been studied periodically since about 1950, and several recent studies have been quite extensive. The following descriptions of aquatic ecology in the Clinch River and in WOC rely mostly on the recent survey by Loar et al., who sampled the streams between March 1979 and June 1980.[18]

3.4.2.1 Clinch River

The hydrologic regime established by releases from Melton Hill Dam (Sect. 3.2.1) has major influence on the ecology of the Clinch River near ORNL. The river's daily discharge typically varies from almost zero flow (slack pond) to 283 to 566 m^3/s (10,000 to 20,000 cfs), which may last for several hours. The velocity of this pulse discharge scours the river channel, and substrate consists of exposed bedrock.[18] Near the mouth of WOC, deposition of sediment is confined to the regions immediately adjacent to the banks. In these areas substrates consist mostly of fine clay, silt, and sand together with some gravel and small rubble. Growth of macrophytes is apparently limited by high current velocity and the fluctuation of water levels. At some locations cover for aquatic species is provided by overhanging and submerged tree limbs, shrubs, tree stumps, and at times of high water level, partially submerged riparian vegetation.[18] Appreciable deposition of sediments on the bed of the river begins near Gallaher Bridge at about CRK 22.5 (CRM 14.0).

The release of cold hypolimnetic water from Norris Dam can influence water temperatures throughout Melton Hill Reservoir and in the lower Clinch River. Surface temperatures in the Clinch River just below Melton Hill Dam rarely exceed 21°C (70°F).[74]

A major survey of aquatic communities from CRK 24.1 to 29.0 (CRM 15 to 18) was performed in 1974 and 1975 in connection with the CRBRP.[14] Information from this survey is summarized in a food web diagram (Fig. 3.19). In 1979 and 1980, aquatic biota were sampled[18] in the WOC basin and at points in the Clinch River upstream [CRK 35.4 (CRM 22.0)] and downstream [CRK 30.6 (CRM 19.0)] from the creek's mouth (Fig. 3.11). The number of taxa collected and the dominant group are summarized for the downstream station and the WOC basin in Table 3.31. Very little difference was noted between the upstream and downstream Clinch River stations. The phytoplankton of the Clinch River was dominated by diatoms in the spring. This was followed by a shift to dominance by green algae and *Cryptomonas* in the summer and a return to a diatom-dominated assemblage with lower water temperatures in the fall. No extraordinary algal blooms were observed, and blue-green algae remained a minor component of the assemblage. However, the ratio of biomass to chlorophyll *a* (the autotrophic index or AI) for eight samples averaged 320 for CRK 30.6 (CRM 19.0) and 365 for CRK 35.4 (CRM 22.0).[18] Values of the AI that exceed 100 suggest enrichment of the water's organic content.[75]

The zooplankton in the Clinch River were dominated by rotifers. The benthic macroinvertebrate community consisted mostly of midge larvae, with aquatic earthworms and the Asiatic clam occasionally dominant. Ichthyoplankton of eight taxa were collected together with many unidentified eggs. Clupeids were dominant, and larvae of freshwater drum, carp, suckers, minnows, crappies, and bass were collected in smaller numbers.

The fish community of the lower Clinch River includes at least 21 species collected at the two stations near WOC. Gizzard shad was the most abundant; sauger, yellow bass, and bluegill were also numerous. Popular sport fishes in the lower Clinch include sauger, bluegill, white bass, and

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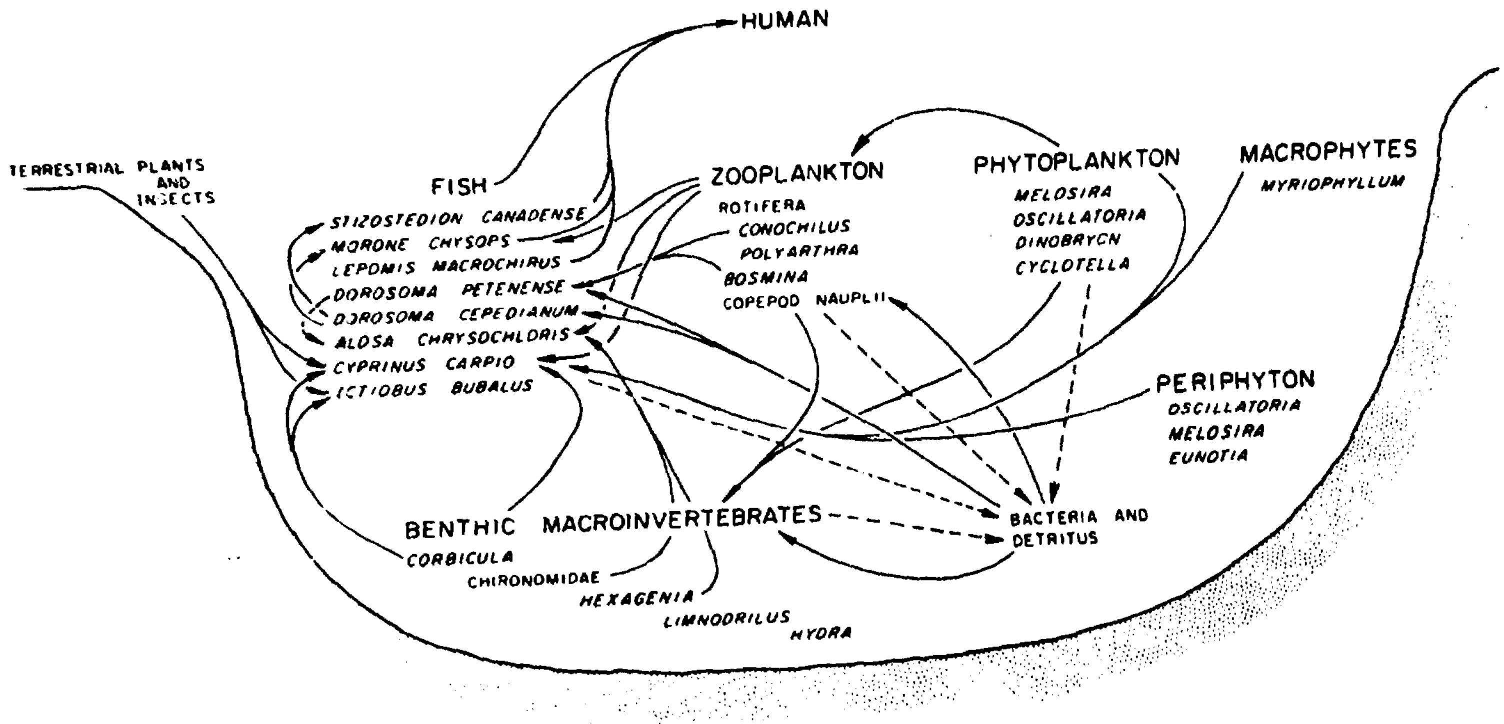

Fig. 3.19. Aquatic food web diagram. Source: J. W. Boyle et al., *Preliminary Draft Environmental Impact Statement for Hot Engineering Test Project at Oak Ridge National Laboratory*, ORNL/TM-6520, Oak Ridge National Laboratory, Oak Ridge, Tenn., August 1978, Fig. 3.16.

Table 3.31. Number of taxa and dominant group in White Oak basin and the Clinch River, 1979-1980

Taxa	White Oak Creek above ORNL (WOCK 6.3)	White Oak Creek below ORNL (WOCK 2.7)	Melton Branch (MBR 0.6)	White Oak Lake (WOCK 1.1)	White Oak Creek Embayment (WOCK 0.1)	Clinch River below WOC mouth (CRK 30.6)
Periphyton	21 Achnanthes (37%)	27 Achnanthes (91%)	32 Achnanthes (63%)	38 Navicula (19%)	29 Achnanthes (55%)	26 Achnanthes (91%)
Phytoplankton	NS[a]	NS	NS	68	71	63
				green algae – dominant taxon varied with algal blooms		Diatoms, with green algal blooms
Zooplankton	NS	NS	NS	70 Rotifers (80%) Brachionus spp. (66%)	74 Rotifers (89%)	80 Rotifers (94%)
Ichthyoplankton	NS	NS	NS	2 Lepomis (probably sunfish) Clupeids (probably gizzard shad)	>2 Unidentified eggs Clupeid larvae	8 Clupeid larvae
Benthic macroinvertebrates	44 Mayfly larvae (41%)	14 Midge larvae (98%)	25 Midge larvae (80%)	13 Spring-diptera (90%) Fall-Physa (48%)	14 Midge larvae (43%)	12 Midge larvae (57%)
Fish	3 Stone roller (57%)	None	None	7 Bluegill (78%) Mosquitofish	15 Gizzard shad	15 Gizzard shad

[a]NS = not sampled.

Source: J. M. Loar, J. A. Solomon, and G. F. Cada, A Description of the Aquatic Ecology of White Oak Creek Watershed and the Clinch River Below Melton Hill Dam, ORNL/TM-7509/V2, Oak Ridge National Laboratory, Oak Ridge, Tenn., October 1981.

striped bass. Yellow bass, which are also taken by fishermen, appear to be increasing in this reach of the river.[18]

In summary, the Clinch River near WOC supports aquatic communities that appear to be both diverse and productive. Based on the organisms present, there is no suggestion of excessive loadings of nutrients or organic material.

3.4.2.2 White Oak Creek

Five distinct environments were sampled (Table 3.31) within the WOC basin represented by the following stations (Fig. 3.11): (1) a control station [WOCK 6.3 (WOCM 3.9)] upstream from ORNL, (2) a station [MBK 0.6 (MBM 0.4)] in Melton Branch, (3) two stations [WOCK 2.7 and 2.1 (WOCM 1.7 and 1.3)] below ORNL but upstream from White Oak Lake, (4) a station in White Oak Lake [WOCK 2.1 (WOCM 1.3) near the dam], and (5) a station in WOC embayment near the creek's mouth [WOCK 0.2 (WOCM 0.1)].

Upper WOC probably resembles the drainage basin as it was before construction of ORNL. Periphyton sampled here were dominated by the diatoms *Achnanthes*, *Gomphonema*, and *Navicula*.[18] Green algae made up approximately 9% of the algal cells observed. Benthic samples at WOCK 6.3 (WOCM 3.9) contained 24 taxa of macroinvertebrates—by far the greatest diversity observed in the basin. The mayfly larvae and many other species observed here are characteristic of stream habitats of high oxygen content.[76] Although midge larvae were collected throughout the drainage, lower densities were observed at this upstream station. Three species of fishes were collected; most abundant were the stone roller and blacknose dace (28 and 20 fish caught respectively). One banded sculpin was also collected. The stoneroller and blacknose dace are typically abundant in small southeastern streams.[18]

At the two stations below ORNL only 16 taxa of macroinvertebrates were collected. Benthic organisms were overwhelmingly dominated by midge larvae but were otherwise depauperate. Only one mayfly specimen and no stonefly larvae were observed. Although blue-green algae were an insignificant component of the periphyton throughout the creek, the total number of blue-green algae was approximately five times greater at WOCK 2.7 (WOCM 1.7) than at WOCK 6.3 (WOCM 3.9) or MBK 0.6 (MBM 0.4). In addition, at WOCK 2.1 and 2.7 (WOCM 1.3 and 1.7) the maximum values for the AI (841 and 1729 respectively) were far higher than at WOCK 6.3 (WOCM 3.9) and MBK 0.6 (MBM 0.4), where AIs were 295 and 285 respectively. Fishes collected at WOCK 2.1 (WOCM 1.3) included bluegill and mosquitofish, but ichthyoplankton sampling suggested that little or no significant spawning activity occurs in WOC between ORNL and White Oak Lake. No fish could be found at WOCK 2.7 (WOCM 1.7).

Melton Branch [MBK 0.6 (MBM 0.4)] was also found to be devoid of fish (sampled in November 1979 and in late January 1980). This station had higher diversity of benthic macroinvertebrates than WOC below ORNL (25 taxa), but midge larvae still accounted for 80% of the organisms collected. Mayflies and stonefly larvae were collected but had very low abundance (1.9 and 0.2% of total respectively). Diatoms were the dominant periphyton.

A comparison of data from the WOC and Melton Branch stations[18] could not demonstrate any statistically significant difference between any of the four stations for the biomass and chlorophyll *a* levels for periphyton. Using a dissimilarity coefficient, the assemblage of macroinvertebrates at WOCK 6.3 (WOCM 3.9), however, was shown to be substantially different from the other stations; stations WOCK 2.1 and 2.7 (WOCM 1.3 and 1.7) were most similar.

In White Oak Lake, diatoms were the dominant periphyton, but phytoplankton were dominated by various genera of green algae. Major pulses of algae occurred in April (*Scenedesmus*, with *Chlamydomonas* and *Chlorogonium*), in July (*Schroederia* and *Actinastrum*), and in October (dominants similar to April pulse). Blue-green genera including *Dactylococcopsis (Merismopedia)*, *Trachelomonas* (*Euglenophyta*), and *Chryptomonas* also exhibited pulses but were never a major component of the flora. It has been suggested that the densities of phytoplankton in White Oak Lake are limited by the lake's short hydraulic retention time and high flushing rate.[18]

Forty-four species of rotifers were present, and the copepod *Eucyclops agilis* dominated crustacean zooplankton. Ichthyoplankton sampling collected clupeid larvae and *Lepomis*. Clupeid larvae were believed to be gizzard shad,[18] based on previous records of their occurrence in White Oak Lake. *Lepomis* larvae were probably bluegill, redear sunfish, or bluegill/redear hybrids. Larval forms of other fishes which occur in White Oak Lake may have been missed because of the difficulty of sampling near shore.

Benthic sampling in White Oak Lake collected 13 taxa. The assemblage was dominated by chironomid midge larvae but also showed a seasonal succession. Midge larvae reached peak density in early June; mayfly, dragonfly, and damselfly larvae increased in abundance during the summer; and the snail *Physa* became the dominant macroinvertebrate by October.

Fishes collected in White Oak Lake were mostly bluegill (78%); redear sunfish, mosquitofish, and largemouth bass were taken also. Gizzard shad, carp, and goldfish have also been observed recently and are believed present. Difficulties with sampling shallow areas may have caused an underestimation of the abundance of mosquitofish.[18]

The WOC embayment is a habitat influenced both by the Clinch River and discharge from White Oak Lake. The phytoplankton assemblage and its dynamics were similar to those of White Oak Lake, probably reflecting the washout of organisms from the lake. However, the rotifer, macroinvertebrate, and fish populations of the embayment more closely resembled those in the Clinch River. Benthic organisms were dominated by midge larvae, but the Asiatic clam (*Corbicula manilensis*) was also well represented. This species was virtually absent from White Oak Lake. The densities of fish eggs observed in the embayment were an order of magnitude greater than densities in either White Oak Lake or the Clinch River, suggesting that fish spawning occurs in the embayment. Like in the Clinch River, fishes in WOC embayment were dominated by gizzard shad, but channel catfish and carp were more abundant and sauger and bluegill less abundant at WOCK 0.2 (WOCM 0.1) than in the river.

3.4.2.3 Trace elements in fish

Since 1978, mercury levels in fishes from the Clinch River have been sampled routinely by UCC-ND at four stations (Table 3.32).[29] The species sampled were those commonly caught in the river. Scales, head, and entrails were removed, and ten fish of each species were composited for each sample. The concentrations observed in 1980 were markedly higher than those of the two previous years. The lowest concentrations were observed in fishes from Melton Hill Reservoir, while the highest levels (maximum of 0.47 μg/g) were observed at the mouth of Poplar Creek. The mercury concentrations in bluegill for 1980 at the mouth of WOC (0.22 μg/g) agree fairly well with those observed by Loar et al. (Table 3.33).

The 1979–1980 survey[18] included sampling of seven trace elements in fish tissue from migratory species in the Clinch River below Melton Hill Dam and resident fishes from lower WOC watershed and the Clinch River. Fishes were collected in March 1979, and trace element concentrations in axial muscle were determined (Table 3.34). Statistical analysis of the concentrations in sauger showed no significant differences between the stations upstream and downstream of the mouth of WOC.

Because bluegill was the only resident species abundant in both the Clinch River and WOC, it was chosen for analysis. Ten bluegills of approximately the same size were collected at each station except at WOCK 0.2 (WOCM 0.1), where only four small fish could be obtained. The most significant finding was the occurrence of significantly higher levels of total mercury in the fish from White Oak Lake and WOC embayment compared with those collected from the Clinch River and Melton Hill Reservoir (Table 3.33). The mercury concentration of one fish from CRK 35.4 (CRM 22.0) was 1.07 μg/g, a level exceeding the Food and Drug Administration's action level of 1.0 μg/g, wet weight.

The concentrations of nickel in fishes from the Clinch River and WOC appear to be somewhat elevated above the levels reported for fishes in relatively uncontaminated environments (Table 1.5–7

Table 3.32. Mercury concentrations (μg/g) in fish from the Clinch River, 1978–1980

Location	Species	Year 1978	1979	1980
Centers Ferry (CRK 8.0)	Bass	0.0072	0.0026	0.16
	Bluegill	0.0090	0.0031	0.22
	Carp	0.0059	0.0056	0.20
	Shad	0.0012	0.0007	0.025
	Crappie	NS[a]	0.0020	0.065
Mouth of Poplar Creek (CRK 19.3)	Bass	0.0019	0.0052	0.43
	Bluegill	0.0027	0.0059	0.47
	Carp	0.0060	0.022	0.10
	Shad	0.0045	0.0017	0.016
	Crappie	0.0076	0.0042	0.12
Mouth of White Oak Creek[b] (CRK 33.4)	Bass	0.0031	0.0015	0.10
	Bluegill	0.0032	0.0037	0.22
	Carp	0.0031	0.0026	0.19
	Shad	0.0007	0.0005	0.024
	Crappie	0.0037	0.0032	0.045
Melton Hill Reservoir (CRK 40.2)	Bass	0.0008[c]	0.0012	0.011
	Bluegill	0.0034	0.0007	0.059
	Carp	0.0015	0.0014	0.11
	Shad	0.0001	0.0002	0.0074
	Crappie	NS	NS	0.021

[a]NS = not sampled.
[b]Average of quarterly samples.
[c]Fish were collected at CRK 38.6 in 1978.
Source: Environmental Monitoring Reports, U.S. Department of Energy, Oak Ridge Facilities, Calendar Years 1978–1980, Y/UB-10, -13, -15, Union Carbide Corporation-Nuclear Division, Oak Ridge, Tennessee 1979–81.

in ref. 77). The concentrations of other trace elements are generally within the ranges that have been reported in freshwater fishes from relatively uncontaminated environments.

Chromium is of interest because of its past use as a corrosion inhibitor in ORNL cooling towers. Discharges of chromium were phased out during 1976. The level of chromium observed in bluegill from the Clinch River below the mouth of WOC [CRK 30.6 (CRM 19.0)] was significantly higher than concentrations from White Oak Lake and Melton Hill Reservoir.[18] These data are somewhat difficult to explain; if fish were exposed to elevated levels of chromium from WOC, differences might be expected between CRK 30.6 (CRM 19.0) and CRK 35.4 (CRM 22.0). The concentrations observed may be caused by fish movement[18] and thus exposure of fish to varying levels over their life history. Chromium levels in fish from White Oak Lake were previously studied,[42] with sampling occurring between 1969 and 1974. Levels from bluegill and largemouth bass were not significantly different between White Oak Lake and Melton Hill Reservoir. However, the average levels detected by Elwood et al.[42] for bluegill and largemouth bass (Table 3.35) were an order of magnitude greater than the levels reported by Loar et al.[18] (Table 3.33). Between 1969 and 1974 Elwood et al.[42] detected a significant drop in the concentration of chromium in goldfish from White Oak Lak. Average levels were 9.79 μg/g in 1969 and 90% lower (0.92 μg/g) in 1973.

It is not clear whether chromium levels in fish from White Oak Lake have been steadily declining. The data suggest this, but they also suggest an order of magnitude decline in chromium

Table 3.33. Comparison of the mean concentration of seven trace elements in axial muscle of bluegill collected at five sites

Site	Mean weight[a], g (±1 standard error)	Mean concentration[a], μg/g wet weight (±1) standard error)						
		Cd[b]	Cr[c]	Cu	Hg[d]	Ni	Pb	Zn[e]
White Oak Lake (WOCK 1.1)	86.2 (4.8)	0.0057 (0.0018)	0.027 (0.003)	0.16 (0.01)	0.70 (0.07)	0.46 (0.14)	0.039 (0.006)	5.9 (0.2)
White Oak Creek embayment (WOCK 0.2)	48.0 (5.4)	0.0039 (0.0025)	0.042 (0.008)	0.31 (0.17)	0.57 (0.07)	0.22 (0.15)	0.040 (0.008)	10.1 (3.0)
Clinch River (CRK 30.6)	85.6 (8.4)	0.0207 (0.0066)	0.056 (0.012)	0.31 (0.10)	0.06 (0.01)	0.60 (0.16)	0.061 (0.026)	5.4 (0.5)
Clinch River (CRK 35.4)	77.2 (7.0)	0.0097 (0.0035)	0.038 (0.004)	0.19 (0.03)	0.21 (0.10)	0.88 (0.36)	0.044 (0.007)	5.8 (0.4)
Melton Hill Reservoir (CRK 84)	89.7 (7.5)	0.0178 (0.005)	0.030 (0.002)	0.16 (0.02)	0.06 (<0.01)	0.40 (0.06)	0.027 (0.002)	5.4 (0.3)

[a] n = 10 for all sites except WOCK 0.2 (n = [illegible]).

[b] Cadmium values less than limit of detection (0.5 ng/g wet weight) were not included in the computation of mean concentrations. In the order listed, n = 9, n = 2, n = 6, n = 8, n = 10, respectively. No statistical analysis performed.

[c] Mean concentration at CRK 30.6 was significantly different from that at sites WOCK 1.1 and CRK 84 ($p < 0.05$).

[d] Mean concentration at sites WOCK 1.1 and WOCK 0.2 was not significantly different ($p > 0.05$), but the concentration at both sites was significantly different from that at the other three stations ($p < 0.05$).

[e] Mean concentration at WOCK 0.2 was significantly different from that at the other four sites ($p < 0.05$).

Source: J. M. Loar, J. A. Solomon, G. F. Cada, A Description of the Aquatic Ecology of White Oak Creek Watershed and the Clinch River below Melton Hill Dam, ORNL/TM-7509/V2, Oak Ridge National Laboratory, Oak Ridge, Tenn. October 1981, Table 4.27.

Table 3.34. Mean concentration of seven trace elements in axial muscle of fish collected in March 1979 at two sites in the Clinch River above and below the mouth of White Oak Creek [Clinch River Kilometer (CRK) 33.5]

Site	Species	Mean weight, g (± 1 standard error)	Mean concentration, μg/g wet wt (± 1 standard error) Cd	Cr	Cu	Hg	Ni	Pb	Zn
CRK 35.4	Sauger[a]	576 (92)	0.0008 (0.0001)	0.069 (0.026)	0.18 (0.01)	0.103 (0.015)	0.49 (0.08)	0.012 (0.001)	2.6 (0.2)
CRK 30.6	Sauger[b]	488 (108)	0.0014 (0.001)	0.011 (0.001)	0.16 (0.02)	0.077 (0.017)	0.65 (0.19)	0.012 (0.002)	3.0 (0.1)
CRK 30.6	Striped bass[c]	1250 (738)	0.0005 c	0.017 (0.005)	0.24 (0.04)	0.134 (0.043)	1.54 (1.18)	0.009 (0.004)	3.0 (0.3)
CRK 30.6	Yellow bass[d]	98 (19)	0.0014 (0.0003)	0.020 (0.003)	0.34 (0.07)	0.100 (0.024)	1.28 (0.17)	0.027 (0.013)	4.1 (0.4)

[a]Number of fish analyzed for each element was 10. Seven of the analyses for Cd were below limit of detection (< 0.5 ng/g); these were not included in the computation of mean concentration of Cd.

[b]Number of fish analyzed for each element was 4. Two of the analyses for Cd were below limit of detection; these were not included in the computation of mean concentration of Cd.

[c]Number of fish analyzed for each element was 3. Two of the analyses for Cd were below limit of detection and were ignored and no standard error ascertained.

[d]Number of fish analyzed for each element was 3.

Source: Tables 4.24 and 4.26, J. M. Loar, J. A. Solomon, and G. F. Cada, A Description of the Aquatic Ecology of White Oak Creek Watershed and the Clinch River Below Melton Hill Dam, ORNL/TM-7509/V2, Oak Ridge National Laboratory, Oak Ridge, Tenn., October 1981.

Table 3.35. Within-species comparison of geometric mean Cr concentrations in axial muscle of bluegill and largemouth bass from a Cr-contaminated reservoir (WOL) and an uncontaminated reservoir (MHR)

Species	Cr concentration in muscle, µg/g wet weight (95% confidence level) (wet mean weight (g), range, and number of fish analyzed)	
	White Oak Lake[a]	Melton Hill Reservoir[a,b]
Bluegill	1.22 (0.44–3.38) (4.3, 2.6–6.0, n = 5)	0.73 (0.23–2.32) (60, 25–98, n = 5)
Largemouth bass	0.38 (0.22–0.65) (12.4, 5.7–25.0, n = 13)	0.53 (0.23–1.22) (49, 34–70, n = 4)

[a]Difference between stations was not significant (P>0.05).
[b]Fish collected at CRK 53.1 (CRM 33).
Source: Table 3, J. W. Elwood, J. J. Beauchamp, and C. P. Allen, "Chromium Levels in Fish from a Lake Chronically Contaminated with Chromates from Cooling Towers," Int. J. Env. Studies, 14, 289–298, 1980.

levels in fish from Melton Hill Reservoir, an area assumed not to be contaminated. It is possible that differences in analytical technique or other factors account for the differences observed.

3.4.2.4 Rare and endangered species

Largely because of impoundments, the Clinch River and WOC do not provide suitable habitat for the rare and endangered species that inhabit the river system. Both the federal government[78,79] and the state of Tennessee[80,81] have listed endangered or threatened species in the Clinch River watershed, but these species require unmodified (i.e., free-flowing) habitat and are known to occur only in the upper reaches of the Clinch River or its major tributaries. No threatened or endangered species have been encountered in the biological sampling programs for ORNL,[18] ORGDP,[77] or other proposed facilities nearby.[14,23,24]

3.5 AMBIENT RADIOLOGICAL CHARACTERISTICS

3.5.1 Natural Background

The natural background radiation dose to man is received from cosmic rays (primarily galactic and solar cosmic rays) and from external and internal exposure to terrestrial sources. Terrestrial sources include both cosmogenic radionuclides (^{3}H, ^{7}Be, ^{14}C, ^{22}Na, and ^{24}Na) and primordial radionuclides (mainly ^{238}U, ^{235}U, ^{232}Th, and daughters and ^{40}K and ^{87}Rb).[82] The cosmogenic radionuclides are produced through the interaction of cosmic rays with target atoms in the atmosphere and in the earth; the primordial radionuclides are those that have always existed in the earth's crust.[83] The estimated average annual genetically significant dose to individuals in the Oak Ridge area population from natural radiation is about 1.29 mSv (129 mrems/year).[83,84] Of this total, external exposure from cosmic and terrestrial radiation accounts for 0.44 mSv (44 mrems) and 0.60 mSv (60 mrems) respectively. Internal exposure via inhalation and ingestion of naturally occurring radioactivity yields about 0.25 mSv (25 mrems).

3.5.2 Man-made Radioactive Pollutants

Man-made radiation sources include residual fallout from nuclear weapons testing, routine nuclear power plant operation, medical uses of radiation, air transportation, technologically enhanced radiation, and consumer products containing and/or emitting radiation. Annual doses to a typical U.S. resident from these sources are estimated[85] to be 40 μSv (4 mrems) from fallout, 3 μSv (0.3 mrem) from nuclear power, 0.92 mSv (92 mrems) from medical uses (diagnostic and radiopharmaceutical), 40 μSv (4 mrems) from technologically enhanced radiation, 5 μSv (0.5 mrem) from air travel, and about 50 μSv (5 mrems) from consumer products. In the Oak Ridge area, in addition to the above sources are routine releases from the Oak Ridge nuclear facilities (see Sect. 4.5). Radionuclides in sediments in the Clinch River are discussed in Sect. 3.2.4.

3.6 SOCIAL, ECONOMIC, AND POLITICAL CHARACTERISTICS

3.6.1 Regional Demography

Of a total of approximately 19,000 UCC-ND personnel employed at the three Oak Ridge plants, 4906 are employed at ORNL. This number includes approximately 740 ORNL employees who are members of the Biology, Energy, Engineering Technology, Fusion Energy, and Information divisions located at the Y-12 site. Most of the ORNL employees live within 40 km (25 miles) of the site; less than 1% of ORNL personnel commute 80 to 120 km (50 to 75 miles) each way daily from their homes in surrounding communities. The ORR is surrounded by five counties [Anderson, Knox, Loudon, Morgan, and Roane (Fig. 3.20)], which have a combined population of 480,622. The population has increased 10% since 1975. ORNL is located within the city limits of Oak Ridge (1980 population 27,662) about 16 km (10 miles) from population concentrations. Knoxville, the principal population center in the area (1980 population of 183,139), lies 48 km (30 miles) east of Oak Ridge. The ORNL site is within 32 km (20 miles) of residential development in western Knox County.

Population changes in Anderson, Knox, Loudon, and Roane counties are given in Table 3.36. Morgan County is not included nor described further in this section because less than ten ORNL employees reside there. These neighboring counties are expected to increase in growth through the next several decades, but most of the growth is expected to occur in Knox County.

The DOE/contractor operations represent a significant portion of the employment in Anderson and Roane counties. The number of employees on the DOE/contractor payroll is larger than for any other single employee group in the state (including state employees). A high fraction of the individuals working at DOE facilities in Oak Ridge reside in communities other than Oak Ridge, particularly in Knoxville. Annual surveys indicate that the fraction residing in Oak Ridge continues to decrease. In 1971, 62% of the employees of the three DOE facilities lived outside of Oak Ridge. This increased to 64% in 1974 and reached 73% as of April 1981, perhaps largely because of rapid residential development in western Knox County.

3.6.2 Socioeconomic Characteristics

3.6.2.1 Four-county region

The population characteristics of the four-county region surrounding ORNL represent a typical distribution of societal categories as measured by age, employment, occupations, and income. The area ranges generally from rural to urban, trending increasingly to urban with the expansion of Knoxville as a major urban center and with the development of other smaller urban centers. The city of Oak Ridge has a cosmopolitan character, due principally to the above average educational background of its residents. More than 25% of the population 25 years of age or older has completed 4 or more years of college education. The median number of years of education completed by Oak Ridge inhabitants falls between 12 and 13, about 2 years more than the state average.

Governmental activities have effected major growth in the area and account for a significant fraction of regional employment. The largest state expenditures are those that support The Univer-

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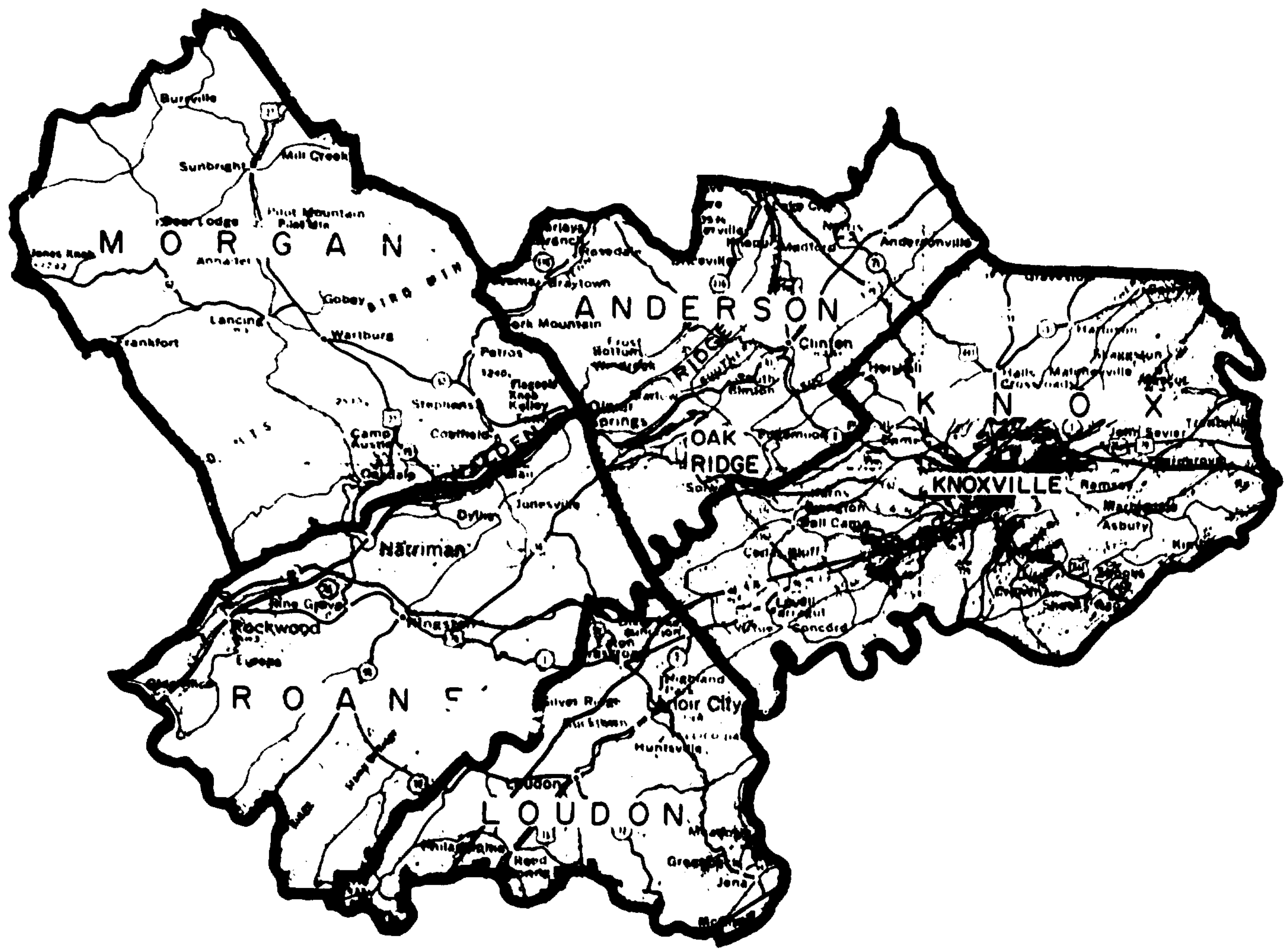

Fig. 3.20. Tennessee counties in proximity to the Oak Ridge Reservation.

Table 3.36. Populations of Anderson, Knox, Loudon, and Roane counties and the state of Tennessee during the period 1960-1980)

County: urban[a]/rural	Population 1960	1970	1980[b]
Anderson County	60,032	60,300	67,346
Clinton	4,943	4,794	5,245
Oak Ridge[c]	27,124	26,829	25,300
Oliver Springs[c]	336	2,208	2,525
Rural	27,629	26.469	34,276
Knox County	250,523	276,293	319,694
Knoxville	111,821	174,587	183,139
Rural	138,702	101,706	136,555
Loudon County	23,757	24,266	28,553
Lenoir City	4,979	5,324	5,446
Loudon	3,812	3,728	3,940
Rural	14,966	15,214	19,167
Roane County	39,133	38,881	48,425
Harriman	5,931	8,734	8,303
Kingston	2,010	4,142	4,441
Oak Ridge[c]	45	1,490	2,362
Oliver Springs[c]	827	1,163	1,075
Rockwood	5,345	5,259	5,767
Rural	27,812	18,093	26,477
Tennessee (total)	3,567,089	3,926,018	4,590,750

[a]According to the 1970 Census of Population, urban population comprises all persons living in places of 2,500 or more inhabitants.

[b]U.S. Bureau of Census, 1980 Census of Population and Housing, Tennessee, PHC80-V-44.

[c]Parts of Oak Ridge and Oliver Springs are in two counties.

Source: U.S. Census Data.

sity of Tennessee and other public educational and vocational training institutions. The principal federal expenditures are for the TVA and DOE operations in Oak Ridge.

Construction and operation of the three major installations, currently operated by UCC-ND under contract with DOE, have greatly influenced the region. Federal monies distributed in payroll to almost 5000 ORNL employees in 1981 amounted to a dispersal of $128.1 million (Table 3.37). About 98% of these monies was distributed in six eastern Tennessee counties, accounting for as much as 7% of individual county employment. Total personal income and per capita income are shown in Table 3.38. The taxable payroll in Anderson County is about $117 million, which is well above the 16-county East Tennessee Development District and state averages of $77 million and $73 million respectively.[86] Similarly, Roane County, with $129 million, is also above these averages and somewhat above Anderson County in total taxable payrolls.

Table 3.37. Distribution (by county of residence) of ORNL employees and payroll, March 1982

County	No. of employees	Percent of county employment[a]	Employee annual payroll ($)	Percent of total payroll
Anderson[b]	2,066	7.1	59,929,000	46.8
Blount	72	0.2	1,695,000	1.3
Campbell	30	0.3	613,000	0.5
Knox	1,741	1.3	42,844,000	33.4
Loudon	270	2.1	7,794,000	6.1
Roane[b]	612	4.3	12,931,000	10.1
All others	115	NA[c]	2,347,000	1.8
Total	4,906	NA	128,153,000	100.0

[a]County employment figures are from Current Population Labor Force Summary, Tennessee Department of Employment Security, February 1982.

[b]All employees living in City of Oak Ridge are shown as residents of Anderson County.

[c]NA = not applicable.

Source: Employee Relations Division of the Oak Ridge National Laboratory.

Table 3.38. Total personal income and per capita income for Anderson, Knox, Loudon, and Roane counties and state of Tennessee, 1978

County	Total personal income	Per capita income
Tennessee	$28,527,000,000	$6,547
Anderson	502,400,000	7,624
Knox	2,101,400,000	6,949
Loudon	163,700,000	6,002
Roane	260,200,000	5,825

Source: Center for Business and Economic Research, Tennessee Statistical Abstract, 1980.

Table 3.39 shows representative distributions of employment in the Oak Ridge area by occupation in comparison with the corresponding distributions for the state of Tennessee. Table 3.40 displays the sources of revenue for the four counties in the Oak Ridge area.

The bulk of the revenues for local governments usually comes from the following sources: property tax, local sales tax, and state and federal aid including "assistance payments," payments in lieu of taxes, and revenue sharing. Counties in Tennessee, as throughout the United States, rely heavily on the property taxes as a principal source of local revenue. Some counties have also adopted the sales tax option.

Table 3.39. Employment (percent by occupation) in Anderson, Knox, Loudon, and Roane counties and state of Tennessee, 1978

Occupation	Anderson County	Knox County	Loudon County	Roane County	Tennessee
Professional, technical & related	25.6	16.4	7.8	11.6	12.0
Nonfarm managers & administrators	6.8	9.1	6.1	6.2	7.7
Sales workers	5.7	8.2	3.3	4.4	6.5
Clerical	13.4	16.9	11.5	10.6	14.6
Craftsmen	18.0	13.6	17.6	18.0	14.3
Operatives	10.4	12.6	29.5	27.4	18.6
Transport operatives	2.5	4.5	4.1	4.4	4.5
Nonfarm laborers	4.6	3.9	5.9	5.6	5.1
Service workers[a]	12.2	14.0	9.5	10.8	12.5
Farm workers	0.8	0.8	3.9	1.0	3.9
Number employed	27,920	128,360	10,120	14,050	1,815,000

[a]Includes household workers.

Source: Tennessee Department of Employment Security, Tennessee Data for Affirmative Action Plans, Annual Averages 1978, February 1980.

3.6.2.2 Anderson County

Anderson County (1980 population: 67,346) includes two distinct population groups because of the unique way in which the city of Oak Ridge was formed. In the 1940s, the federal government acquired about 23,500 ha (58,000 acres) of rural Tennessee land for weapons development during World War II.[87] Part of the land, originally set aside for the residential, commercial, and support services needed by the government employees, became the self-governing city of Oak Ridge in 1959. Although the entire original "Oak Ridge Reservation" is designated as the city of Oak Ridge, about 15,100 ha (37,300 acres) remain under DOE's control.

Table 3.40. Revenues by source in Anderson, Knox, Loudon, and Roane counties, 1978

	Federal ($/capita)	State ($/capita)	Property ($/capita)	Sales ($/capita)	All other ($/capita)	Federal (%)	State (%)	Local (%)
Anderson	51	89	79	15	54	18	31	51
Knox	46	58	99	67	45	15	18	67
Loudon	29	100	80	29	102	9	29	62
Roane	47	101	68	38	49	16	33	51

Source: Based on revenue data in Table 15.8, Tennessee Statistical Abstract, 1980. (Original source: County and Municipal Finances Fiscal Year Ended, June 30, 1978, Table II, Comptroller of the Treasury, State of Tennessee, 1979.)

The Anderson County population, excluding Oak Ridge, has much in common with the surrounding rural Tennessee population. Oak Ridge, on the other hand, has demographic characteristics that set it apart from other communities in the area and from the rural population. For example, in 1970, Anderson County had a rural black population of 228 (less than 1%), which is similar to the rural population of the region. Even though only 5.5% of Oak Ridge citizens are black citizens, Oak Ridge contains over 75% of all black citizens in Anderson County. Other differences between the two populations include the following: (1) Anderson County residents outside Oak Ridge are more evenly distributed by age groups, whereas Oak Ridge has proportionately more working-age and proportionately fewer retirement-age people; (2) only 52.8% of Oak Ridge's citizens are native Tennesseans compared with 85.9% native Tennesseans in the rest of Anderson County; and (3) virtually all foreign-born residents in Anderson County live in Oak Ridge.

The creation of Oak Ridge was the main contributing factor in the urbanization of the previously rural area. Population growth in Anderson County was most dramatic between 1940 and 1950 as a consequence of the establishment of the federal reservation.[87] Between 1950 and 1980, the population has increased from 59,407 to only 69,346.

About 42% (2066) of ORNL employees reside in Anderson County. ORNL employees contribute about 8% of the property taxes and 7% of the retail trade taxes collected in the county. The county trade and services sectors capture about 38% of the local expenditures made by ORNL employees.

3.6.2.3 Knox County

Knox County, including the city of Knoxville, is the population and service center of the region. The urban area dominates the region as a center of sports activity, theaters, restaurants, and as a major shopping center. Knox County population has grown steadily since 1960, as shown in Table 3.36. As a result of the extensive residential and commercial development in western Knox County (from the city limits of Knoxville toward the DOE reservation), many ORNL employees have selected this area for their place of residence. Commuting distances are generally 16–32 km (10–20 miles) one way. Recent employment statistics indicate that Knoxville, as a place of residence, is attracting a larger share of new employees than any other area, although Oak Ridge still accounts for the largest group of employees. About 36% (1741) of ORNL employees reside in Knox County. ORNL employment supports about 1.5% of the county property and sales tax base. The county's trade and services sectors capture about 50% of the local expenditures made by ORNL employees.

3.6.2.4 Roane County

Roane County's population (see Table 3.36) currently is slowly becoming more urbanized. Urban areas, which account for 45.3% of the population, include Harriman, Kingston, Rockwood, and parts of Oliver Springs and Oak Ridge. About 13% (612) of ORNL employees reside in Roane County. These employees support 4% of the property tax and 1.5% of the sales tax base in the county. The trade and services sectors capture about 7% of the local expenditures made by ORNL employees.

3.6.2.5 Loudon County

Loudon County is a small, predominantly rural county with two small municipalities: Lenoir City and Loudon. The county has grown, as shown in Table 3.36, with about equal growth in both urban and rural areas. About 5.5% (270) of ORNL employees reside in Loudon County. ORNL employment supports about 2% of the property and sales tax base in the county. The trade and services sectors receive about 4% of the local expenditures made by ORNL employees.

3.6.3 Political Profile

The legislative branch of Tennessee counties is the County Board of Commissioners. Commissioners are elected from districts within each county. Each board can determine the boundaries of districts within the county and apportion the number of commissioners according to state law. While the boards have limited ordinance-making power, they are empowered to appoint sub-boards, such as zoning boards and planning commissions. The primary function of the Board of Commissioners is as a fiscal body concerned with the determination of property and other local taxes, appropriation of funds, issuance and retirement of bonds, and maintenance of county property.

The county executive is the chief administrative officer of the county. Additional authority is dispersed among independently elected and appointed officeholders (i.e., sheriff, registrar, trustee, and property assessor). Many counties have private acts (adopted for a particular purpose by the Tennessee legislature for a specific county) that provide for a county judge or, less frequently, a county administrator.

Cities in Tennessee are corporations that operate under charters granted by the state. Until 1953, the Tennessee State Legislature had exclusive approval of the local governing body or approval of the local electorate through referendum. The Tennessee State Constitution also provides for optional home-rule provisions. The typical forms of municipal government are the mayor-council, the council-manager, and the commission. The prevalent form is the mayor-council arrangement.

3.6.4 Public Services

County governments in the Oak Ridge area provide public services similar to other counties in the United States including general county administration, administration of justice, law enforcement and care of prisoners, natural resources supervision, recording and preservation of documents, health and welfare (including solid waste disposal and ambulance service), recreation, road maintenance, planning, a library, and education.

A study of the quality of public services in Anderson County[88] concluded that in comparison with Blount, Loudon, and Roane counties, Anderson County provides higher quality educational services with a "strong, balanced" educational program of "urban quality." Likewise, the study concluded that the public welfare services in Anderson County are of a generally high quality and that the "statistical profile" of these services is similar to that of industrialized counties in eastern Tennessee and more favorable than that found in Appalachian counties. As is general elsewhere in the United States, there has been a continuing increase in the demand for county services in the last 30 years.

The bulk of Anderson County's expenditures are on education (approximately two-thirds of all revenues), with highway construction and maintenance, health and welfare, law enforcement, and county government and administration making up the other major expenditures.

3.6.5 Finances

Anderson County receives revenues from local property taxes; payments in lieu of taxes made by TVA, Clinton Utilities Board, city of Oak Ridge, and the Anderson County Industrial Development Board; financial assistance from DOE; licenses and fees; fines; state and federal aid; and various service charges. The county relies primarily on the property tax to raise local revenues. The actual and effective tax rates in Anderson County are the highest of any county in Tennessee. The tax base of Anderson and Roane counties is relatively low because the DOE installations that occupy significant fractions of county domains are exempt from ad valorem taxes.

Federal assistance payments to the city of Oak Ridge generally increased during the period from 1960 to 1982 (Table 3.41). Although the payments increased from $1.2 million to about $2.8 million during this period, the amount of revenues collected by the city of Oak Ridge from other local sources (primarily from the property tax) increased from $236,000 to more than $3 million. Thus, the city assumed steadily increasing responsibility for its fiscal support, a development that is in line with the provisions of the Atomic Energy Community Act of 1955 that anticipates the eventual financial self-sufficiency of the city. From 1960 to 1970 the AEC payment as a percentage of total tax revenues dropped from 84 to 33%. To maintain a continuing high level of public services, the city adopted city-county property tax rates that by 1971 were the highest in the state and among the highest in the nation. Renewed efforts by the city have gained force in the intervening years to achieve self-sufficiency from DOE by increasing the tax base rather than by increasing the tax rate further.

Beginning in 1972, separate subsistence payments for support of the Oak Ridge city schools began to be received from the federal government under the provisions of the Impacted Communities Act (P. L. 874). Accordingly, the AEC, and subsequently its successors ERDA and DOE, reduced annual assistance payments to the city.

Although the aggregate revenues received from taxes and assistance payments represent typical funding for Tennessee counties with populations of similar size to that of Anderson County, the tax base that remains after omission of federal property from the rolls has given rise to the perception that taxes on private residences, farms, and small businesses are excessive.

The presence of large tax-exempt facilities and the expectations of federally related employees for local public services has repeatedly raised the issues of added financial assistance, in-lieu-of-tax payments, and possible taxation of DOE contractors and activities. The issue of financial assistance has been pursued by the local entities in terms of two statutory authorities available to the DOE: Section 168 of the Atomic Energy Act of 1954, as amended, and the Atomic Energy Community Act of 1955, as amended. Assistance payments are currently made to Anderson and Roane counties and the city under the Atomic Energy Community Act of 1955. Beginning October 1, 1979, 10% of the annual financial assistance payments to the city, Roane County, and Anderson County were matched with an equal amount of DOE funds earmarked as "self-sufficiency fund" payments for 5-year plans designed to reduce reliance on DOE financial support. Each entity has developed a plan of action for the 5-year period with the approval of DOE. The city's approved 5-year plan, for example, calls for the development of the Valley Industrial Park and construction of the Industrial Building, a facility that functions as an "incubator" for assistance to new small business enterprises. A major land acquisition in concert with the proposed Tennessee Technology Corridor is planned. Although the city continues to maintain that it is not reasonable to expect complete elimination of the DOE annual assistance payment, the plan does take affirmative action to provide for the city's financial well-being in the future.[86] Several analyses have been developed with the purposes of reviewing the justification for financial payments leading toward complete self-sufficiency and establishment of an acceptable means for determining a level of financial payments within the framework of the DOE statutory authorities.[88–90] Such efforts have originated partly from local dis-

Table 3.41. Oak Ridge municipal revenues, 1960 - 1982

Fiscal year	City tax revenue from local source	DOE assistance payments	P. L. 874 payments to Oak Ridge schools	Total	DOE payments as % of total
1960	$ 235,829	$1,247,000		$1,482,829	84.09
1961	1,278,579	2,472,107		3,750,686	65.91
1962	1,438,679	1,238,740		2,677,419	46.27
1963	1,516,093	1,228,740		2,744,833	44.77
1964	1,611,126	1,230,000		2,841,126	43.29
1965	1,717,330	1,252,000		2,969,330	42.16
1966	1,841,819	1,302,480		3,144,299	41.42
1967	2,038,970	1,373,160		3,412,130	40.24
1968	2,493,253	1,474,130		3,967,383	37.16
1969	2,850,063	1,524,613		4,374,676	34.85
1970	3,083,848	1,534,710		4,618,558	33.23
1971	3,473,537	1,433,333		4,906,870	29.21
1972	3,752,318	1,036,766	$529,933	5,319,017	19.49
1973	4,071,868	1,239,449	459,358	5,770,675	21.48
1974	4,591,157	1,323,176	604,303	6,518,636	20.30
1975	5,001,633	1,422,030	580,215	7,003,878	20.30
1976	5,124,841	1,595,825	36,962	6,757,628	23.62
1977	5,514,360	949,680	445,837	6,909,877	13.74
1978	6,170,153	1,913,858	532,089	8,616,100	22.21
1979	6,762,709	1,636,324	571,968	8,971,001	18.24
1980	7,413,046	2,254,833	298,909	9,966,788	22.62
1981	7,604,010	2,453,270	278,910	10,336,190	23.73

Sources: U.S. Department of Energy, Oak Ridge Operations Office, 1982; Oak Ridge City Schools, 1982; City of Oak Ridge, 1982.

satisfaction with the amounts of money received and uncertainty of the assistance, particularly in comparison with what private industry would pay, and partly from local and DOE efforts to establish a more effective solution to the problem. As yet, no resolution of the issues that gains a major consensus has occurred.

Such lack of consensus has led to several attempts by the local entities to collect taxes with respect to the government's activities in Oak Ridge. To date, such attempts have not been successful. In one case, the Tennessee legislature failed to enact the desired legislation; in another case, a tax law was enacted, but the state could not collect the tax; in yet another case, a law was enacted, was declared unconstitutional by the U.S. District Court, and is now on appeal; and finally, Anderson County's attempt to assess ad valorem property tax against the DOE contractor operating the Y-12 Plant is being challenged in the courts.

3.6.6 Land Use

The region in which the X-10 site is located encompasses residential, agricultural, industrial, and recreational areas. The region is traversed by numerous public roads and highways. Figure 2.4 shows the relation of the site to other features in the region. Population centers in the immediate area include Oak Ridge, Oliver Springs, Harriman, Kingston, Lenoir City, Loudon, Knoxville, and Clinton. Residential developments, a part of Knoxville's westward urban movement, are steadily increasing the population density of the area south of the site in Knox County.

Farming in the area has decreased, although beef cattle production has gradually increased over the years. No commercial dairy farms exist within a 16-km (10-mile) radius of ORNL in Morgan, Anderson, or Knox counties;[14] there are four in Roane County and one in Loudon County.

For many years, the principal cash crops harvested in the surrounding counties have been tobacco, corn, soybeans, and wheat. Commercial forest land accounts for more than one-half of the land area in surrounding counties. As tree crops are removed, the areas are generally replanted in fast-growing pines. Most of the federally owned land in the vicinity of the site is under a forest management plan (see Sect. 2.8.5).

The Clinch River and associated waterways forming the Tennessee Valley lakes have become an increasingly attractive recreational resource and attract many visitors to the area.

No hunting areas, wildlife preserves, or sanctuaries exist in the immediate vicinity of the site. Although various wildlife inhabit the federal reservation, hunting is not permitted within its boundary.

3.6.7 Regional Historical and Archaeological Resources

3.6.7.1 Historical landmarks

The *National Register of Historic Places* lists 23 sites in the five-county area (Anderson, Knox, Loudon, Morgan, and Roane) surrounding ORNL, only four of which occur within a 16-km (10-mile) radius of the plant site.[91] The Graphite Reactor at ORNL is listed in Anderson County but actually is in Roane County.[91] The Graphite Reactor was the world's first full-scale nuclear reactor and the first reactor to produce significant amounts of heat as well as measurable amounts of ^{239}Pu.

Harriman City Hall, Roane County Courthouse in Kingston, and Southwest Point at the confluence of the Clinch and Tennessee rivers are Roane County listings in the *National Register of Historic Places*.[91] A 1975 study of the ORDGP area[92] indicated that no other historical structures or sites in the area require preservation or mitigation of adverse impacts under federal criteria.

3.6.7.2 Archaeological sites

An archaeological survey[93] of the ORR was conducted by the Department of Anthropology, The University of Tennessee, Knoxville, from March 15 to June 30, 1974. Sites of aboriginal occupation that might be affected by future activities on the reservation were located and evaluated

Reconnaissance and testing were done in several different physiographic zones including the Clinch River and its larger tributary-stream terraces, the interior valleys, selected forested ridges, and specific facility areas. Previously recorded sites, known but unrecorded sites, and previously unknown sites were investigated. The survey techniques included collecting surface artifactual materials, examining subsurface soil strata, and interviewing longtime residents and employees.

Altogether, 45 sites of prehistoric aboriginal occupation and several historic Euroamerican homestead sites were examined. The primary emphasis of the study was on the prehistoric sites.

Most of the major archaeological periods in the eastern Tennessee chronological sequence were represented in the material collected during the survey. The sites were distributed along the drainage system of the Clinch River, with the majority located on the main stream. Several sites, however, were located on the tributary streams of Poplar Creek, East Fork Poplar Creek, and WOC.[93]

3.6.7.3 Visitor attractions

The American Museum of Science and Energy (formerly the American Museum of Atomic Energy) is located in Oak Ridge. The $3.5 million building, which houses displays, movies, demonstrations, and equipment on energy, recorded more than 210,000 visitors during 1981. The Graphite Reactor, a national historic landmark (Sect. 3.6.7.1), attracts 13,000 visitors annually. ORNL itself attracts many visitors who view it from an overlook. The University of Tennessee maintains one of the southeast's largest and most complete collections of Appalachian plant species at its Arboretum east of ORNL. The arboretum is heavily used throughout the year.

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4. ENVIRONMENTAL IMPACTS

4.1 ASSESSMENT METHODOLOGY

4.1.1 Gaseous Releases

4.1.1.1 Meteorological data selection

The selection of suitable meteorological data for use in the dispersion models is crucial. Surface observations of wind speed, wind direction, and atmospheric stability from Knoxville, Tennessee [32 km (20 miles) ESE], have been used in the Industrial Source Complex Long Term (ISCLT) model and AIRDOS-EPA. Ten years (1955–1964) of these hourly observations have been arranged in 6 speed classes, 16 direction sectors, and 6 stability classes to produce a joint frequency of occurrence record. Knoxville surface observations have been used in ISCLT and in AIRDOS-EPA because of the long record available in this joint frequency format, despite the slight difference in terrain between Oak Ridge National Laboratory (ORNL) and Knoxville. A comparison of ISCLT modeling results using Knoxville and Tennessee Valley Authority (TVA) Kingston Steam Plant [19 km (11 miles) W] data shows considerable agreement. However, the Knoxville data provide generally more conservative results than the Kingston data. Also, Knoxville's lower wind-measuring height [16.2 m (53 ft) vs 120.0 m (394 ft)] provides data more appropriate for the near ground-level emission releases at ORNL. A mean mixing height of 1.03 km (3380 ft) derived from Nashville soundings [210 km (130 miles) W] has been used.[1] The mixing height is the height of the atmospheric surface layer lying below an inversion, this being the volume of air generally available for dispersion of a plume. Nashville has the nearest National Weather Service station routinely making atmospheric soundings.

Although there are inherent weaknesses in using meteorological data from offsite locations, the data selected have been judged to be the best currently available. The Knoxville and Nashville meteorological observations selected for use in the dispersion models are the most representative data for the ORNL site in a form compatible with model requirements. Observations made at the ORNL site would have been preferred, because of the tendency for site-specific weather conditions in the complex terrain of East Tennessee (see Sect. 3.3). However, the limited onsite data are insufficient for use in the models because these data are available only for individual years rather than for the 5- and 10-year average from Kingston and Knoxville respectively. Because weather conditions typically vary considerably from one year to the next in the temperate latitudes, a single year's record cannot be relied upon to represent climate. A 5-year mean has been accepted for regulatory purposes, and a 10-year mean is marginally more representative. Therefore, because the Kingston and Knoxville data indicate little local variation in climate, whereas substantial interannual variations are known to occur, the longer Knoxville record is the best climatic record currently available for the ORNL site.

4.1.1.2 Radiological

Methodology. The radiation dose commitments resulting from the atmospheric releases of radionuclides are calculated using the AIRDOS-EPA computer code.[2] The methodology is designed to estimate the radionuclide concentrations in air; rates of deposition on ground surfaces; ground-surface concentrations; intake rates via inhalation of air and ingestion of meat, milk, and fresh vegetables; and radiation doses to man from the airborne releases of radionuclides. The highest estimated dose to an individual in the area and the doses to the population living in the surrounding area of the plant site can be calculated with the code. The doses may be summarized by radionuclide, exposure mode, or significant organ of the body.

Many of the basic incremental parameters used in AIRDOS-EPA are conservative; that is, values are chosen to maximize dose to man. Many factors that would reduce the radiation dose, such as shielding provided by dwellings and time spent away from the reference location, are not considered. It is assumed that an individual lives outdoors at the reference location 100% of the time. Moreover, in estimating the doses to individuals via ingestion of vegetables, beef, and milk, all of the food consumed by the individual is generally assumed to be produced at the reference location. Thus, the dose estimates calculated by these methods are likely to be higher than the doses that would actually occur.

The basic equation used to estimate the dispersion of an airborne plume is the Gaussian plume equation of Pasquill[3] as modified by Gifford.[4] Radionuclide concentrations in meat, milk, and vegetables consumed by man are estimated by coupling the output of the atmospheric transport models with the U.S. Nuclear Regulatory Commission (NRC) *Regulatory Guide 1.109*, "Terrestrial Food Chain Models."[5] The models are described by Pleasant.[6]

The atmospheric dispersion model used in estimating the atmospheric transport to the terrestrial environment is discussed in detail in the AIRDOS-EPA computer code.[2] For particulate release, the meteorological χ/Q values are used in conjunction with dry deposition velocities and scavenging coefficients to estimate air concentrations and steady-state ground concentrations. The atmospheric dispersion model estimates the concentration of radionuclides in air at ground surfaces as a function of distance and direction from the point of release. Radioactive decay during the plume travel is taken into account in the AIRDOS-EPA code. Daughters produced during plume travel are calculated separately and added to the source term.

The area surrounding the plant site is divided into 16 sectors of 22.5° by compass direction. For population dose calculation, each sector is bounded by radial distances of 1.2, 1.8, 2.4, 4.0, 5.6, 7.2, 12.0, 24.0, 40.0, 56.0, and 72.0 km (0.75 to 45 miles) from the point of release. Each distance represents the midpoint of a sector, and χ/Q values are calculated for each sector. Concentrations in the air for each sector are used to calculate dose via inhalation and submersion in air. Ground deposition of particulates results in external gamma dose. Deposited particulates are also assimilated into food to contribute dose upon ingestion via the food chain.

The meteorological data required for the calculations are joint frequency distributions of wind velocity and direction summarized by Pasquill atmospheric stability category. These meteorological data are used to calculate the concentrations of radionuclides at a reference point per unit of source strength. Depletion of the airborne plume as it is blown downwind is accounted for in the AIRDOS-EPA code by taking into account the deposition on surfaces by dry deposition, scavenging, and radioactive decay.

Radiation exposure pathways and dose conversion factors. Environmental transport links the source of release to the receptor by numerous exposure pathways. Figure 4.1 is a diagram of the most important pathways that result in the exposure of man to radioactivity released to the environment. The resulting radiation exposures may be either external or internal. External exposures occur when the radiation source is outside the irradiated body, and internal exposures are those from radioactive materials within the irradiated body.

The dose conversion factors for converting the radiation exposures to estimates of dose are calculated using the latest dosimetric criteria of the International Commission on Radiological Protection (ICRP) and other recognized authorities.

External dose conversion factors. Releases of radioactive gases and particulates to the atmosphere may result in external doses by exposure to and/or immersion in the plume and to contaminated land surfaces. The dose conversion factors have been computed as summarized by Kocher.[7]

Internal dose conversion factors. Factors for converting internal radiation exposure to estimates of dose have been computed and summarized[8,9] implementing recent models.[10,11] These factors are input data into the AIRDOS-EPA computer code for dose estimation from inhaled and ingested radionuclides.

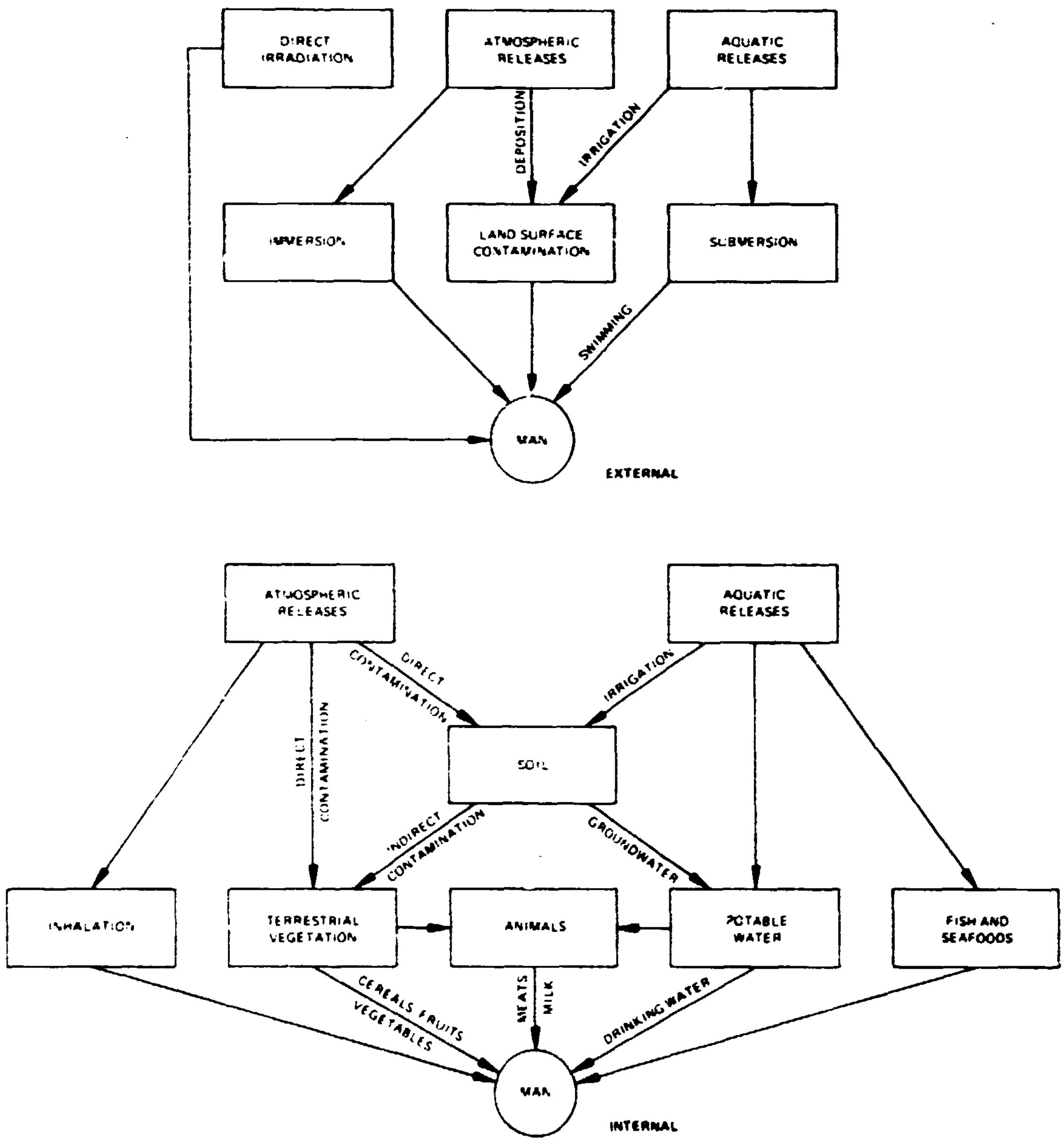

Fig. 4.1. Pathways for exposure of man from releases of radioactive effluents. Source: *Environmental Assessment of the Oak Ridge Gaseous Diffusion Plant Site*, U.S. Department of Energy, DOE/EA-0106, December 1979, Fig. 5.1.

Radiation dose to the individual. Internal exposure continues as long as radioactive material remains in the body, which may be longer than the duration of the individual's residence in the contaminated environment. The best estimates of the internal dose resulting from an intake are obtained by integrating over the remaining lifetime of the exposed individual; such estimates are called "dose commitments." The remaining lifetime is assumed to be 50 years for an adult.

External doses are assumed to be annual doses. The dose rate above the contaminated land surface is estimated for a height of 100 cm (40 in.). Following the initial deposition of radionuclides, the potential for exposure of man may persist, depending on the influence of environmental redistribution, long after the plume leaves the area. Concentrations of radionuclides at the point of deposition normally are reduced by infiltration of radionuclides into the soil, by loss of soil particles due to erosion, and by transport in surface water and in groundwater.

When the effects of these processes cannot be quantified, a conservative estimate of dose due to external exposure to a contaminated surface is obtained by assuming that the radionuclide concentrations are diminished by radioactive decay only.

The dose is estimated for individuals at the nearest site boundary and the nearest residence. The intake parameters used for individual dose determination are shown in Table 4.1.

Table 4.1. Intake parameters (adult) used in lieu of site-specific data

Pathway	Maximum exposed individual	Average exposed individual[a]
Vegetables, kg/year	281	190
Milk, L/year	310	110
Meat, kg/year	110	95
Drinking water, L/year	730	370
Fish, kg/year	21	6.9
Inhalation, m^3/year	8000	8000

[a]Used for calculating population doses.
Source: Regulatory Guide 1.109.

Radiation dose to the population. The total dose received by the exposed population is estimated by the summation of individual dose estimates within the population. The area within the 80-km (50-mile) radius of the site is divided into 16 sectors (22.5° each) and into a number of annuli. The average dose for an individual in each division is estimated, that estimate multiplied by the number of persons in the division, and the resulting products are summed across the entire area. The unit used to express the population dose is person-sievert. For this report the population dose estimates are calculated for a population composed entirely of adults. The parameters used for calculating population doses are included in Table 4.1.

Fifty-year dose commitments for tritium are also calculated for the continental United States and the world population. The doses were calculated using existing person-sievert per becquerel estimates derived from a National Committee on Radiation Protection (NCRP) report.[12] The United States and world populations were based on information from the U.S. Bureau of the Census[13] and from a United Nations report[14] respectively.

4.1.1.3 Nonradiological methodology

Nonradiological gaseous releases to the atmosphere are routinely made from a number of the facilities at ORNL (see Sect. 2.5). A numerical dispersion model has been employed to assess the ground-level concentrations of the chemical species released. A long-term (annual) model has been used to predict concentrations within 15 km (10 miles) of the ORNL site. This model has been approved by the Environmental Protection Agency (EPA) for use in estimating the environmental impact of new emission sources as part of the permitting process and therefore has been considered appropriate for use in this study.

The ISCLT model used for predicting annual concentrations is a steady-state Gaussian plume model using a Briggs plume rise function for application to continuous emission sources.[15] The source parameters needed as input to ISCLT are the pollutant emission rates, stack heights and inside diameters, exhaust gas exit velocities and temperatures, and stack locations. A Cartesian coordinate system roughly centered on the ORNL site has been selected as the receptor grid with receptors at 500-m (1600-ft) intervals across the 30- by 30-km (20- by 20-mile) study area. Although the ISCLT model allows the simulation of physical relief within the receptor grid, this option has not been selected. The ISCLT model has been written to abort any attempts to model for an emission source of lower elevation than any of the receptors. Because some of the emission sources at ORNL are near ground level on the valley floor, even the inclusion of terrain elevations truncated to this low level has been deemed an unproductive exercise. This weakness in terrain modeling is not unique to ISCLT, and thus no other model has been judged overall to be any more appropriate. The influences of building wake and stack tip downwash on the plume have been included in model calculations. Because of the relatively short ranges and brief travel times considered, the emitted species have been assumed to be nonreactive and neither deposited nor scavenged from the plume.

4.1.2 Liquid Releases

4.1.2.1 Radiological methodology

The methodology used for calculating the 50-year dose commitments to man from the release of radionuclides to an aquatic environment is described in detail in ORNL-4992,[16] which also gives and bioaccumulation factors for radionuclides in freshwater fish. AQUAMAN is a computer code[17] that can also be used for calculating similar dose commitments from exposures by aquatic pathways.

Three exposure pathways are considered in dose determination: water ingestion, fish ingestion, and submersion in water (swimming). The internal dose conversion factors for converting exposure to dose are discussed in Sect. 4.1.1.2. Intake parameters are shown in Table 4.1.

4.1.2.2 Nonradiological

The impacts of nonradiological liquid releases on water quality are assessed by (1) calculating the concentrations of water quality constituents that result from dilution of releases in the receiving streams, (2) evaluating the available data that reflect recent operating performance of ORNL, and (3) comparing predicted and observed concentrations with water quality standards. To examine typical conditions, instream concentrations are calculated for average flows of White Oak Creek (WOC) and the Clinch River. To assess the impacts of liquid releases under worst-case conditions, it is typically assumed that waste discharges are diluted in the low flow for the system. However, the Clinch River's flow is regulated (Sect. 3.2.1) and periods of zero flow occur. Therefore, effects of an undiluted discharge from White Oak Dam are considered. Within WOC, worst-case conditions are assessed by assuming that discharges are diluted in the lowest recorded flow.

Impacts to aquatic biota are assessed by (1) comparing predicted and observed instream concentrations of constituents with water quality criteria levels set for protection of aquatic life and (2) evaluating the bioaccumulation of certain contaminants in key species.

4.1.3 Solid Waste Disposal

This section discusses the role of modeling in assessing the impacts of solid waste disposal and the models applicable to the assessment of ORNL solid waste disposal operations. The assumptions that are used in the assessment of impacts are identified, and the assessment methodology is introduced. The regulatory requirements applicable to the ORNL solid waste disposal operations are summarized to identify the applicable standards of performance.

4.1.3.1 Assessment models

The assessment of the environmental impacts from solid waste disposal often is accomplished by using models. Models of the performance of a solid waste facility can be used to quantitatively predict the transport of waste products through available environmental pathways and the potential effects of the transported waste products on the environment, human health, and safety. The most significant environmental pathway for the transport of solid waste products is groundwater; other potential pathways of concern include surface water and the atmosphere. The surface water pathway is of concern because aquifers typically discharge to surface water; transport of surface water is much faster than groundwater. The atmospheric pathway is of concern because it permits rapid transport of any gaseous waste products that may evolve from solid waste disposal facilities.

Modeling of solid waste disposal can be performed with the use of analytical, numerical, or empirical techniques. Analytical models generally require simple geologic settings to produce results that are useful for assessment. Numerical models generally require extensive input data generated from thorough field and laboratory investigations to produce results useful for assessment. Empirical models generally require extensive input data and an extended development period for results to be validated sufficiently for use in assessment. Any of these three types of models can provide results that can be related to the doses received by humans or the environment from solid waste disposal facilities if the models have been properly developed and applied to the site.

Modeling the groundwater pathway of the solid waste disposal facilities at ORNL has been initiated; however, modeling activities have concentrated on research investigations. The initial models of the transport from solid waste disposal facilities were prepared by Reeves and Duguid.[18,19] Their models were substantially improved by Yeh and Ward.[20,21] These models are not well adapted to geologic environments dominated by fractures and solution channels. Current research at Lawerence Berkeley Laboratory is directed toward developing a numerical model of flow in fractured media. When completed, the model will be investigated for its applicability to the ORNL solid waste disposal facilities. (Modeling of the atmospheric pathway is discussed in Sect. 4.1.1.) Modeling of the surface water pathway previously has received limited attention (Sect. 4.1.2). Recently, investigation into the hydrology of the WOC watershed was initiated to evaluate the effectiveness of proposed remedial actions related to past solid waste disposal.

While modeling of the solid waste disposal facilities would be a useful method for assessing the impacts of waste disposal, the current state of the art limits the applicability of model results to the ORNL site. Current research activities can be anticipated to provide results that would permit their use in future assessments.

4.1.3.2 Assumptions for impact assessment

Predictive models of the groundwater and surface water pathways at ORNL are not currently available; an alternative methodology that relies on several assumptions is discussed in Sect. 4.2.3. The assumptions identified in this section represent conservative estimates of the probable transport of groundwater and surface water at the ORNL solid waste disposal facilities.

The impact analysis assumes that the impacts to groundwater and surface water are the most significant factors in the assessment of the solid waste disposal facilities. It also assumes the impacts to groundwater and surface water are indicative of the impacts of solid waste disposal at the ORNL site. Because groundwater, surface water, and water quality data represent the most complete data base for waste disposal operations, the evaluation of these data are considered to be the best method for assessing the impacts of solid waste disposal. The analysis of solid waste disposal acknowledges the difficulty of predictably modeling the flow of groundwater at the ORNL site; as a result, modeling of the groundwater flow is not included in the analysis. The groundwater in Melton Valley is assumed to flow within Melton Valley and to discharge to WOC. The groundwater in Bethel Valley is assumed to flow within Bethel Valley and to discharge to WOC and to Racoon Creek. The groundwater in Bear Creek Valley is assumed to flow within Bear Creek Valley and to discharge to Bear Creek.

4.1.3.3 Regulatory requirements for solid waste disposal

Regulations applicable to the ORNL radioactive solid waste disposal activities have not been finalized. The EPA, NRC, and the U.S. Department of Energy (DOE) are developing regulations related to radioactive solid waste disposal that are expected to have similar requirements when they are finalized. This section provides a brief review of these proposed regulations as they relate to solid waste disposal operations at ORNL and reviews the relevant regulations issued by the state of Tennessee.

The DOE is preparing an order on low-level radioactive waste management (DOE Order 5820). These guidelines under development are for the selection, design, operation, closure, and postclosure activities for shallow land burial of low-level radioactive waste. The draft guidelines are presented in Appendix E.

The NRC has issued a proposed rule (10 CFR Pt. 61) providing technical standards or criteria for the commercial land disposal of radioactive waste. A draft environmental impact statement (NUREG-0782)[22] has been issued, and a draft technical position on site suitability and site characterization has been prepared. While these proposed regulations do not have any direct influence on solid waste disposal operations at ORNL, they are expected to be similar to the DOE standards being developed.

The EPA is developing environmental standards applicable to low-level radioactive waste disposal (40 CFR Pt. 191) which are anticipated to be as stringent as those presented in 40 CFR Pt. 190, which regulate nuclear power operations. These regulations were utilized in developing the DOE site suitability criteria. Regulations governing permissible levels of contamination of groundwater and surface water have been finalized by the EPA (40 CFR Pt. 141) and were used in developing the DOE site suitability criteria (see Sect. 3.2.3.5). The EPA has issued final regulations on the underground injection of hazardous or radioactive materials [40 CFR Pts. 122 and 146 (*Fed. Regis.* 47 (23), 4992–5001, Feb. 3, 1982)]. Reporting and monitoring requirements for injection wells are incorporated into 40 CFR Pt. 146.

Hazardous waste disposal is regulated by the EPA. Asbestos waste disposal regulations are included in 40 CFR Pt. 61, subpart B. Asbestos disposal at ORNL is regulated by Procedure 1.0 in the ORNL *Environmental Protection Manuel.* Disposal of hazardous biological wastes are regulated under 40 CFR Pt. 267.

The state of Tennessee has issued regulations that apply to the operation of the Sanitary Landfill (Bear Creek Valley) and the Contractors' Landfill (Tennessee Rule 1200-1-7) which prohibit open dumps and the contamination of groundwater and surface water unless a waiver is given by the commissioner of the Tennessee Department of Public Health or his authorized representative.

4.2 IMPACTS FROM RELEASES TO THE ENVIRONMENT

4.2.1 Gaseous Releases

4.2.1.1 Radiological

Doses to the individual. Quantities of radionuclides released to the atmosphere from routine operations at ORNL are included in Tables 2.3 through 2.7. For assessing impacts at the point of maximum exposure [southwest from ORNL, 3660 m (12,000 ft) from Bldg. 7911 stack and 4115 m (13,500 ft) from the other release points], 1981 release data were used, and it was assumed that the particulates were 0.3 μm in diameter and soluble in the lung upon inhalation.

Estimated total-body and organ doses to the maximally exposed offsite individual are shown in Table 4.2. The estimated total-body dose is 3.8 μSv (0.38 mrem), of which tritium contributes 95%. The highest estimated organ dose, 22 μSv (2.2 mrems), is to the thyroid, primarily a result of ^{131}I (82%) via the ingestion pathway. All dose commitments are well below the allowable standards[23] to the maximally exposed individual of 5 mSv (500 mrems) to the total body, gonads, and bone marrow and 15 mSv (1500 mrems) to other organs. Table 4.3 illustrates the contribution of exposure pathway to the maximum total-body and organ doses. Ingestion is the primary exposure mode to the total body and organs.

Doses to the regional population. The population dose estimates for distances out to 80 km (50 miles) from ORNL are included in Tables 4.4 and 4.5. The total dose to the total body is 0.1 person-Sv (11 person-rems), which is primarily from tritium releases. This estimate represents about a 0.01% increase over the 1.1×10^3 person-Sv (1.1×10^5 person-rems) already received by the same population from natural background radiation. The highest organ dose, 0.28 person-Sv (28 person-rems), is to the thyroid and is primarily from ingestion of ^{131}I.

Doses to the U.S. and global populations. Release of tritium from ORNL will expose the population of the United States and the world as well as the population living within an 80-km (50-mile) radius of ORNL. To model the behavior of tritium in the environment, a seven-compartment model was developed by Easterly and Jacobs;[24] this model is also described in NCRP Report No. 62.[25] For an atmospheric release rate of 37 PBq/year (1 MCi/year) of tritium, the tissue dose in man is 2.1 nGy (0.21 μrad) for the world population and 11 nGy (1.1 μrad) to the population in 30–50° N Lat. (in which the United States falls).[25] The doses including that to the regional population (Table 4.4) are shown in Table 4.6 and compared with the background from naturally produced tritium and the natural background from all sources. The population dose to the United States is only about 5% of the similar dose from naturally occurring tritium.

Radiological health effects. Risk estimates used here, as referred to in the report on the Biological Effects of Ionizing Radiation (BEIR),[26] are based on a linear dose-effect relationship, a

Table 4.2. Contribution of airborne radionuclides to the estimated 50-year dose commitments to the maximally exposed individual[a] from routine operations at ORNL

Radionuclide	Dose, Sv[b]				
	Total body	Bone	Lung	Thyroid	Kidneys
^{3}H	3.6E-6	3.5E-6	3.6E-6	3.6E-6	3.6E-6
^{85}Kr	2.5E-9	3.1E-9	4.7E-9	2.0E-9	2.1E-9
^{131}I	3.0E-8	4.0E-8	3.0E-8	1.8E-5	2.0E-8
^{133}Xe	2.0E-7	4.0E-7	2.0E-7	2.0E-7	1.0E-7
Alpha[c]	1.8E-11	4.9E-10	4.2E-12	6.9E-13	1.2E-11
Total	3.8E-6	3.9E-6	3.8E-6	2.2E-5	3.7E-6

[a]The point of maximum exposure is southwest of ORNL; 3660 m from 7911 stack and 4115 m from the remaining release points.

[b]Multiplier factors for converting International System of Units (SI) to English units are located on inside back cover.

[c]Unidentified alpha releases from Buildings 5505 and 4508 were assumed to be ^{239}Pu.

Source: Tables 2.3 through 2.7 (Summation 1981 data).

Table 4.3. Contribution of major atmospheric pathways of exposure to the estimated 50-year dose commitments to the maximally exposed individual[a] from routine operations at ORNL

Exposure pathway	Dose, Sv[b]				
	Total body	Bone	Lung	Thyroid	Kidneys
Submersion in air[c]	1.9E-7	3.7E-7	1.4E-7	2.1E-7	1.2E-7
Contaminated ground[c]	2.5E-8	3.5E-8	2.3E-8	2.2E-8	2.0E-8
Inhalation[d]	5.0E-7	3.9E-7	5.1E-7	6.7E-7	5.1E-7
Ingestion[e]	3.1E-6	3.1E-6	3.1E-6	2.1E-5	3.1E-6
Total	3.8E-6	3.9E-6	3.8E-6	2.2E-5	3.7E-6

[a]The point of maximum exposure is southwest of ORNL; 3660 m from 7911 stack and 4115 m from the remaining release points.

[b]Multiplier factors for converting International System of Units (SI) to English units are located on inside back cover.

[c]Exposure is for 100% of time; no shielding.

[d]Inhalation rate of 8000 m^3 of air per year.

[e]All food is assumed to be produced and consumed at the location of dose calculation; maximum annual intakes are 217 kg produce, 310 L milk, 110 kg meat, and 64 kg leafy vegetables (Table E-5, Regulatory Guide 1.109).

Source: Tables 2.3 through 2.7 (Summation of 1981 data).

Table 4.4. Contribution of airborne radionuclides to estimated 50-year dose commitments to the population around ORNL[a]

Radionuclide	Dose, person-Sv[b]				
	Total body	Bone	Lung	Thyroid	Kidneys
^{3}H	1.0E-1	9.7E-2	1.0E-1	1.0E-1	1.0E-1
^{85}Kr	9.1E-5	1.1E-4	1.7E-4	7.3E-5	7.8E-5
^{131}I	4.5E-4	5.4E-4	3.7E-4	1.7E-1	3.2E-4
^{133}Xe	6.6E-3	1.3E-2	5.3E-3	7.6E-3	4.4E-3
Alpha[c]	2.7E-7	7.5E-7	3.3E-3	1.1E-8	1.8E-7
Total	1.1E-1	1.1E-1	1.1E-1	2.8E-1	1.0E-1

[a]Population of 841,211 persons within 80 km of ORNL.

[b]Multiplier factors for converting International System of Units (SI) to English units are located on inside back cover.

[c]Unidentified alpha releases from Buildings 5505 and 4508 were assumed to be ^{239}Pu.

Source: Tables 2.3 through 2.7 (Summation of 1981 data).

Table 4.5. Contribution of major atmospheric pathways of exposure to the estimated 50-year dose commitments to the population around ORNL[a]

Exposure pathway	Dose, person-Sv[b]				
	Total body	Bone	Lung	Thyroid	Kidneys
Submersion in air[c]	6.7E-3	1.4E-2	5.1E-3	7.7E-3	4.5E-3
Contaminated ground[c]	3.7E-4	5.0E-4	3.4E-4	3.2E-4	3.0E-4
Inhalation[d]	1.4E-2	1.1E-2	1.4E-2	1.6E-2	1.4E-2
Ingestion[e]	8.6E-2	8.6E-2	8.6E-2	2.6E-1	8.6E-2
Total	1.1E-1	1.1E-1	1.1E-1	2.8E-1	1.0E-1

[a]Population of 841,211 persons within 80 km of ORNL.

[b]Multiplier factors for converting International System of Units (SI) to English units are located on inside back cover.

[c]Exposure is for 100% of time; no shielding.

[d]Inhalation rate of 8000 m^3 of air per year.

[e]Annual intake rates are 167 kg produce, 110 L milk, 95 kg meat, and 23 kg leafy vegetables (Table E-4 and E-5, Regulatory Guide 1.109).

Source: Tables 2.3 through 2.7 (Summation of 1981 data).

Table 4.6. U.S. and global population doses from airborne tritium releases from ORNL

Population group[a]	Population dose, person-Sv[b]		
	ORNL operation	Natural background for tritium only	Natural background from all sources
United States[c]	1.3E-1	2.7E0	2.3E5
World[c]	2.1E-1	5.3E1	4.5E6

[a]1980 population of U.S. is 2.27 x 10^8 persons. Estimated 1980 world population is 4.49 x 10^9 persons (from World Almanac and Book of Facts: 1982, Newspaper Enterprise Association, Inc., 1982).

[b]Multiplier factors for converting International System of Units (SI) to English units are located on inside back cover.

[c]Includes dose to local population.

Source: National Council on Radiation and Measurements, Tritium in the Environment, NCRP Report 62, March 9, 1979; for ORNL operation, Tables 2.3 and 2.5 (Summation of 1981 data).

somewhat more conservative approach than the linear-quadratic or threshold hypotheses for low-level, low-LET radiation. Potential health effects from routine releases at ORNL are estimated assuming an excess cancer mortality risk factor from total-body irradiation of 0.02 cancer deaths per person-Sv (0.0002 cancer deaths per person-rem) of annual exposure. For a collective total-body dose to the regional population of 0.1 person-Sv (10 person-rems), an excess of 0.002 cancer deaths would be expected. For total-body doses to the U.S. and world populations of 0.13 and 0.21 person-Sv (13 and 21 person-rems), respectively, excesses of 0.003 cancer deaths (to the U.S. population) and 0.004 cancer deaths (to the world populations) can be expected from routine ORNL operations. Of these latter estimates, 0.002 deaths would occur in the regional [80-km (50-mile) radius around ORNL] population.

Because the mortality rate from thyroid cancer is very low, we estimated a radiation-induced incidence of thyroid disease using a risk factor of 400 cases per 10^6 person-years per gray (4 cases per 10^6 person-years per rad or roughly 4×10^{-4} cases per person-Sv), as given in the BEIR III report.[27] A collective thyroid dose of 0.28 person-Sv (28 person-rems) could yield an excess of 0.001 cases of thyroid disease from routine radionuclide releases from ORNL.

Impacts on terrestrial biota other than man. The radiological exposure of various biota to a variety of radionuclides has been estimated by the staff to be as high as 3.9 mSv/year (390 mrems/year) for the shrew near ORNL and up to 2.25 mSv/year (225 mrems/year) for the mouse because of ^{60}Co. Doses to deer muscle were based on the average ^{137}Cs level measured in 19 deer killed in the environs of ORNL during 1980 of 1.2 Bq/kg (32 pCi/kg).[28] An average dose to the deer of 3.5 μSv/year (0.35 mrem/year) was estimated, with a high of 11 μSv/year (1.1 mrems/year). The external dose to terrestrial animals from immersion in radioactive gases or particles released by ORNL was assumed to be identical with that estimated for humans.

4.2.1.2 Nonradiological

Nonradiological releases to the air include gaseous and particulate emissions from the coal-fired steam plant (Sect. 2.5.2), chemical vapors from a large number of hoods and other building vents, exhausts and dust from vehicular traffic and heavy construction equipment, and several chemicals in cooling tower drift. These releases affect air quality and have impacts on biota, land use, and inanimate objects. Portions of the following assessments use data presented in Tables 2.8 and 2.9. These data are thought to be representative of 1981 release data.

Effects on air quality. Releases to the air and national air quality standards are indicated in Table 4.7. The estimated concentrations of the criteria pollutants (SO_x, NO_x, CO and particulates) indicate that the national ambient air quality standards are unlikely to be exceeded as a result of ORNL operation. The emissions of hydrocarbons appear to be relatively large—large enough to exceed the national guidelines (3-h annual maximum of 160 $\mu g/m^3$). However, the emission estimates for hydrocarbons may be overly conservative because they represent emissions from pre-1967 vehicles and do not reflect hydrocarbon emission controls on more recent models.

The several cooling towers located at ORNL emit biocides and corrosion inhibitors to the air. However, most of these chemicals are contained in water droplets that settle to the ground close to the towers. Therefore, it is believed that they do not significantly deteriorate air quality except near the towers.

Airborne particulates resulting from traffic on roads and wind erosion of soil occur only in minor quantities. Most roads at ORNL are paved, and most vacant areas are well-vegetated, thus holding particulate concentrations from these sources to insignificant levels.

Effects on biota and land use. Releases of pollutants to the air could potentially adversely affect the productivity of vegetation and thus could cause impacts on ecosystem function and on land uses such as forestry and agriculture. However, because the criteria pollutants (SO_x, NO_x, and particulates) emitted from ORNL result in concentrations far below the national standards (Table 4.7), the ORNL emissions are unlikely to have significant impacts on vegetation. Hydrocarbon concentrations appear relatively high (Table 4.7). However, with the exception of ethylene, hydrocarbons themselves generally do not significantly affect vegetation except in extremely high concentra-

Table 4.7. Source terms and maximum annual average ground-level concentrations of various substances emitted to the air at ORNL compared with national air quality standards

Pollutants	Source terms: Steam plant[a] (g/s)	Diesel-powered vehicles[b] (g/s)	Gasoline-powered vehicles[b] (g/s)	Vents and hoods (g/s)	Total (g/s)	Air concentration ($\mu g/m^3$)	National air quality standard, annual average ($\mu g/m^3$)
Hydrocarbons and organics from evaporation	N.A.[c]	<0.3	1.4[d]	2.8[e]	4.5	18	
Hydrocarbons from combustion	0.1	0.5	2.7[f]	N.A.	3.3	13	
Total hydrocarbons and organics	0.1	<0.8	4.1	2.8	7.8	1+31=32[g]	None
SO_x	55	0.1	0.2	N.A.	55.3	3+2=5	80
NO_x	9	0.6	1.5	N.A.	11.1	1+9=10	100
CO	0.5	0.2	29.5	0.002	30.2	1+121=122	None[h]
Particulates	0.3	0.3	0.2	N.A.	0.8	1+3=4	60
Ammonia	0	N.A.	N.A.	0.06[i]	0.06	0+1=1	None
Sulfur hexafluoride	N.A.	N.A.	N.A.	0.7	0.7	0+3=3	None

[a]Emissions were derived using composition and consumption data in Sect. 2.5.2 and emission factors for CO and HC from Compilation of Air Pollution Emission Factors, 3rd. ed., Environmental Protection Agency, Research Triangle Park, N.C., 1977, p. 1.1-2. In dispersion modeling, the steam plant was treated as an elevated point source, while all other emission sources were lumped together as low level area sources.

[b]Calculations assumed 249 working days of 8 hours each per year. The resulting low total number of hours yields conservative estimates of source terms calculated from quantities released over a one year period. Vehicular-related emissions were based on the annual use (April 1981 to March 1982) of the following quantities of fuels: diesel fuel, 146,000 liters; and gasoline, 767,000 liters. Emission data were obtained from R. G. Bond and C. P. Staub, Eds., Handbook of Environmental Control, Vol. 1: Air Pollution, the Chemical Rubber Co., Cleveland Ohio, 1972.

[c]N.A. = not applicable.

[d]Evaporations at gasoline pumps and from vehicle carburetors and gasoline tanks are included.

[e]Calculations were based on the assumption that 75% of the entire quantity of organics purchased by the ORNL Chemical Stores (Data on the quantities of organic chemicals purchased by personnel directly from vendors were not available.) was released to the air through evaporation. The data used are from Table 2.8.

[f]Emissions for combustion of fuel do not reflect hydrocarbon emission controls on recent model vehicles (i.e., post 1967), thus making the emission estimates conservative.

[g]Steam plant + other sources = total. The first number represents the steam plant.

[h]There is not a standard for the annual average. The CO standard for the 8-h maximum concentration is 10,000 $\mu g/m^3$. Extrapolating from the estimated annual average, the standards for the maximum 8-h concentration is highly unlikely to be exceeded.

[i]The data used are from Table 2.9.

tions much higher than those at ORNL.[29] Very low ethylene concentrations of 1 to 3 $\mu g/m^3$ can affect certain highly sensitive plant species. Such effects include drooping of flower petals, flower sepals, and leaves.[30] Short-term (less than 72-h) concentrations from about 45 to 120 $\mu g/m^3$ can retard plant growth in several sensitive species. At ORNL ethylene is emitted in the exhausts of gasoline and diesel engines constituting about 14% of the total hydrocarbon exhausts.[30] Although effects of ethylene on plant species have not been observed at ORNL, the occurrence of such effects at ORNL is possible. In the presence of ultraviolet light, hydrocarbons react with nitrogen oxides to produce oxidants, which are known to affect vegetation.[29] Oxidant levels are high in the Oak Ridge–Knoxville region (Sect. 3.3.6) and probably have some deleterious effects on vegetation. Emissions of hydrocarbons at ORNL contribute slightly to this regional problem.

Some fluoride compounds can also affect vegetation. Gaseous sulfur hexafluoride (Table 2.9) is released at ORNL, but this chemical is nontoxic and chemically inert;[31] therefore, it should not have any effects on vegetation at ORNL.

Impacts of cooling tower emissions at ORNL and at the Oak Ridge Gaseous Diffusion Plant (ORGDP) were the subject of several ORNL research projects from 1972 through 1980 (e.g., see ref. 32). These projects examined accumulation of cooling tower emissions in soil and its effects on insects, rodents, and vegetation. The impacts are apparently insignificant except in areas very near the towers [less than 200 m (650 ft)], where growth inhibition was observed in a selected highly sensitive plant species (Kentucky Burley No. 21 tobacco). Impacts on animals and native vegetation were not detected or were insignificant.

In conclusion, emissions to the air at ORNL appear to have little or no effect on nearby vegetation and contribute very little to the regional levels of air pollutants. Therefore, animal life and land uses such as agriculture and forestry should not be affected.

4.2.2 Liquid Releases

Liquid releases from ORNL enter the WOC system, which is described in Sects. 3.2 and 3.4.2. In ORNL's early operation, WOC was dammed to form White Oak Lake creating a settling basin that inhibited offsite dispersion of many of the radionuclides and chemical pollutants discharged into WOC from ORNL facilities. Because of potential radiological exposure and to ensure security of facilities, White Oak Lake and most of the WOC watershed are within a restricted access area. Along the Clinch River and Tennessee Highway 95 (Fig. 3.11), public access is prevented by a chainlink fence, and the area is also posted with warning signs. Entry into a restricted access area is for "official use only" and is controlled by gates that are open only during business hours.

4.2.2.1 Radiological

The radiological impact of liquid effluents from ORNL was assessed by calculating the radiological dose to individuals from various uses of the Clinch River and to populations taking their drinking water from the Clinch and Tennessee rivers downstream from ORNL.

Effluents containing waste radionuclides are discharged into the Clinch River via the WOC about 4.8 km (3 miles) downstream from the Melton Hill Dam. The annual release of radionuclides to the river are shown in Table 2.10. The dose calculations are based on actual sampling data for water and aquatic food where such data are available.

Individual dose. The aquatic pathways (Fig. 4.1) considered in calculating the maximum dose to the individual included shoreline exposure (includes exposure from sediment deposition) for 240 h/year, submersion in water (swimming) for about 90 h/year, ingestion of fishes [21 kg/year (46 lb/year)], and ingestion of water [730 L/year (190 gal/year)]. Further assumptions, models, and codes are discussed in Sect. 4.1.2 and in Table 4.1.

The annual total-body and organ doses estimated for the proposed aquatic pathways associated with the Clinch River at ORNL are summarized in Table 4.8. The point of maximum potential exposure is on the site boundary located along the Clinch River adjacent to a cesium field experimental plot. Based on information in ORNL-5821,[28] the average external gamma dose rate of 1.94

Table 4.8. Estimated 50-year dose commitment to the maximally exposed individual from aquatic pathways in the Clinch River near the mouth of White Oak Creek from ORNL liquid effluents

Exposure pathway	Dose, Sv[a]			
	Total body	Bone[b]	Thryoid	Kidney
Submersion in water[c]	4.3E-10	4.3E-10	5.0E-10	4.0E-10
Ingestion of fish[d]	6.6E-6	2.4E-5	6.0E-6	6.9E-6
Ingestion of water[e]	8.7E-7	5.0E-6	4.1E-7	3.3E-7
Shoreline exposure[f]	5.3E-5	5.3E-5	5.3E-5	5.3E-5
Total	6.0E-5	8.2E-5	5.9E-5	6.0E-5

[a]Sv may be converted to rem by multiplying by 100.
[b]Dose is to the endosteal cells of the bone.
[c]Assumes that individual spends 1% of the year swimming in the Clinch River at this point.
[d]Assumes that 21 kg/year of fish is consumed. Doses are based on the radionuclide analysis of fish caught near this location.
[e]Assumes that the maximum adult water intake is 730 L/year (Regulatory Guide 1.109).
[f]Shoreline exposure (240 hours/year) based on measurement taken along the shore of the Clinch River downstream from the mouth of the White Oak Creek.
Source: Table 2.10 (1981 data) and Industrial Safety and Applied Health Physics Annual Report for 1980, ORNL-5821, Oak Ridge National Laboratory, Oak Ridge, Tennessee, November 1981, Tables 4.4.9 and 4.5.3.

mSv/year (194 mrems/year) at the shoreline near the cesium field was due primarily to the "skyshine" from the ^{137}Cs experimental plot. This area is accessible only by boat, and the likelihood of continuous exposure is remote. For a more realistic determination of dose from shoreline exposure, it was assumed that the maximally exposed individual spends only 240 h/year at this location. The primary exposure pathway from the aquatic releases was due to the external gamma at this shoreline exposure point (Table 4.8). About 88% of the total-body dose of 60 μSv (6.0 mrems) was due to this pathway.

The dose from eating fishes of 6.6 μSv (0.66 mrem) caught at various locations of the Clinch River (Table 4.9) accounts for most (11%) of the remainder of the total-body dose.

The doses from drinking water from the river (Table 4.8) are based on measured radionuclide concentration in the Clinch River at CRK 23.2 (CRM 14.5) (see Table 4.10). The highest total-body dose to the maximally exposed individual from this pathway is only about 0.9 μSv (0.09 mrem). The highest organ dose of 5 μSv (0.5 mrem) is to the bone and was due primarily to ^{90}Sr (94%) and ^{3}H (5%).

The maximum individual total-body dose from all aquatic pathways (Table 4.8) of 60 μSv (6.0 mrems) is only about 1.2% of the allowable standard of 5 mSv (500 mrems).[23] The maximum organ dose (to the bone) of 82 μSv (8.2 mrems) is only about 0.6% of the allowable standard of 15 mSv (1.5 rems).[23] Additionally, all doses are well below the EPA standard (40 CFR 190) of 0.25 mSv (25 mrems) to the total body and all organs except the thyroid, which is 0.75 mSv (75 mrems). The highest organ dose of 82 μSv (8.2 mrems) is approximately 30% of the EPA limit.

Population dose. The population dose from drinking water from the Clinch and Tennessee rivers into which the ORNL liquid effluents have been released are shown in Table 4.11. The popu-

Table 4.9. Radionuclide content in fish[a] caught at various Clinch River Kilometer (CRK) locations

Radionuclide	Average concentration (Bq/kg wet-weight)[b]			
	CRK 0.8	CRK 19.3	CRK 33.5	CRK 40.2[c]
^{90}Sr	4.3E-1	6.8E-1	3.5E0	1.7E-1
^{239}Pu	1.4E-3	2.2E-4	3.8E-1	1.6E-3
^{238}Pu	1.2E-3	1.9E-3	2.9E-3	3.4E-3
^{238}U	9.0E-2	1.1E-1	4.0E-2	3.8E-2
^{235}U	7.1E-3	8.1E-3	7.1E-3	1.5E-2
^{234}U	7.1E-2	1.5E-1	5.4E-2	
^{137}Cs	3.2E0	3.9E0	1.5E1	2.9E-1
^{60}Co	4.2E-2	1.7E-1	9.0E-1	1.1E-1

[a]Composite of 50 fish at each location.

[b]Multiplier factors for converting International System of Units (SI) to English units are located on inside back cover.

[c]Clinch River Kilometer 40.2 is upstream of ORNL above the Melton Hill Dam and radionuclide concentrations here are considered to be background.

Source: Industrial Safety and Applied Health Physics Annual Report for 1980, ORNL-5821, Oak Ridge National Laboratory, Oak Ridge, Tennessee, (November 1981), Table 4.4.9.

Table 4.10. Radionuclides in the Clinch and Tennessee rivers

Location	Average annual concentration (Bq/L)[a]				
	^{90}Sr	^{137}Cs	^{106}Ru	^{60}Co	^{3}H
CRK[b] 37.2 Melton Hill Dam	4.1E-3	2.6E-3	6.3E-3	4.1E-3	2.8E3
CRK 23.3 Gallaher (near ORGDP)	2.8E-2	3.0E-3	6.3E-3	7.7E-3	5.6E3
TRK[c] 914 Kingston Water Plant	4.4E-2	2.6E-3	2.4E-2	3.0E-3	3.5E3

[a]Multiplier factors for converting International System of Units (SI) to English units are located on inside back cover.

[b]CRK = Clinch River Kilometer.

[c]TRK = Tennessee River Kilometer.

Source: Industrial Safety and Applied Health Physics Annual Report for 1980, ORNL-5821, Oak Ridge National Laboratory, Oak Ridge, Tennessee (November 1981), Table 4.4.2.

lation dose to the total body is 0.038 person-Sv (3.8 person-rems), which is only 0.0097% of that dose to the similar population of 391 person-Sv (3.91 × 10^4 person-rems) from natural background radiation (see Sect. 3.5).

Impacts on aquatic biota other than man. Radiation doses to aquatic plants, invertebrates, fishes, muskrats, and waterfowl have been estimated for WOC at White Oak Dam and for the Clinch River at the mouth of WOC.

The estimated maximum doses to aquatic plants and animals living in WOC are shown in Table 4.12. The highest dose was to the muskrat or waterfowl from ^{90}Sr, for which these animals have a high bioaccumulation factor. The dose to plants and invertebrates was due almost entirely to ^{90}Sr, while ^{137}Cs was responsible for 70% of the dose to fishes.

Table 4.11. Estimated 50-year dose commitment to the population from the ingestion of drinking water[a]

Location	1980 population using water	Dose[b] (person-Sv)[c]			
		Total body	Bone[d]	Kidney	Thyroid
Harriman	13,900	6.7E-3	5.7E-2	5.2E-3	4.1E-3
Kingston Steam Plant	600	2.9E-4	2.5E-3	2.2E-4	1.8E-4
Kingston	7,500	3.6E-4	3.1E-2	2.8E-3	2.2E-3
Rockwood	8,100	1.0E-3	8.9E-3	7.8E-4	6.2E-4
Spring City and resorts	2,300	2.9E-4	2.5E-3	2.2E-4	1.8E-4
Soddy-Daisy	9,300	9.0E-4	7.6E-3	6.9E-4	5.5E-4
Chattanooga and resorts	261,400	2.5E-2	2.1E-1	1.9E-2	1.5E-4
Total	303,100	3.8E-2	3.2E-1	2.9E-2	8.0E-3

[a]Assumed 100% of drinking water (average adult intake of 370 L/year, Regulatory Guide 1.109) is taken from the Clinch and Tennessee rivers and that there is no reduction in radioactivity during purification.

[b]Doses for Harriman, Kingston, and Kingston Steam Plant are based on measured radionuclide concentrations in the Tennessee River at the Kingston water intakes (Table 4.10). Harriman's water intake is on the Emory but at times may draw Clinch River water. Doses for Rockwood and Spring City are based on concentrations of the radionuclides at Kingston diluted by the Tennessee River (Watts Bar Lake) at the Watts Bar Dam. Doses to Soddy-Daisy and Chattanooga populations are based on calculated concentrations near Chickamauga Dam.

[c]Person-Sv may be converted to person-rem by multiplying by 100.

[d]Dose is to endosteal cells of the bone.

Table 4.12. Dose to biota living in White Oak Creek within the ORNL boundary

Radiation exposure	Dose (Gy/year)[a]			
	Aquatic plants	Invertebrates	Fish	Waterfowl, muskrats
Internal dose	2.7E-2	9.6E-3	4.1E-3	5.4E0
External beta plus gamma dose	5.7E-5	5.7E-5	5.7E-5	5.7E-5
Total	2.7E-2	9.7E-3	4.2E-3	5.4E0

[a]To convert Gy to rad multiply dose by 100.

Source: G. S. Hill, Jr., Health and Safety Research Division at the Oak Ridge National Labortory.

The doses to the biota in the Clinch River (shown in Table 4.13) are considerably lower than in WOC because the river furnishes more dilution to the radionuclides in the effluents. The maximum annual doses are as follows: [illegible] μGy (8.3 mrads) to the aquatic plants, 28 μGy (2.8 mrads) to the invertebrates, 12 μGy (1.2 mrads) to fishes, and 1.2 mGy (120 mrads) to waterfowl or muskrat. Whereas no dose limits are established for these biota, aquatic organisms are generally thought to be at least as resistant to radiological effects as is man. No demonstratable biological effects are indicated at the present level of release of radioactive materials to uncontrolled or offsite streams.

Table 4.13. Dose to biota living in the Clinch River at the mouth of White Oak Creek at the ORNL boundary

Radiation exposure	Dose (Gy/year)[a]			
	Aquatic plants	Invertebrates	Fish	Waterfowl, muskrats
Internal dose	8.3E-5	2.8E-5	1.2E-5	1.2E-3
External beta plus gamma dose	1.7E-7	1.7E-7	1.7E-7	1.7E-7
Total	8.3E-5	2.8E-5	1.2E-5	1.2E-3

[a]To convert Gy to rad multiply dose by 100.
Source: G. S. Hill, Jr., Health and Safety Research Division at the Oak Ridge National Laboratory.

4.2.2.2. Nonradiological

The point sources of the potential water quality contaminants at ORNL include treated sanitary wastewater, discharges from numerous facilities, and cooling tower blowdown. Nonpoint sources include (1) runoff from parking lots, streets, buildings, and the grounds and (2) runoff and seepage from disposal areas for radioactive solid waste (Sect. 4.2.3.2). Although estimates are available of the waste loadings discharged from some ORNL facilities (Table 2.12), the discharge of potential contaminants has not been thoroughly quantified. In particular, waste loadings from nonpoint sources are poorly documented and difficult to ascertain. Fortunately, however, the water quality currently observed in WOC and the Clinch River can be used to indicate the effects of operations at ORNL.

Clinch River. To assess ORNL's impacts on water quality in the Clinch River, the average discharge at White Oak Dam is assumed to be diluted with the average flow of the Clinch River. The water quality at Station P-2, just above White Oak Dam (Fig. 3.11), is assumed to be representative of water passing the dam's spillway. The concentrations predicted to result from WOC's discharge into the Clinch River are calculated by a formula that describes simple, complete mixing:

$$C_m = \frac{(C_a Q_a) + (C_d Q_d)}{Q_a + Q_d} \quad (4.1)$$

where:

C_m = the predicted concentration after complete mixing,
C_a = the ambient (or background) concentration,
Q_a = the flow rate of the receiving stream,
C_d = the concentration in the discharge stream,
Q_d = the flow rate of the discharge stream.

Table 4.14 shows the results of the analysis for both average and maximum observed concentrations of water quality constituents. Average flows for the Clinch River and WOC are 150 m^3/s (5280 cfs) and 0.38 m^3/s (13.5 cfs) respectively. This analysis shows that, with complete mixing, the water quality constituents discharged from WOC have a negligible effect on the Clinch River's water quality. In fact, the average concentrations of most trace elements are greater in the Clinch River than in the discharge from White Oak Dam. The concentrations of nitrate and phosphorus are approximately ten times greater in WOC's discharge, but the increases in Clinch River concentrations are trivial.

Table 4.14. Predicted and observed concentrations of water quality constituents in the Clinch River

Constituent	Concentrations of White Oak Dam Discharge[a]		Ambient concentrations in Clinch River[b]		Predicted downstream concentrations[c]		Observed concentrations in Clinch River[d]	
	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum
Total dissolved solids, mg/L	198	312	133	150	133	150	183	283
Nitrate, mg/L	2.9	7.2	0.43	0.57	0.45	0.59	0.6	2.8
Total phosphorus, mg/L	0.27	0.59	0.02	0.08	0.021	0.081	NA[e]	
Sulfate, mg/L	59	95	17	24	17.1	24.2	23	35
Total hardness, mg/L	144	188	109	140	109.1	140.1	NA	
Phenol, μg/L	2	8	1[f]	2[f]	1	2	NA	
Cd, μg/L	0.17	0.53	0.9	4	0.9	4	<2	4
Cr, μg/L	2.7	12.0	11	30	11	30	<10	30
Cu, μg/L	3.9	6.6	22	80	22	80	NA	
Fe, μg/L	132	640	330	1000	330	1000	NA	
Hg, μg/L	0.09	0.50	0.36	2.3	0.36	2.3	<1	<1
Mn, μg/L	122	430	48	200	48.2	200.6	NA	
Ni, μg/L	7.6	20	36	100	36	100	<30	200
Pb, μg/L	1.3	3.0	9	33	9	33	<10	<10
Zn, μg/L	12.9	30	23	170	23	170	<60	100

[a]Data from Station P-2 (see Fig. 3.11), M. A. Montford, T. W. Oakes, and W. F. Ohnesorge, *Water Quality in White Oak Creek and Melton Branch*, ORNL/TM-8131, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1982, in press.

[b]Data from Table 3.13 (primarily USGS data).

[c]See text for calculations.

[d]Data from CRK 23.3 (CRM 14.4) ORGDP Sanitary Water Intake, *Environmental Monitoring Report, U.S. Department of Energy, Oak Ridge Facilities, Calendar Year 1980*, Y/UB-15, UCC-ND, Oak Ridge, Tenn., June 10, 1981, Table 17.

[e]NA = not available.

[f]Value estimated, based on typical concentrations for unpolluted water bodies.

Discharge from Melton Hill Dam follows a pulsatory pattern (Sect. 3.2.1.3), and at times the Clinch River at the mouth of WOC is an almost slack pool. Thus, it is necessary to consider the impact during periods when WOC discharge undergoes little or no mixing with the Clinch River water. These impacts can be seen by considering data collected from 1979 through 1980 for Stations P-1 and P-2 in Figs. 3.12 through 3.15. Average concentrations at Station P-2 (White Oak Dam) are below EPA standards or criteria for protection of aquatic life for most water quality constituents, cadmium and manganese being the exceptions. Levels of mercury and nickel have occasionally exceeded the criteria levels, but the average levels are 64 and 57% of the respective EPA criteria for protection of human health (Table 3.13). The cadmium level (average 0.17 μg/L) does not appear to represent degradation of water quality, because background (0.12 μg/L at Station P-6) levels exceed the criteria (0.026 μg/L) by about five times. The average concentration of manganese (122 μg/L) exceeds the secondary drinking water standard (50 μg/L); however, this standard is based on aesthetic properties of water, not effects on human health. Mixing would reduce this concentration prior to the intake for the ORGDP drinking water supply. In summary, the discharge of WOC into the Clinch River appears unlikely to cause any significant adverse effect on water quality or on human health.

With respect to aquatic ecology, the WOC discharge should not have a detectable adverse effect on biota except for minor sublethal or chronic effects that might occur because of occasionally elevated levels of contaminants. Discharges of nitrogen and phosphorus would cause local enrichment, with possible increases in productivity, but adverse effects (e.g., blooms of nuisance organisms) have not been observed in previous surveys and appear quite unlikely. As discussed in Sect. 3.4.2.1, very little difference could be detected between aquatic communities upstream and downstream from the mouth of WOC, and likewise, no significant differences for the trace elements in fish tissue were noted between these two stations.

White Oak Creek basin. Water quality impacts in WOC basin were analyzed by assuming that waste loads are diluted in the recorded low flows of WOC and Melton Branch. The summer of 1980 and October 1981 were very dry periods, and low flows of 123 and 9 L/s (1950 and 140 gpm) were recorded for WOC (Station P-4) and Melton Branch (Station P-5) respectively [as reported in ORNL's national pollutant discharge elimination system (NPDES) monitoring reports]. The estimated flows of wastewater (Table 2.12) were 41 and 8 L/s (650 and 125 gpm), respectively, for WOC and Melton Branch (representing 34 and 89% of the low flows). Concentrations of wastewater constituents expected to occur were calculated using a modification of Eq. 4.1:

$$C_m = \frac{C_a Q_a + W}{Q_a + Q_w} \quad (4.2)$$

where

W = total waste loads (from Table 2.12),
Q_w = waste discharge.

The flow upstream from ORNL discharge (ambient flow or Q_a) was calculated as the difference between the total flow (as measured by the gauge) and the estimated wastewater discharge.

The predicted concentrations based on waste loadings at low flow are compared to observed concentrations in Tables 4.15 and 4.16. If the ambient concentrations of water quality constituents were perfectly constant, one would expect to see the maximum predicted concentrations occurring at the time of lowest stream flow. In WOC (Table 4.15) there is fairly good correspondence between the predicted low-flow concentrations and observed maximum concentrations for total dissolved solids (TDS), phosphate, cadmium, copper, chromium, and nickel. Dilution of waste loadings predicts concentrations for iron and zinc that greatly exceed the observed maxima, perhaps because these metals precipitate after discharge and accumulate in sediments. The maxima observed for biological oxygen demand, suspended solids, phenol, chromium and manganese greatly exceed

Table 4.15. Predicted and observed concentrations of water quality constituents in White Oak Creek

Constituent	Average upstream ambient concentration[a]	Predicted low-flow concentration with waste loading[b]	Observed concentrations[c]	
			Average	Maximum
BOD, mg/L	1.0[d]	2.04	<5	13
Suspended solids, mg/L	2.0[d]	2.3	<7.5	44
Total dissolved solids, mg/L	101	293	204	302
Ammonia, mg/L	0.1[d]	0.63	NA[e]	NA
Phosphate,[f] mg/L	0.02	0.70	0.27	0.47
Phenol, μg/L	2	2	3	12
Al, μg/L	60[d]	570	NA	NA
Ag, μg/L	0[d]	0.5	NA	NA
Cd, μg/L	0.12	3	0.3	1.2
Cr, μg/L	0.5	3	4	37
Cu, μg/L	0.9	12	6	13
Fe, μg/L	65	1800	136	316
Hg, μg/L	0.02	NA	0.19	0.72
Mn, μg/L	12	40	43	105
Ni, μg/L	4	20	7	21
Pb, μg/L	0.9	3	2	5.6
Zn, μg/L	3	88	21	42

[a]Data for Station P-6 (see Fig. 3.11).
[b]See text for details of calculations.
[c]Data for Station P-4 (see Fig. 3.11).
[d]Values estimated based on Table 3.16 and on typical concentrations for unpolluted streams.
[e]NA = not available.
[f]Values for total phosphorus.
Source: M. A. Montford, T. W. Oakes, and W. F. Ohnesorge, Water Quality in White Oak Creek and Melton Branch, ORNL/TM-8131, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1982, in press.

the predicted concentrations, perhaps because of occasional slug discharges or periods of poor performance by the sanitary waste treatment lagoons. The above discrepancies, of course, may also result from inaccurate estimation of waste loads. In Melton Branch (Table 4.16) there are greater discrepancies between the observed and predicted concentrations, although a fairly good correspondence exists for TDS, cadmium, chromium, and copper.

The significance of ORNL's waste discharges for WOC's water quality can be assessed by inspecting Figs 3.12 through 3.15 and Table 4.17. Operations at ORNL caused elevation of the concentrations of all the water quality constituents that were measured. At stations T-10, P-4, and P-3 (downstream from ORNL) the average concentrations of cadmium and copper exceed the EPA criteria for protection of aquatic life. The average concentrations of mercury at Stations T-10 and P-3 on WOC also exceed the EPA criteria for protection of aquatic life. Average concentrations of manganese in Melton Branch and in White Oak Lake exceed the EPA's secondary drinking water standard. Criteria levels are occasionally or routinely exceeded for nitrate and all of the trace ele-

Table 4.16. Predicted and observed concentrations of water quality constituents in Melton Branch

Constituent	Average upstream ambient concentration[a]	Predicted low-flow concentration with waste loading[b]	Observed concentrations[c] Average	Observed concentrations[c] Maximum
BOD, mg/L	1.0[d]	NA[e]	<5	<5
Suspended solids, mg/L	2.0[d]	16	<17	310
Total dissolved solids, mg/L	159	931	352	700
Ammonia, mg/L	0.1[d]	0.04	NA	NA
Phosphate,[f] mg/L	0.2	4.7	0.5	1.1
Phenol, μg/L	2	1[g]	2	7
Al, μg/L	60[d]	180	NA	NA
Ag, μg/L	0[d]	<3	NA	NA
Cd, μg/L	0.1	1	0.2	0.7
Cr, μg/L	0.5	2	1.3	2.3
Cu, μg/L	0.9	8	3	8
Fe, μg/L	130	20	180	670
Hg, μg/L	0.05	NA	0.03	0.36
Mn, μg/L	32	5	153	340
Ni, μg/L	5	78	10	35
Pb, μg/L	0.9	NA	1.2	3.5
Zn, μg/L	3	500	23	81

[a]Data for Station T-7 (see Fig. 3.11).
[b]See text for details of calculations.
[c]Data for Station P-5 (see Fig. 3.11).
[d]Values estimated based on Table 3.16 and on typical concentrations for unpolluted streams.
[e]NA = not available.
[f]Values for total phosphorus.
[g]The predicted low-flow concentration is lower than the upstream ambient concentration because the small flow in Melton Branch is diluted with water containing no phenol.

Source: M. A. Montford, T. W. Oakes, and W. F. Ohnesorge, Water Quality in White Oak Creek and Melton Branch, ORNL/TM-8131, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1982, in press.

ments monitored except for chromium. Concentrations of polychlorinated biphenyls (PCBs) in sediments also appear to be elevated above background in WOC between ORNL and White Oak Dam, although this observation is based on only four samples at each site.

The water quality conditions in WOC represent a complex situation that is difficult to interpret. The sources of contaminants include (1) point-source discharges from ORNL facilities (estimated in Tables 4.15 and 4.16), (2) nonpoint sources [such as contaminated groundwater seepage from the solid waste disposal areas (SWDAs) and runoff from streets and parking lots (Sect. 4.2.3.2)], and (3) sediments of WOC which may contain contaminants released during past years. With these multiple sources of potential contaminants, it is impossible to define a mixing zone resulting from ORNL's point-source discharges.

Table 4.17. Summary of water[a] quality observed in White Oak Creek basin

Constituent	EPA Criteria[b]		WOC above ORNL[c]		WOC below ORNL[d]		Melton Branch[e]		White Oak Dam[f]	
	Average (24-hr)	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum
BOD, mg/L	None		NA[g]	NA	<5	13	<5	<5	NA	NA
Suspended solids, mg/L	None		NA	NA	<7.5	44	<17	310	NA	NA
Total dissolved solids, mg/L	None		101	239	204	302	352	700	198	312
Phenol, μg/L	3500		1.9	8	3	12	2	7	2	8
Cd, μg/L	0.036	4.4	0.13	0.45	0.3	1.2	0.2	0.7	0.17	0.5
Cr, μg/L[h]	50		0.5	1.5	4	37	1.3	2.3	2.7	12
Cu, μg/L	5.6	31	0.9	2.6	6	13	3	8	3.9	6.6
Fe, μg/L	1000		65	285	136	316	180	670	132	640
Hg, μg/L	0.20[i]	4.1	0.02	0.36	0.19	0.72	0.03	0.36	0.09	0.50
Mn, μg/L[h]	50		12	20	43	105	153	340	122	430
Ni, μg/L	126	2400	4.2	15	7	21	10	35	7.6	20
Pb, μg/L	9.0	270	0.9	4.0	2	5.6	1.2	3.5	1.3	3.0
Zn, μg/L	47	434	3.3	5.8	21	42	23	81	12.9	30
PCB (sediment) μg/g[j]	None		0.23	0.5	0.83	2.0	0.1	0.1	0.2	0.4

[a]Average concentrations based on 36 weekly samples between April 1979 and January 1980.

[b]Water Quality Criteria for Toxic Substances, 45 FR 79318-79 (except as noted). Criteria are for protection of aquatic life. Hardness dependent values based on average hardness (as $CaCO_3$) at White Oak Dam = 144 mg/L.

[c]Data for Station P-6 (see Fig. 3.11).

[d]Data for Station P-4 (see Fig. 3.11).

[e]Data for Station P-5 (see Fig. 3.11).

[f]Data for Station P-2 (see Fig. 3.11), assumed to be representative of water passing White Oak Dam spillway.

[g]NA = not available.

[h]Drinking water standard (see Table 3.13).

[i]Mercury criterion for protection of human health from ingestion of organisms and water is 0.14 μg/L.

[j]PCB data are based on only 4 samples at each station.

Source: Data are from M. A. Montford, T. W. Oakes, and W. F. Ohnesorge, Water Quality in White Oak Creek and Melton Branch, ORNL/TM-8131, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1982, in press. See also Figs. 3.12 through 3.15.

The complexity of WOC's water quality situation presents difficulties for developing waste control strategies or water quality improvement plans. White Oak Creek's exceedance of EPA water quality criteria for copper, cadmium, and mercury between ORNL and White Oak Dam is indicative of a water quality problem; however, it should be emphasized that, at present, these are criteria and, as such, are not established standards (see discussion in refs. 33 and 34).

The administration of the Clean Water Act allows the EPA's criteria to be interpreted in light of regional variation in water quality. This is particularly relavent for cadmium in WOC. At Station P-6, in the reach of WOC upstream from ORNL, the average concentration of cadmium (0.12 μg/L) is about four times the EPA criterion for protection of aquatic life. This station reflects undisturbed water quality, and its "background" cadmium level suggests that the EPA criterion is more strigent than necessary for protection of indigenous freshwater life in WOC basin. In considering the elevated concentrations of cadmium, copper, and mercury in WOC, it should also be remembered that the WOC levels are substantially less than the average ambient concentrations in the Clinch River above WOC's discharge (Table 3.13).

Although PCB concentrations in sediments of WOC appear to be elevated above background between ORNL and White Oak Dam (Table 4.17), PCB concentrations in the water were below the detection limit of 0.5μg/g. This suggests an earlier release of PCBs and subsequent accumulation in sediments of WOC. Highest PCB concentrations were at Station P-3 (just upstream from White Oak Lake), where the average and maximum levels (1.2 and 2.5 μg/g respectively) were about ten times greater than background levels observed at Station P-6.[35] Analysis of sediments from 17 major drainage basins in the United States between 1971 and 1974 showed PCB residue levels of 0.0012 to 0.160 μg/g (medians of the positive detections).[36] Recent samples of fine-grained sediments from large U.S. rivers and estuaries indicated a maximum PCB concentration of 10 μg/g in the Hudson River (levels in other water bodies varied from 0.08 to 0.70 μg/g).[37] If PCB levels in WOC have been measured accurately, the concentrations betwee. ORNL and White Oak Lake represent a moderate level of contamination. This finding would appear to warrant further investigation, especially sampling of PCB levels in tissues of fishes from WOC and White Oak Lake. Fortunately, the elevated PCB concentrations in WOC sediments pose little threat to human health, since there is no public access or fishing in the affected areas.

For contaminants that are absorbed to sediments (e.g. mercury, PCBs, and certain radionuclides), dispersion is controlled by sediment transport. The transport of sediments from White Oak Lake occurs predominantly during peak flow conditions.[38] However, the rates at which sediments and sorbed contaminants exit White Oak Lake are poorly known for several reasons. First, the concentrations of many contaminants in sediments have not been systematically measured (Sect. 3.2.4), and second, flood flows from White Oak Dam have not been accurately measured (Sect. 3.2.1.3). Floods and associated sediment transport may be an important mechanism by which contaminants enter the Clinch River. To date, however, analysis of sediments and trace elements in fishes from the Clinch River have not shown significant adverse impact (Sects. 3.2.4 and 3.4.2.1). At present a spillway and flow-monitoring guages are being installed at White Oak Dam, and these will allow more accurate characterization of flood flows and associated sediment transport.

The biological sampling of WOC by Loar et al[39] (1981) (Sect. 3.4.2) provides clear evidence that waste discharges from ORNL have significantly degraded the aquatic communities in the creek. This is best indicated by the absence of fishes at White Oak Creek Kilometer (WOCK) 2.7 or White Oak Creek Mile (WOCM) 1.7 and the marked reduction in diversity of macroinvertebrates at WOCK 2.1 and 2.7 (WOCM 1.3 and 1.7) compared with the upstream control station, WOCK 6.3 (WOCM 3.9). It seems likely that conditions observed in WOC downstream from ORNL were not the result of insufficient dissolved oxygen (DO) nor the result of any single toxicant. Aquatic sampling took place between March 1979 and June 1980, with sampling of fishes and invertebrates completed by February 1980. During this period, minimum DO levels remained above the 5.0 mg/L level critical for maintaining fish populations (Table 4.18). During the first four months of 1979, NH_3 loadings were high, and the in-stream concentration of un-ionized NH_3 is calculated to have reached 0.3 mg/L, an order of magnitude greater than the EPA's "Blue Book" cri-

Table 4.18. Sanitary treatment system waste loadings and dissolved oxygen concentrations in White Oak Creek[a]

Year and month	Average BOD loading[b] (kg/day)	Average NH_3 loading[c] (kg/day)	Minimum DO at Station P-4[d] (mg/L)	Low flow at Station P-4 (L/s)
		1979		
Jan.	9.5	9.7	5	70[e]
Feb.	13.3	19.1	6.2	236
Mar.	11.9	19.4	5.5	285
Apr.	28.6	9.7	5.6	315
May	26.6	1.5	7.2	276
Jun.	9.3	<0.18	9.9	206
Jul.	8.6	1.7	9.3	151
Aug.	7.5	3.4	NA[f]	NA
Sep.	6.7	0.27	7.1	188
Oct.	6.5	5.3	7.1	162
Nov.	6.9	5.2	5.6	197
Dec.	6.1	7.4	6.3	180
		1980		
Jan.	NA	NA	5.5	267
Feb.	NA	NA	5.7	215
Mar.	NA	NA	5.1	171

[a]Data from Monthly NPDES monitoring reports.

[b]Permit condition requires BOD loading less than 27.2 kg/day (60lbs/day).

[c]Permit condition requires NH_3 loading less than 6.8 kg/day (15 lbs/day).

[d]Permit condition requires DO concentrations greater than 5.0 mg/L.

[e]This low flow value appears to be in error.

[f]NA = not available.

terion of 0.02 mg/L (based on the lowest streamflow and the maximum observed pH of 8.0). While elevated NH_3 concentrations may have caused some degradation of the aquatic community, it seems more likely that multiple pollutants, acting synergistically, are responsible. It is possible that WOC's sediments, contaminated by accumulated toxicants released in prior years, also contribute to the depauperate fauna observed in the creek.

The principal impact observed in the aquatic communities of White Oak Lake and WOC embayment appears to be nutrient enrichment. The development of algae blooms, however, does not appear to reach nuisance levels, perhaps because of the lake's short hydraulic retention time and the mixing and flushing that occurs in WOC embayment. The elevated level of mercury in fishes from White Oak Lake and WOC embayment (Sect. 3.4.2.3) is a finding that requires further monitoring and investigation of possible causes. The average level of mercury in bluegill from White Oak Lake was 0.70 μg/g, 70% of the Food and Drug Administration (FDA) action level of 1 μg/g, and two of the ten bluegill caught in the lake had mercury levels exceeding the action level. Most important, however, is the fact that the areas in question, White Oak Lake and WOC, lie within a federal reservation that is inaccessible to the public; thus, no fishing occurs in these areas, eliminating any health risk from consumption of fishes from these water bodies. However, fishes can enter the Clinch River from White Oak Lake (by washing over the sluiceway during higher flows into WOC embayment). Although this increases the potential for mercury ingestion by sport fisherman who take fishes from the Clinch River below Melton Hill Dam, the average level of mercury measured in all fishes from near the mouth of WOC was 0.11 μg/g, which is 11% of the FDA action level.

Discussion and summary of nonradiological impacts. The summary of water quality (Table 4.17) indicates that WOC has average concentrations of cadmium, copper, and mercury that exceed the EPA's water quality criteria for protection of aquatic life and human health. The trace elements mercury, chromium, and zinc show the greatest elevation in concentration, being ten, eight, and seven times more concentrated, respectively, in stream water downstream from ORNL compared with upstream (Table 4.15). Other trace elements show less than a fivefold increase. Notably, in the reach of WOC which is affected by ORNL's discharges (from ORNL downstream to White Oak Lake), the average levels of trace elements are uniformly less than the ambient concentrations in the Clinch River upstream from the WOC discharge (Table 4.14). In addition, the affected areas are inaccessible to the general public.

Of the trace element contaminants in WOC, mercury certainly represents the most serious problem. The elevated concentrations of mercury, both in stream water and in fish tissue in White Oak Lake and WOC embayment, constitute a significant degradation of water quality. Biological sampling has also indicated significant degradation of the aquatic environment in WOC downstream from ORNL; this is probably attributable to the combined effects of several contaminants present at elevated levels.

Contaminants enter WOC from both nonpoint sources and numerous point-source discharges. ORNL is a heavily developed area with extensive SWDAs and substantial automotive traffic. Surface runoff and groundwater seepage contribute to elevated concentrations of trace elements. Nevertheless, the waste loadings from various facilities appear to account for many of the elevated concentrations of trace elements (Table 4.15). With respect to chromium (and perhaps mercury), however, it is possible that past discharges have contaminated stream and lake sediments and that contaminants released from sediments are contributing to current water quality.

At White Oak Dam, water quality is improved such that only cadmium and manganese have average concentrations exceeding EPA's criteria. Cadmium exceeds the criteria for the protection of aquatic life; manganese exceeds the drinking water standard. White Oak Lake acts as a sink for many of the trace elements and nutrients that enter in WOC and Melton Branch. Discharge from White Oak Dam appears to have very little impact on the overall (nonradiological) water quality of the Clinch River.

To summarize, it appears that discharges from ORNL are responsible for degradation of water quality within portions of the WOC basin which are inaccessible to the public. The extent of the most significant biotic degradation is limited to the 1–2 km (0.6–1.2 mile) stream reach located between ORNL discharges and White Oak Lake. Ammonia, mercury, copper, and cadmium are the contaminants most probably responsible for the observed effects on aquatic biota. Unplanned events (e.g., large variations in pH) may also contribute to the depauperate condition in this stream reach. In addition, mercury levels are significantly elevated in the fishes of White Oak Lake and WOC embayment, with the average concentration being 70% of the FDA's action level.

4.2.3. Impacts of Solid Waste

4.2.3.1 Radiological impacts

The environmental impact of disposing of radioactively contaminated solid waste was assessed by examining the data collected during monitoring of surface waters in the SWDAs for radioactive content. Figure 4.2 shows the locations of WOC sampling stations and radiation monitors.

Precipitation runoff and groundwater seeps from SWDAs and associated floodplains currently account for the majority of the radioactive input into White Oak Lake. Table 4.19 is an inventory of ^{90}Sr input into WOC during November 1981, a normal period (no intense storms and about average rainfall). SWDAs Nos. 1, 3, 4, and 5 and floodplains contributed 64% of the total ^{90}Sr input into White Oak Lake. The Flume and Sanitary Treatment Plant contributed about 30%. Although the inventory analysis is routinely done only for ^{90}Sr, the SWDAs and floodplains are probably releasing other radionuclides also.

Discharged through the Flume is a natural stream, runoff from a large area including SWDA No. 2 of the ORNL central site, and some nonradioactive once-through cooling water. Normally, no radioactivity from operations is discharged into either the Flume or the sanitary waste system. The source of the radioactivity in the Flume and the sanitary waste system therefore results from contaminated groundwater inflow into these effluent streams. Broken and corroded (out-of-service) pipelines are thought to be the source of most of this radioactivity in the groundwater. Flow and total activity discharged from the Sanitary Treatment Plant increases during periods of precipitation. Broken (in-service) sanitary lines permit inflow of the contaminated groundwater into the sanitary system. This section discusses the radioactivity (64% in November 1981) coming from the SWDAs and associated floodplains.

Several remedial action projects are planned in the SWDAs. The most important action involves SWDA No. 4 which presently contributes about 50% to the total ^{90}Sr discharge of the ORNL site (as measured at White Oak Dam). The problem is caused by surface discharge of three diversion channels onto the floodplain of a small tributary immediately downslope from SWDA No. 4.[40] Groundwater seeps from SWDA No. 4 deposit ^{90}Sr on the floodplain. During storms, uncontaminated water from the diversion channels flushes the ^{90}Sr into WOC. A new diversion channel is planned to direct surface flow away from this floodplain. Implementation of this plan is expected to reduce ^{90}Sr discharge from SWDA No. 4 by 80%.

A second remedial action plan is a proposed groundwater diversion demonstration at SWDA No. 6, where water table elevations typically lie above the trench floors. In 1976 a bentonite seal was placed over 49 of these trenches to prevent downward percolation of rain that falls directly on the backfilled areas. Other remedial actions are evidently required because the water table still lies above the trench floors. The mechanism of groundwater intrusion into the trenches is attributed to lateral flow through the trench walls beneath the bentonite cap. A groundwater diversion system has been proposed to intercept the lateral groundwater flow at the perimeter of the the trench area. Drainage pipe would be placed in trenches or inserted through horizontally drilled holes to direct groundwater into seasonal streams to the east and west of SWDA No. 6. If the groundwater diversion demonstration at SWDA No. 6 is successful, it may be attempted at other ORNL disposal areas. For example, SWDA No. 5 contributes about 30% of the ^{90}Sr discharge to WOC. This discharge originates from a number of groundwater seeps. Groundwater diversion may help reduce or eliminate these seeps. Contaminated groundwater has been recovered from observation wells near intermediate-level waste (ILW) trench 7, and a contaminated groundwater seep is also associated with this trench.

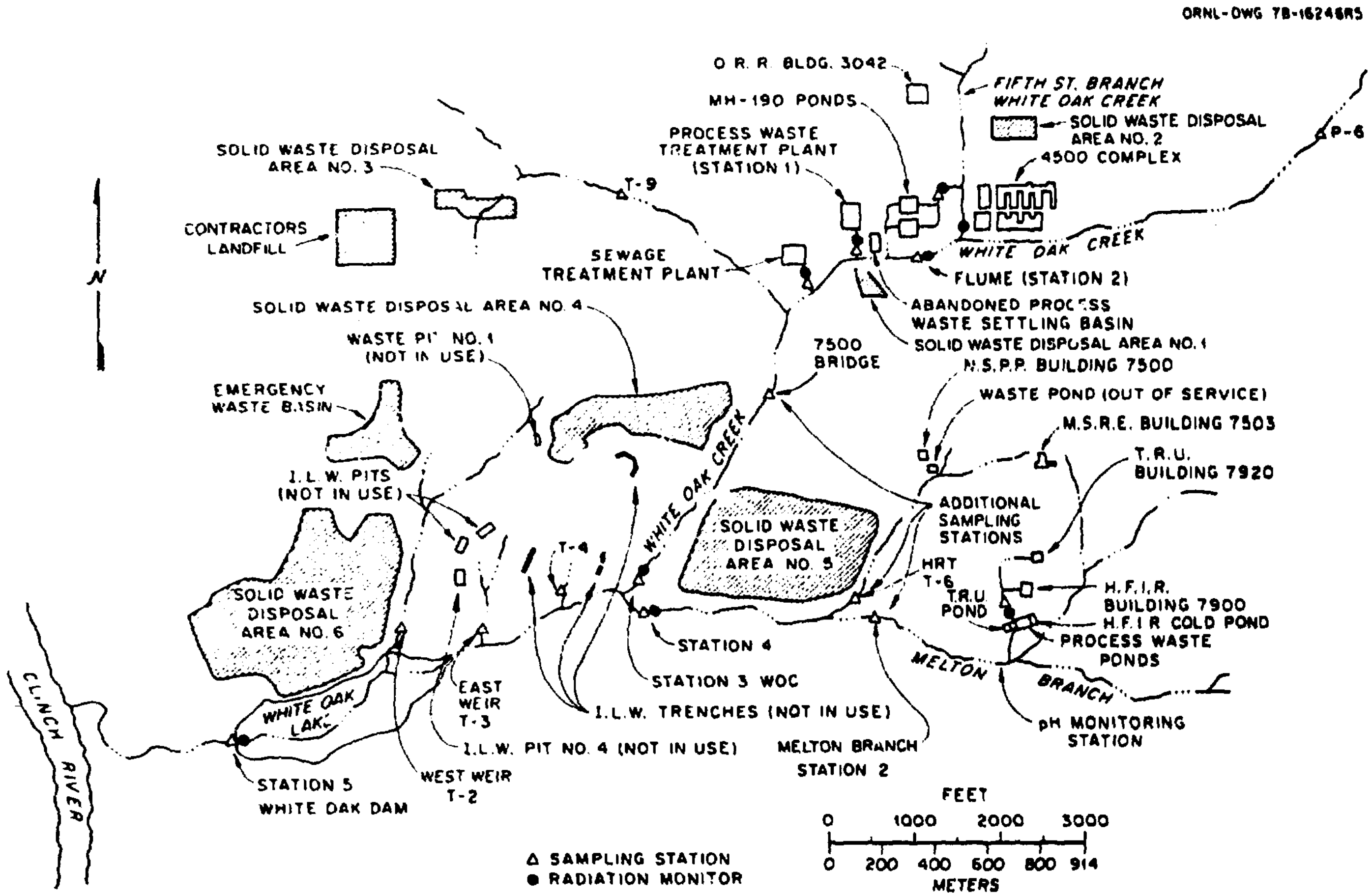

Fig. 4.2. Location plan for solid and liquid waste disposal sites in White Oak Creek basin including sampling stations and radiation monitors. Source: *Preliminary Draft Environmental Impact Statement for Hot Engineering Test Project at Oak Ridge National Laboratory,* ORNL/TM-6520, Oak Ridge, Tenn., August 1978, Fig. 3.17 (modified).

Table 4.19. Inventory of ^{90}Sr released into White Oak Lake, November 1981

Source	^{90}Sr discharge (MBq)[a] Measurement	Difference
White Oak Creek		
Flume	536.5	
190 Ponds	7.4	
Process Waste Treatment Plant	122.1	
Sewage Treatment Plant	1043.0	
Subtotal	1709	
7500 sampling station	3750	
Burial grounds Nos. 1 and 3, and flood plains		2041
Station No. 3	4810	
Burial Ground No. 4		1060
Melton Branch		
7900 Area (HFIR and TRU)	3.7	
7500 Area (NSPP and MSRE)	144.3	
Subtotal	148.0	
Station No. 4	329.3	
Burial Ground No. 5		181.3
ILW pit disposal area		
East weir	3.7	
West weir	14.8	
Subtotal	18.5	
Total ^{90}Sr to White Oak Lake (stations No. 3 and No. 4 plus ground disposal area)	5158	
Total ^{90}Sr from burial grounds, ground disposal area, and flood plains		3300
^{90}Sr from burial grounds, ground disposal area, and flood plains, percent		64.0

[a]To convert from MBq to mCi multiply by 0.027.

Source: L. C. Lasher and C. B. Scott, Operations Division of the Oak Ridge National Laboratory.

Since 1975 a continuing effort has been under way to upgrade the groundwater monitoring system in Melton Valley.[40] A quarterly groundwater sampling and analysis effort was initiated in 1980 to determine the approximate extent and range of groundwater contamination with radionuclides. Nearly 300 observation wells are now located throughout the SWDAs in Melton Valley. A groundwater monitoring program was initiated in 1981 for the entire ILW pit and trench disposal area in response to the experience gained at ILW trench 7. A systematic analysis of the voluminous groundwater data is not presently available. No evidence suggests, however, that releases of contaminated water are occurring anywhere other than at White Oak Dam.

Concentrations of various radionuclides (^{90}Sr, ^{137}Cs, ^{131}I, ^{106}Ru, ^{60}Co, ^{3}H, and transuranics) are routinely determined at various points in the various streams (Fig. 4.2). Table 2.10 lists the annual discharges of radionuclides to the Clinch River from 1949 to 1981. Annual release rates have declined since the 1950s by one or more orders of magnitude for all isotopes except tritium and the transuranics. These declines are attributable to changes in processing and disposal techniques such as the cessation of direct releases into WOC and the disposal of liquid wastes in hydrofractured shale.

Average annual percentages of recommended concentration guidelines CG_w are available for the period 1977 through 1981 (Fig. 4.3), though the frequency of daily exceedance of CG_w has not been tabulated. (An average annual concentration near 100% of CG_w implies that the CG_w is exceeded about as often as it is not.) The values are the sum total CG_w's for all the detectable radionuclides. The chief contributor is ^{90}Sr (about 50%). The measured concentrations at White Oak Dam have been above or near the CG_w throughout the period shown. The measured concentrations at the mouth of WOC were substantially less (<30% CG_w) but were still significant (Fig. 4.4). The latter results represent an estimated maximum (undiluted) impact on the Clinch River under normal conditions. The calculated concentrations in the Clinch River, based on measurements at White Oak Dam and dilution afforded by thorough mixing in the Clinch River, were at or below 0.5% of CG_w throughout the period (Fig. 4.5). The percent of CG_w was higher in 1981 than in previous years because natural Clinch River flow was below normal by a factor of 2, resulting in less than normal dilution. Thorough mixing probably does not take place for several kilometers downstream from the confluence with WOC.[41]

Apart from measurement errors, there are several uncertainties associated with the above analysis. Foremost among these uncertainties is the release of radionuclides during extreme events. White Oak Dam has been overtopped on several occasions during intense storms. Although it is known to be large, we can but speculate as to the total amount of radionuclides released to the Clinch River during such periods. It has been estimated that three or four intense storms per year are responsible for 25 to 50% of the annual suspended sediment releases over White Oak Dam.[38] About 70% of the ^{137}Cs and 20% of the ^{60}Co are transported in the sediment load. Releases of water-soluble radionuclides (such as ^{90}Sr and ^{106}Ru) also increase during storms but to a lesser extent relative to sediment-transported radionuclides.[41] Releases during intense storms are not included in Table 2.10 because they are undocumented and highly speculative.

The release of radionuclides to the Clinch River by underflow beneath and through the White Oak Dam embankment is probably small although documentary evidence of this is incomplete. Over 90% of the surface inflow to White Oak Lake passes through the weir at White Oak Dam (discounting flood periods when nearly all the water passes over the dam). Therefore, less than 10% of the water released from the lake occurs as seepage. Proportionately fewer radionuclides escape in the seepage water than in overflow because they are partially adsorbed by shale in the foundation, embankment soils, and lake sediments. If one assumes a complete absence of adsorption, the total radionuclide release as underflow would be less than 10% of the release rate documented as overflow.

Though some seepage evidently occurs, a formal seepage analysis has never been done. Intuitively one may conclude that seepage exists because the reservoir is unlined and because the dam has no clay core or cut-off wall. In fact, two small seeps (The origin of one of these seeps is uncertain because its water chemistry does not match that of White Oak Lake.) were observed below the

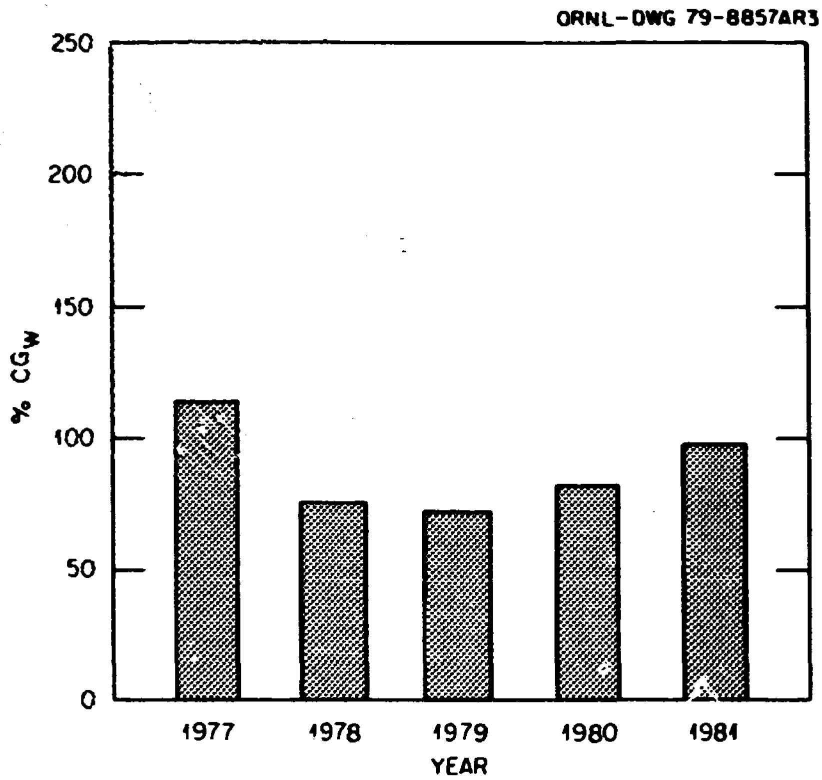

Fig. 4.3. Measured percent of concentration guide (water) discharged over White Oak Dam, 1977-1981. Source: J. A. Auxier, *Industrial Safety and Applied Health Physics Annual Report for 1981*, ORNL-5859, Oak Ridge National Laboratory, Oak Ridge, Tenn., in press, 1982.

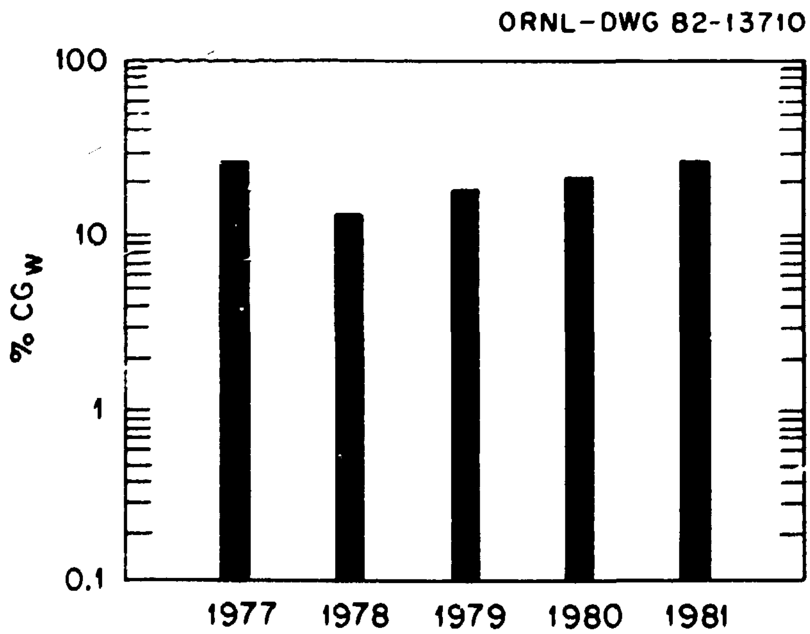

Fig. 4.4. Measured percent of concentration guide (water) at mouth of White Oak Creek, 1977-1981. Source: L. C. Lasher and C. B. Scott, Operations Division of the Oak Ridge National Laboratory.

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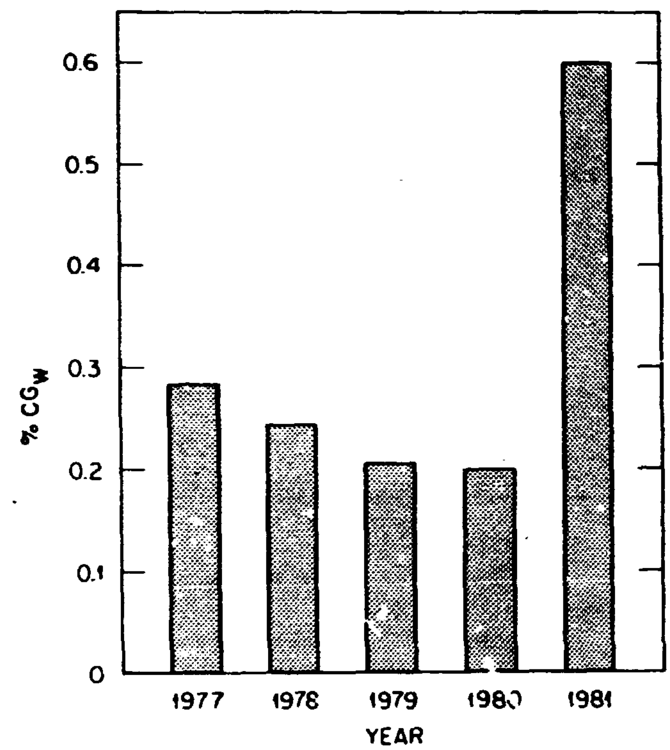

Fig. 4.5. Calculated percent of concentration guide (water) in the Clinch River using dilution afforded by Clinch River, 1977–1981. Source: J. A. Auxier, *Industrial Safety and Applied Health Physics Annual Report for 1981*, ORNL-5859, Oak Ridge National Laboratory, Oak Ridge, Tenn., in press, 1982.

toe of the dam in 1979. Subsequently, internal erosion of the embankment was discovered by exploratory drilling. Recently the dam was stabilized by the addition of a rock berm.[41] A sand filter was placed between the embankment and berm to prevent further interior erosion. These recent improvements were designed to prevent erosion and slope failure but not seepage. Some seepage is desirable because it prevents a buildup of destabilizing excess pore pressure. The quantity of seepage has never been a matter of concern because of the small difference in hydraulic head [1 to 2 m (3 to 6 ft)] between White Oak Lake and the Clinch River.

Near the end of White Oak Lake's useful life (1994), sediment collected behind the dam will contain a conservatively high estimate of 37 TBq (1000 Ci) of radioactivity. The principal sediment-borne radionuclides are ^{137}Cs (by far the greatest contributor of radioactivity in the lake sediments), ^{60}Co, and ^{90}Sr, with trace amounts of ^{152}Eu, ^{154}Eu, and various transuranics (mainly ^{244}Cm). Table 4.20 gives the average radioactivity of the above radionuclides in sediments of White Oak Lake in 1979.[41] It is estimated that White Oak Lake contained 64,000 m^3 (2.3 million ft^3) of water at normal pool elevation [227.1 m (745 ft)] in 1981, and an estimated 130,000 m^3 (4.6 million ft^3) of sediment had collected behind the dam, accumulating about 23.8 TBq (644 Ci) of radioactivity from 1948 through 1981.[41] If (1) the lake eventually accumulates an additional sediment load equivalent to the volume of water stored there in 1979, (2) these future sediments have the same average radioactivity as sediments previously deposited, and (3) the sedimentation rate remains the same, then the lake will contain about 200,000 m^3 (7.0 million ft^3) of sediment and 37 TBq (1000 Ci) of radioactivity near the end of its useful life.

The above estimate of sediment-contained radioactivity is conservatively high. Sediments now entering the lake are less radioactive than those of the 1940s and 1950s when radioactive fluids

Table 4.20. Average radioactivity in the sediments[a] of White Oak Lake

Significant radionuclides	Concentration (Bq/g wet)[b]
^{137}Cs	17.6
^{60}Co	3.6
^{90}Sr	1.5
^{152}Eu, ^{154}Eu	0.5

[a]Upper 15 cm.

[b]To convert to pCi/g multiply by 27.

Source: T.W.Oakes, et al., Technical Background Information for the Environmental and Safety Report, vol. 4: White Oak Lake and Dam, ORNL-5681, Oak Ridge National Laboratory, Oak Ridge, Tenn., March 1982.

were discharged directly to WOC. Furthermore, it is unrealistic to believe that sediments will accumulate to the volume of water being stored in White Oak Lake in 1981. This implies, of course, that without remedial action the lake's useful life will end before 1994.

The lake's life could be extended by dredging the reservoir or by increasing the height of the embankment dam. Dredge spoil could be transported to the hydrofracture facility for disposal. On the other hand, if the embankment were raised, then Tennessee Highway 95 would probably require relocation. Because these remedial actions are speculative, their environmental impacts will not be addressed.

The offsite radiological impacts of White Oak Lake are reflected in the exposures to the maximum exposed individual and the regional population as discussed in Sect. 4.2.2.1 and in the doses shown in Tables 4.8 through 4.13.

4.2.3.2 Nonradiological impacts

The solid wastes in the SWDAs and in the contractors' landfill (Fig. 4.2) are a source of nonradiological contaminants in WOC and in its tributaries. Several of these tributaries were sampled between April 1979 and January 1980 as part of a survey of water quality in WOC basin[35] Table 4.21 presents water quality data from several of WOC's tributaries, and Figs. 3.12 through 3.15 and Table 4.17 indicate the water quality in WOC and in Melton Branch.

In the tributary streams that receive groundwater seepage from waste disposal areas, concentrations of TDS (Table 4.21) are increased from 60 to 320% above the background levels observed at Station P-6 (Fig. 4.2) upstream from ORNL. Station T-3, the east weir, shows the highest concentrations of most contaminants (especially high levels of nitrate, sulfate, and nickel are evident).

This tributary drains an area containing several pits used previously for disposal of intermediate-level radioactive waste (Fig. 4.2). Station T-6, which is adjacent to SWDA No. 5, shows greatly elevated concentrations of manganese and iron. Station T-2, adjacent to SWDA No. 6 (the currently active SWDA), shows moderately elevated concentrations of nitrate and sulfate. The maximum concentrations of mercury at Stations T-9 and T-3 are elevated fourfold to fivefold above the maximum background level; this suggests the ILW trenches, SWDA No. 3, and/or the contractors' landfill as possible sources of mercury that may leach into WOC's tributaries. The data from the tributary streams indicate average levels of cadmium, lead, and PCBs (in sediment) which are very close to background concentrations, suggesting that the waste disposal areas are not sources of these contaminants.

The inputs from SWDAs to surface waters are classified as nonpoint source inputs. Because the flows of the tributaries are not well characterized and because there are other unmonitored tributaries and seepage areas, it is difficult to consider the effects of these nonpoint source inputs quantitatively. The inputs to the WOC system (point and nonpoint sources) are diluted by the flow of WOC, and White Oak Lake serves as a sink for many of the contaminants that enter the system (see Sect. 4.2.2.2). As a result, the quality of the water that passes over the White Oak Dam spillway appears not to cause any significant water quality problems in the Clinch River.

ORNL's dry refuse and cafeteria garbage disposal at the Y-12 Plant's central landfill apparently releases no more than trace amounts of leachate beyond the Y-12 facility.[42] Chemical analyses of water from Bear Creek and the East Fork Poplar Creek indicate that concentrations of most chemicals tested lie well within Tennessee stream guidelines. The nitrate concentration occasionally exceeds standard in Bear Creek. Nitrate contamination could be significant in view of the fact that the Bear Creek sampling station is several kilometers from the Y-12 Plant. The source of contamination is unknown, and ORNL's contribution is an incremental fraction of the total.

4.2.4 Occupational Radiological Exposure

All persons who enter ORNL areas where there is a likelihood of exposure to radiation or radioactive materials are monitored for the kinds of exposure they are likely to sustain. External radiation is measured by badge-meter, pocket ion chambers, and hand exposure film-ring meters. Internal deposition is determined from bioassays and in vivo counting.

4.2.4.1 External exposure

No employees received a total-body radiation dose that exceeded the standards for radiation exposure[23] during 1981. The maximum total-body dose sustained for an employee was about 38 mSv (3.8 rems) or 76% of the applicable standard of 50 mSv (5 rems) per year. The range of doses to persons using ORNL badge-meters is shown in Table 4.22.

The greatest cumulative dose to the skin received by an employee during 1981 was about 59 mSv (5.9 rems) or 39% of the applicable standard of 150 mSv (15 rems) per year. The maximum cumulative hand dose recorded was about 150 mSv (15 rems), or 20% of the applicable standard of 750 mSv (75 rems) per year.

As of December 31, 1981, no employee had a cumulative total-body dose that was greater than the applicable standard based on the age proration:

$$\Sigma \text{Sv} = 0.05 \text{Sv} \times (N - 18) \ , \qquad (4.3)$$

where

Σ Sv = cumulative permissible lifetime dose,
N = the age of the employee.

No employee has an average annual dose that exceeds 0.05 Sv (5 rems) per year of employment (Table 4.23). The greatest cumulative total-body dose received by an employee was approximately

Table 4.21. Water quality[a] in WOC tributaries draining solid waste disposal areas

Constituent	Station T-9[b]		Station T-6[b]		Station T-4[b]		Station T-3[b]		Station T-2[b]		Station P-6[b]	
	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum
Total dissolved solids, mg/L	192	418	163	196	175	224	478	804	163	242	101	239
COD, mg/L	7.8	26	11.6	38	7.5	23	12.8	57	6.5	23	5.6	20
Sulfate, mg/L	16.6	30.2	20.2	25	29.2	35	104	157	27.1	33.7	3.0	4.8
Nitrate, mg/L	0.5	4.0	0.7	1.4	5.5	8.3	60.6	102	12.2	29.8	0.3	0.5
Phenol, μg/L	1.8	5.0	2.9	41	1.7	4.0	1.8	5.0	1.8	6.0	1.9	8.0
Cd, μg/L	0.13	0.49	0.09	0.59	0.12	0.85	0.13	0.39	0.16	1.1	0.13	0.45
Cr, μg/L	1.4	29	0.8	3.2	0.9	6.7	12.3	28	1.1	6.7	0.5	1.5
Cu, μg/L	2.0	37	1.2	2.0	1.0	3.7	4.1	15.0	1.0	2.6	0.9	2.6
Fe, μg/L	167	582	384	765	149	715	146	464	140	350	65	285
Hg, μg/L	0.11	1.4	0.02	0.18	0.02	0.25	0.11	1.8	0.09	1.3	0.02	0.36
Mn, μg/L	81.4	263	444	961	74.2	506	55.6	146	94.0	134	12	20
Ni, μg/L	5.1	16	10.1	49	6.7	16	36.8	60	9.1	20	4.2	15
Pb, μg/L	1.3	6.1	1.2	11.0	1.0	4.5	1.7	5.0	0.6	1.7	0.9	4.0
Zn, μg/L	3.8	37	2.3	2.8	1.2	7.0	5.9	12.4	1.9	12.3	3.3	5.8
PCB (sediment[c]), μg/L	0.32	1.0	0.13	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.23	0.5

[a]Average concentrations based on 36 weekly samples between April 1979 and January 1980.
[b]Location of stations are shown on Fig. 4.2.
[c]Average concentrations based on 4 samples.
Source: Data from M. A. Montford, T. W. Oakes, and W. F. Ohnesorge, Water Quality in White Oak Creek and Melton Branch, ORNL/TM-8131, Oak Ridge National Laboratory, Oak Ridge, Tennessee 1982, in press.

Table 4.22. Dose data summary for monitored personnel involving exposure to total-body radiation for the year 1981

Group	Dose Range (mSv)[a]						Total
	0–10	10–20	20–30	30–40	40–50	50–up	
ORNL employees, No.	295	73	5	2	0	0	375[b]

[a]Multiplier factors for converting International System of Units (SI) to English units are located on inside back cover.

[b]Total number of employees monitored in 1981 because of likelihood of exposure to radiation.

Source: Industrial Safety and Applied Health Physics Division of the Oak Ridge National Laboratory.

Table 4.23. Average dose per year of employment at ORNL, 1981

Group	Dose Range (mSv)[a]						Total
	0–10	10–20	20–30	30–40	40–50	50–up	
ORNL employees, No.	295	73	5	2	0	0	375[b]

[a]Multiplier factors for converting International System of Units (SI) to English units are located on inside back cover.

[b]Total number of employees monitored in 1981 because of likelihood of exposure to radiation.

Source: Industrial Safety and Applied Health Physics Division of the Oak Ridge National Laboratory.

1.15 Sv (115 rems). This was accrued over an employment period of about 38 years and represents an average of about 30 mSv (3.0 rems) per year. The average of the ten highest total-body doses to ORNL employees for each of the years 1977 through 1981 is shown in Table 4.24.

4.2.4.2 Internal exposures

There were no cases of internal exposure during 1981 for which the radioactive material within the body averaged as much as 50% of the maximum permissible organ burden. An estimate of dose is made for all cases in which it appears that one-fourth of a maximum permissible organ burden averaged over a calendar year may be exceeded. Urine and fecal samples are analyzed in determining the internal exposure. Such data require interpretation to determine the dose to the person; computer programs are used for evaluation of the extensive data on urinary excretion. The Whole Body Counter is also used in determining internal exposure. Approximately 750 whole body, chest, wound, thyroid, and liver counts were performed during the year.

4.3 SOCIOECONOMIC IMPACTS OF OPERATION

Environmental effects caused by the operation of a major technical or industrial complex may vary widely—from those that are primarily associated with process effluents to those that are associated with the socioeconomic effects of establishing and operating the complex. In the case of the operation of the ORNL X-10 complex, the group of socioeconomic effects is predominant.

Table 4.24. Average of the ten highest total-body doses and the highest individual dose by year

Year	Average of the ten highest doses (mSv)	(rem)	The highest dose (mSv)	(rem)
1977	28.4	2.8	36.2	3.6
1978	23.9	2.4	33.4	3.3
1979	22.4	2.2	28.0	2.8
1980	24.6	2.5	31.4	3.1
1981	22.0	2.2	38.2	3.8

Source: Industrial Safety and Applied Health Physics Division of the Oak Ridge National Laboratory.

As is noted in Sect. 2.1.2, the primary operational product of the ORNL, unlike those of the ORGDP and the Y-12 Plant, is new scientific and technological information of national importance. Although ORNL produces and sells a few commodities (i.e., radioactive isotopes and special materials), its central function is to develop high-risk, high-payoff technology. It identifies and provides solutions to generic problems in energy-based technologies, provides assistance to various governmental agencies, makes special equipment available to various user groups (both informally and through contractual arrangement), and affords access by universities to major research facilities and programs. ORNL, in association with other organizations in the community supported by DOE, affords facilities and a focus for scientific study that attract a constant influx of foreign scientists on temporary assignment and as permanent residents. The academic flavor of the Oak Ridge community can be attributed to the continuing presence of international visitors and representatives, an ever-changing contingent of graduate students occupied with thesis research, university faculty members, and visiting students and scientists from foreign countries on temporary assignment.

The information produced by ORNL in fulfilling its mission takes many forms, including formal reports, publications in the literature, assessments for governmental bodies (including Congressional testimony), information to be disseminated to national and international scientific and technical groups, consultations with industrial representatives concerning technology and technology transfer, and patent disclosures pertaining to new technology.

Acquisition of the information critical to the advancement of science and technology entails the use and disposition at ORNL of many types of materials and equipment. Operations that minimize the transfer of toxic or hazardous materials to the environment must therefore be performed to protect the local environment. The stringent measures employed to minimize the dispersion of toxic and hazardous materials result in operations that confine virtually all of such substances within ORNL facilities. Accordingly, the predominant effects on the human environment that result from ORNL operations are those that result from long-term advancements in science and technology. These impacts are not within the scope of the current analysis and are not considered further. In order of significance however, the environmental effects are (1) the secondary research and development (R&D) effects of long-range significance, (2) the continuing major socioeconomic effects on the regional community, and (3) small but potentially significant effects associated with the dispersion of the small amounts of materials that are released to the area environment (Sect. 4.2).

It should be further noted that the socioeconomic analysis in this section does not focus on all aspects that may be important in evaluating national R&D institutions. First, the analysis does not quantify the many intangible social and professional welfare benefits of ORNL's R&D activities (e.g., provision of support services to visiting scholars and university- and industry-shared research equipment) or of ORNL's marginal contribution to cost reduction in the local industrial economy. These contributions include savings from the geographic concentration of related industries (i.e. agglomeration economies) and cost reductions due to shared development and industrial use of transportation and other public services in the local region (i.e., external economies of scale). Secondly, the convention and tourism impacts of ORNL-centered meetings is excluded. (ORNL officials estimate that the number of visitors who come to the Oak Ridge area to attend ORNL-centered meetings is approximately 5000 person d/year. In addition to such meetings, some 1500 nonarea visitors travel to ORNL each year on business, generating revenues for area businesses). Finally, issues related to R&D resource-allocation efficiency in the national economy are not addressed in this analysis.

The results are based only on measured industrial output effects (see Appendix F) from ORNL labor and material procurements. Included as results of the analysis are estimates of annual output, employment, and income from the continuous operation of ORNL at the 1981 level and composition of R&D-related procurements including activities at the Y-12 and ORGDP sites.

The local region selected for this evaluation is the Knoxville Bureau of Economic Analysis (BEA) economic area. This area, comprising 24 counties, includes the Knoxville Standard Metropolitan Statistical Area (SMSA) and the counties tied to the SMSA based on journey-to-work patterns.

4.3.1 Economic Impacts

ORNL's R&D and information dissemination activities create many employment, purchasing, and subcontracting transactions that have concommitant impacts on communities in the region. Payroll and procurement disbursements create significant direct as well as additional (indirect plus induced) impacts on the local economy. Large impacts also occur elsewhere (Sect. 4.3.1.2), particularly from ORNL procurements. Estimates of these impacts in 1981 are based on payroll outlays of $128 million and R&D subcontracting and material procurements of $120 million. Together, these expenditures account for over 71% of ORNL's 1981 total operating budget outlay ($350 million).

4.3.1.1 Local economic impact

The economic impact of ORNL operations upon the Knoxville region in 1981 is summarized in Table 4.25. The table lists impacts defined in terms of local employment and income creation for both payroll and procurement expenditures. In addition, Table 4.25 provides information on the distribution of impacts between direct (first occasion in which a dollar is spent in a community) and additional (secondary) effects.

The direct effect of ORNL payroll and procurement expenditures during 1981 was the support of 5600 local jobs and the creation of $139 million of local income (Table 4.25). Because 73% of all ORNL equipment and supplies are procured outside of the local region, the majority of local jobs (4900) and income ($128 million) are attributable to the ORNL payroll effect.

The secondary (indirect plus induced) effects of these same payroll and procurement expenditures on the local economy are shown in Table 4.25 as additional effects. It should be noted that these secondary effects are large for both payroll and procurement, supporting 4800 additional local jobs and creating $74 million in local income. Although the majority (78%) of this additional employment and income generation is attributable to the $128-million ORNL payroll, significant secondary impacts are registered locally by ORNL procurement activities.

When these additional effects are added to the direct effects, the total impact of ORNL payroll and procurement expenditures on the local economy is obtained (see Table 4.25). Thus, ORNL employment and purchasing creates a total of 10,400 local jobs (83% or 8600 by payroll and 17%

Table 4.25. Economic impact of ORNL operations on the Knoxville region, 1981 employment and income[a]

Expenditure category	Employment	Income[b] ($x10^6)
Direct Effects		
Payroll[c]	4,900	128.2
Local procurement[d]	700	10.9
Subtotal	5,600	139.1
Additional effects[e] (indirect + induced)		
Payroll	3,700	57.3
Local procurement	1,100	16.4
Subtotal	4,800	73.7
Total effects		
Payroll	8,600	185.5
Local procurement	1,800	27.2
Total	10,400	212.7

[a]The Knoxville region corresponds to the Knoxville Bureau of Economic Analysis economic area. This region differs from the much smaller four-county ORNL impact region defined by employee residential distribution but the larger region is mandated by data considerations. The employment and income figures shown include payroll and local procurement for ORNL operations.

[b]Expressed in current (1981) dollars.

[c]See Table 3.37.

[d]Includes both "direct charge" and procurement of items for stores, as well as local utility purchases. The number shown represents that portion of total ORNL procurement, both obtained and produced, in the Knoxville region. Greater detail on this figure is provided in Appendix F.

[e]These indirect and induced effects were derived, based upon the methodology described in Appendix F. For ORNL payroll expenditures, the direct income effect of local consumption is included with these additional effects.

Source: C. R. Kerley, Energy Division of the Oak Ridge National Laboratory, based on data supplied by John Human of the Finance and Materials Division and Joe Vogt of Employee Relations Division. Computation assistance provided by Henry Herzog, Sr. and Alan Schlottmann, Department of Economics, The University of Tennessee.

or 1800 by local procurement) and $212.7 million in income. About 87% ($186 million) of the total local income creation stems from payroll and 13% ($27 million) comes from local procurement.

Finally, comparison of the direct and total effects of ORNL employment and procurement shows that each ORNL employee supports an additional 0.75 unit of employment in the local economy through consumer expenditures. Each dollar of ORNL payroll spent locally creates an additional 45¢ of local income, and each dollar of ORNL procurement secured locally creates $1.50 in income.

4.3.1.2 Total economic effect

The total economic impact of ORNL operation is considerably larger than the local impacts described above. A large proportion (73%) of ORNL equipment and supplies is procured from outside the local area. Also, an estimated 10% of personal consumption by ORNL employees occurs outside the local region (the Knoxville BEA area). When added to the local employment and income impacts (Table 4.25), the total economic impact of ORNL payroll and procurement throughout the United States in 1981 was the support of 16,000 jobs and $301 million of personal income (see Table 4.26). About 36% of these jobs and 30% of this income occurred outside the local region. The total employment and income multipliers associated with combined ORNL payroll and procurement activity are estimated to be 2.87 (employment) and 2.17 (income).

The multiplier employment is composed of 35% direct ORNL employment (1.0), 30% local secondary employment (0.87), and 35% nonlocal secondary employment (1.0). The multiplier income includes 46% direct income (1.0), 24% local secondary income (0.54), and 29% nonlocal secondary income (0.63). The local secondary effects are generated primarily from ORNL payroll, but secondary effects outside the region are created primarily by ORNL procurement. The total employment and income effect outside the region (i.e., 5700 employment and $88.7 million income) is slightly larger than the secondary effect component in the region (4800 employees and $74 million income). However, adding local direct effects, the distribution of total employment and income impacts from combined payroll and procurement is about 65% inside and 35% outside the region.

4.3.2 Public Services

Operation of ORNL with its staff of about 4900 requires that neighboring communities in which the staff reside provide public services. ORNL employees offset these costs through higher-than-average incomes, which produce relatively high consumption and, consequently, taxation patterns. Also, because of their broad educational backgrounds, these residents promote a higher quality of public education, particularly in the Oak Ridge and West Knoxville schools.

Although nonquantifiable, the public service burdens of staff families on community services such as correctional institutions (crime), indigent care, and public mental health services are below national and regional averages because of the relative affluence of ORNL employees and because of their third-party insurance coverage.

Current ORNL operations impose little direct impact in neighboring communities on such public services as police, fire protection, and public health agencies. Fire protection and security services required for ORNL operations are maintained independently and do not involve regional community support systems. Some of the communities' normal responsibilities for providing certain public services are lightened by the operation of ORNL and the other DOE Oak Ridge plants. For example, the water purification and supply system for the plant facilities was constructed using federal monies and is operated by the contractor. The city of Oak Ridge water supply (Sect. 2.5.1) is provided by DOE rather than the DOE facilities being supplied by the city.

Commuter traffic control on the access roads to the X-10 site within the Oak Ridge city limits, accident investigations, traffic control equipment, and police patrolling are functions of the city of Oak Ridge; outside the city limits, they are functions of the county-state jurisdictions. Normal traffic control responsibilities may be preempted by DOE security forces in the event of an emergency. Commuter traffic (Sect. 4.3.3) movement does not disrupt any neighboring community's

Area communities have been influenced and continue to be influenced by ORNL staff who serve at various times on the City Council, planning boards, boards of education, area hospital boards of directors, and in public office. Staff members participate actively in cultural and civic ventures, including civic music organizations, art centers, prisoner aid societies, family planning groups, church governing bodies and other civic organizations. Many of the spouses of employees are also involved in city government agencies, and there are many public action groups to which the employees and/or employees' families belong that deal with community affairs such as pollution abatement, school action, and growth plans for the communities.

Employees have several teams entered in the different city leagues in softball, basketball, and other sports. Intraplant athletic programs use local parks and public school facilities. Employees are also involved in the education programs in the area in such ways as (1) teaching courses at The University of Tennessee, Roane State Community College, Knoxville College, Oak Ridge Associated Universities' programs, high schools, adult education classes, and elementary schools and (2) speaking for various programs in the schools and public organizations.

Extensive community participation in nearly all civic activities is thus a significant indirect effect of the operation of ORNL, as well as of the other DOE facilities in Oak Ridge. Voluntary participation is evident in the vitality of many community organizations and in the significant financial commitment of the staff to human services organizations. The amounts of ORNL-related contributions to individual charities are not available. However, as measured by the extent of contributions to the United Fund in the area, it can be concluded that the contributions by ORNL staff significantly affect area charitable organizations. In 1981, the ORNL staff pledged the following amounts to area counties' United Funds:

Anderson	$191,965
Knox	113,651
Loudon	17,889
Morgan	10,556
Roane	4 946
Blount	3,069
Other	1,266
Total	$380,342

4.3.3 Traffic and Transportation

Most ORNL employees use automobiles, car pooling, and busing to travel to and from work. Introduction of the owner-operated van pool has been successful, particularly for those riders who live at considerable distances from the X-10 site.

In 1981, about half of ORNL's employees participated in car pools. Van pools and bus fleets drew 170 and 75 passengers respectively. Although current numerical data are not available, it is recognized that the commuter traffic comprises almost the entire volume of vehicular traffic on Bethel Valley Road and State Highway 95 during peak hours.[43] Roadside noise level measurements taken during morning and afternoon traffic volume peaks on Bethel Valley Road indicate that the periods of high traffic noise are each limited to about an hour (see Appendix D, Tables D.5 and D.6). The noise levels are not excessive.

4.3.4 Land Use

Occupation of land within the Oak Ridge Reservation (ORR) for ORNL facilities, described in Sect. 2.8.5, undesignated vacant land, and land that comprises the National Environmental Research Park preempts 10,360 ha (59 sq miles) from private ownership and use. Public use of the Bethel Valley roadway and the recently constructed Visitor Overlook is permitted. Except for the areas used for disposal of radioactive waste, indefinite custodial care would not be necessary. Federal preemption of sizable areas of Anderson and Roane counties precludes their availability for private industrial development and deprives the counties of a potential tax base. However, the tax base potential may be speculative for several reasons:

- economic accruals to the region equivalent to those generated from DOE plant operations and associated developments may not have occurred in the absence of DOE development;
- incentive tax deferrals often given to encourage new industrial developments tend to shrink projected tax bases; and
- as an alternative to private industrial development, federal activity generally vacillates more moderately than that of the private sector and thereby insulates the local employment base from business downturns.

4.4 EFFECTS OF CONSTRUCTION ACTIVITIES

Construction of new DOE facilities at ORNL and/or extensive modifications of existing ones may constitute a major federal action and therefore be subject to the provisions of the National Environmental Policy Act (NEPA). Compliance with the NEPA process may require the preparation of an environmental impact statement (EIS) which identifies major issues and considers alternatives and mitigating measures. Guidance for complying with the NEPA process has been issued by the DOE.[44]

4.4.1 Air Quality, Land Use, and Terrestrial Ecology

The construction projects for 1980–1981 listed in Table 2.17 affected relatively small areas of land and wildlife habitat, which was usually adjacent to existing facilities. Only minor, transitory degradation of the local environment resulted from this construction, and no lost-time accidents were suffered by construction workers or ORNL personnel.

The possible development of new SWDAs during the next 10 years (Sect. 2.5.8.2) would affect a few hundred hectares of forested land and would reduce vegetation and wildlife populations in proportion to the amount of habitat lost. About 12 ha (30 acres) of hardwood forest were recently cleared for a sanitary waste landfill on Chestnut Ridge near the Y-12 Plant. This landfill will serve the Y-12 Plant and ORGDP as well as ORNL.

Because construction projects affect areas only on government-owned lands designated for use in energy R&D, there will be no effect on use of private lands. Because of the small scale of construction activity at ORNL, only a small number of construction vehicles and a small amount of equipment are required. This equipment emits pollutants to the air but has little effect on air quality. Noise generated by construction activities and heavy equipment is expected to be of limited duration and areal extent, little affecting the local environment.

4.4.2 Endangered Species

The only federally listed endangered animal species that is seen regularly on the ORR is the bald eagle, whose occurence in the area is during the nonbreeding season and depends primarily on the Tennessee River system with its numerous reservoirs (Sect. 3.4.1). Construction activities will not affect the rivers and lakes and will thus not significantly affect the bald eagle.

The Indiana bat (also on the federal endangered species list) may occur on the ORR during the summer. During this season the population is widely dispersed in the eastern United States and does not occur in the dense concentrations found during the winter in certain caves that have been designated as critical habitat (Sect. 3.4.1). Because of this wide dispersion and because no caves on the reservation are known to harbor Indiana bats, the small-scale construction projects at ORNL will not significantly affect this species.

No plant or animal species listed as endangered by the state of Tennessee will be significantly affected by construction activities. Regarding only the Tennessee endangered species not included on the federal list, no plant species and only two of five animal species occur on the ORR (Sect. 3.4.1). The osprey frequents the lakes and rivers in the Oak Ridge area but is not likely to be affected by small-scale construction projects at ORNL. The Bachman's sparrow could potentially occur anywhere on the ORR in old fields or very young pine plantations. However, it has become extremely rare in Tennessee and currently is known to occur in only one area on the ORR (Sect 3.4.1). Because potential habitat for the sparrow is fairly abundant on the ORR and in Tennessee, disruption of small amounts of such habitat by ORNL activities should not have significant adverse effects on this species.

4.5 ASSESSMENT OF CUMULATIVE EFFECTS

4.5.1 Cumulative Effects on Air Quality

Several major facilities in the area emit pollutants to the air and all contribute to effects on air quality. The Bull Run Steam Plant and the Kingston Steam Plant are coal-fired power plants and emit much larger quantities of SO_x, NO_x, and particulates than does ORNL. The ORGDP[45] and the Y-12 Plant[42] are facilities roughly comparable to ORNL in terms of air emissions. Air quality monitoring in the Oak Ridge area reflects the cumulative emissions from all of these sources as well as emissions from more distant sources. Results of this monitoring (Sect. 3.3.6) indicate that air quality in the region does not violate the national ambient air quality standards. Because of its relatively minor emissions, ORNL adds little to the cumulative effect on air quality in the region.

4.5.2 Cumulative Radiological Effects on the Individual

The cumulative radiological effects of ORNL and nearby ORGDP and the Y-12 Plant are given in Table 4.27 for the maximally exposed individuals for each facility. The composite doses are the sum of the maximum doses to different hypothetical individuals residing at the site boundaries of ORNL, ORGDP, and Y-12 Plant. The composite dose of 70 μSv (7 mrems) is about 0.05% of the dose expected from natural background radiation in the vicinity of ORNL (see Sect. 3.5.1). Should the proposed Clinch River Breeder Reactor (CRBR) be built, it is estimated that the average annual boundary total-body dose to the individual from this facility would be <20 μSv (2 mrems).[46]

4.5.3 Cumulative Radiological Effects on Population

The cumulative effects on the 80-km (50-mile) populations around ORNL, ORGDP, and Y-12 Plant are given in Table 4.28. Assuming an average annual dose of 1.29 mSv (129 mrems) from natural background radiation in the Oak Ridge area, a population dose from natural background was estimated for each facility using its respective 80-km (50-mile) radius population. The composite dose from routine releases from all three plants is 0.084 person-Sv (8.4 person-rems). This dose is less than 0.01% of the population doses expected from natural background. It is estimated that the proposed CRBR would increase the population dose within 80 km (50 miles) of the plant by an additional 0.02 person-Sv (2 person-rems).[46]

4.5.4 Cumulative Effects on Water Quality (Nonradiological)

Operations at ORNL affect the quality of water discharged from WOC (as described in Sect. 4.2.2). However, because the discharge is diluted almost 400-fold by the average flow of the Clinch River, this discharge causes negligible impact to water quality of the lower Clinch River. The quality of water discharged from Poplar Creek has definite effects on Clinch River water quality and aquatic ecology,[45,47] but any contributions from ORNL's operations would be undetectable.

4.6 ACCIDENTS

4.6.1 Safety Policy

It is the policy of the DOE to ensure that its operations are conducted in a manner that will (1) limit risks to health and safety of the public and employees and (2) adequately protect property

Table 4.27. Composite radiological impacts on the maximally exposed individual[a] from major nuclear facilities in the vicinity of ORNL (Sv)[b]

Exposure pathway	ORNL (1981)	ORGDP[c] (1984)	Y-12 (1978)
Gaseous	3.8E-6	3.7E-8	6.1E-6
Liquid	6.0E-5[d]	3.2E-10	e
Total	6.4E-5	3.8E-8	6.1E-6
Composite[f]	7.0E-5		
Natural background	1.29E-3	1.29E-3	1.29E-3

[a]Fifty year dose commitment to the total body from each facility. Radiation doses are not to the same individual.

[b]To convert sieverts to rem multiply by 100.

[c]Assessment of ORGDP operations were made for 1984, after all cascade upgrading and improvements have been completed.

[d]Doses from liquid effluents from ORNL include a shoreline dose.

[e]Liquid effluents from Y-12 into East Fork Poplar Creek not considered an exposure threat.

[f]Composite = ORNL + ORGDP + Y-12.

Source: ORNL, Tables 2.3 through 2.7 and 2.10.

ORGDP, U.S. Department of Energy, Environmental Assessment of the Oak Ridge Gaseous Diffusion Plant Site, DOE/EA-0106, December 1979.

Y-12, U.S. Department of Energy, Environmental Impact Assessment, Oak Ridge Y-12 Plant, DOE/EA-0182, 1982.

and the environment. To implement this policy, the Safety Analysis and Review System (SARS) was established to document and identify systematically all potential hazards of a proposed project, to analyze the potential consequences of the hazards through an objective safety analysis assessment, and to explore ways to control, mitigate, or eliminate the hazards.[48] Safety analysis assessments are reviewed to determine if a formal Safety Analysis Report (SAR) is required. A SAR is normally required if the safety assessment indicates that failure of any single safety system may result in unacceptable consequences (and may be required under other circumstances). Prior to authorization of the project, the SAR is reviewed independently and is approved by ORNL/UCC-ND and DOE management. All new projects are covered by SARS. In accordance with the requirements of DOE Order 5480.1. Chap. 5, ORNL is conducting a review of the safety of all existing nuclear facilities that present radiation hazards equivalent to 1 g of ^{239}Pu or 37 TBq (1000 Ci) of beta-gamma emitters.[23] The review is scheduled for completion in 1985.

DOE has continued the policy established by the Atomic Energy Commission (AEC) of requiring that accidents be reported.[49] Criteria for determining reportability, investigation requirements,

Table 4.28. Composite radiological impacts on the surrounding population[a] from major nuclear facilities in the vicinity of ORNL (person-Sv)[b]

Exposure pathway	ORNL (1981)	ORGDP[c] (1984)	Y-12 (1978)
Gaseous	1.1E-3	4.4E-4	4.5E-2
Liquid	3.8E-2	1.5E-5	d
Total	3.9E-2	4.6E-4	4.5E-2
Composite[e]	8.4E-2		
Natural Background[f]	1.1E3	8.7E2	9.5E2

[a]Fifty year dose commitment to the total body: for gaseous releases, population used for ORNL was 841,211 persons; for ORGDP, population was 678,053 persons; and Y-12 population was 734,387 persons.

[b]To convert person-Sv to person-rem multiply by 100.

[c]Assessment of ORGDP operations were made for 1984, after all cascade upgrading and improvements have been completed.

[d]Only includes drinking water from Clinch and Tennessee rivers (downstream from ORNL and ORGDP). Liquid effluents from Y-12 into East Fork Poplar Creek not considered an exposure threat.

[e]Composite = ORNL + ORGDP + Y-12.

[f]Using 1.29 mSv as background dose to individual multiplied by each population group.

Source: ORNL, Tables 2.3 through 2.7 and 2.10.

ORGDP, U.S. Department of Energy, Environmental Assessment of the Oak Ridge Gaseous Diffusion Plant Site,, DOE/EA-0106, December 1979;

Y-12, U.S. Department of Energy, Environmental Impact Assessment, Oak Ridge Y-12 Plant, DOE/EA-0182, 1982.

and procedures for the conduct of accident investigations are reported in DOE Order 5484.1.[50] DOE publishes a summary of accident experience for their facilities annually.[51]

At ORNL, safety is the responsibility of line (or functional) organization (Sect. 2.1.3) and cannot be delegated. The line organization is assisted in carrying out their responsibilities in safety matters by the Central Safety Committee, the General Safety Committee, the Health Division, the Industrial Safety and Applied Health Physics Division, the Office of Environmental Control Coordinator, the Office of Occupational Safety, and the Laboratory Director's standing review committees. The current principal standing committees are the Radioactive Operations Committee, Reactor Operations Review Committee, Reactor Experiments Review Committee, Accelerators and Radiation Sources Review Committee, Criticality Committee, Biohazards Committee, Electrical Safety

Committee, High-Pressure Equipment Review Committee, and the Transportation Committee. The names of the committees indicate their general areas of responsibility. A description of the responsibilities and functions of these groups and committees is presented in ORNL/ENG/TM-19.[52]

In this report, it is not intended to cover safety and accidents comprehensively; the SARS and current safety review do this. The institutional aspects of safety at ORNL have been presented to show the way in which potential accidents, and safety in general, are handled. A brief summary of reportable accidents that have occurred at ORNL is given in Sect. 4.6.2. In Sect. 4.6.3 are presented assessments of some selected postulated accidents. Five reactor accidents, floods, earthquakes, and tornadoes are included. Only postulated accidents involving radioactivity are presented because these are unique to a facility such as ORNL.

4.6.2 Accident Experience

Cumulative summaries of accident experience, injuries, and property losses have been published for the operations under the direction of the Manhattan Engineer District, the AEC,[53] and the Energy Research and Development Administration.[54] For operations under the DOE, annual summaries are published.[51,55]

Review of these summaries indicates that the majority of accidents and injuries are the result of common industrial activities, particularly construction, and are not related to activities involving nuclear materials. Incidence rates for fatalities, reportable injuries, and lost-workday cases are consistently below the rates reported by the National Safety Council for comparable industries and are not addressed in this analysis. Accidents and incidents related to radioactive materials are summarized in Sect. 4.6.2.1. Accidents resulting in the release of nonradioactive materials to the environment are summarized in Sect. 4.6.2.2.

Since 1943, five rainstorms have produced flooding conditions that caused minor property damage but that did not result in the accidental release of radioactive materials. No accidents attributable to earthquakes (Table B.1, Appendix B) or tornadoes have occurred. In 1952 a small tornado passed through the ORR, but no damage was sustained. This is the only recorded tornado for the ORR area.

4.6.2.1 Accidents involving radioactive materials

Reactor fuel melting. Only one incident has resulted in melting of any portion of a reactor fuel assembly (i.e., at the Oak Ridge Research Reactor during the night of June 30–July 1, 1963).[56] The incident occurred at a power level of 24 MWt during a beginning-of-cycle start-up and was caused by a neoprene gasket that blocked circulation of cooling water through one of the fuel elements. The release of some radioactivity from the fuel element was of short duration, probably less than 1 or 2 min, and the major portion of the release appears to have terminated prior to the reduction of reactor power.

It was estimated that about 37 TBq (1000 curies) of volatile fission products were released into the water system. Diffusion of noble gas isotopes (principally ^{138}Xe and ^{88}Kr) from the water system to the building atmosphere resulted in contamination of the atmosphere with ^{138}Cs and ^{88}Rb at established levels up to 40 mBq/m^3 (1 pCi/m^3). Following the reactor shutdown, the building was evacuated for about 6½ h because of this air contamination. The majority of the radioactivity released from the facility was discharged through the central off-gas system. Stack monitors downstream of the filters and scrubber in the off-gas system indicated that from 5 to 7 GBq (150 to 200 mCi) of iodine were discharged to the atmosphere. Noble gas emissions and doses resulting from this occurrence were not estimated. The faulty element was removed from the reactor without difficulty, and the reactor was brought to full power on the evening of July 2.

Nuclear criticality excursions. Three incidents at ORNL occurred in a criticality experiment facility (designed to accommodate criticality excursions) and did not result in personnel exposure or property damage. The most recent event occurred on March 10, 1961, as enriched uranium metal, neutron-reflected and moderated by hydrogen, was being assembled.[53,57] The excursion was caused by the too rapid approach of the two pieces of metal used in the experiment. The energy release was estimated to be between 10^{15} and 10^{16} fissions. Fission product contamination decayed sufficiently overnight to allow unhindered continuation of the experiment.

Two other excursions, both involving solution systems, occurred in 1956 and in 1954.[53,58] In the 1956 incident a homogeneous UO_2F_2 water-moderated critical assembly was made prompt critical by an over-addition of fuel. Before criticality was reached, the hand-operated control valve was turned off; however, fuel continued to be added because of air pressure in the line and resulted in a burst that produced an estimated 1.6×10^{16} fissions. Although the automatic safety system operated ensuring termination of the burst, considerable fuel was displaced from the test critical assembly. Because all personnel were shielded by 1.52 m (5 ft) or more of concrete, no serious personnel exposure resulted. No significant property damage occurred, and all uranium was recovered.

The 1954 incident involved an experiment designed to study criticality conditions of uranium water solutions in annular cylindrical containers. The excursion resulted when the central tube, effectively a poison rod, was displaced because of the dislocation of the positioning spider by a protruding pin that allowed the central tube to fall against an outer cylinder; this caused a large increase in the effective neutron multiplication. The safety system apparently operated normally, and the reaction was stopped automatically. Because all personnel were protected by a minimum of 1.52 m (5 ft) of concrete, no serious personnel exposures were incurred.

Fire and explosion. In the operation of ORNL, only one reportable accident has occurred involving fire or explosion in a facility handling significant quantities of radioactive materials (i.e., November 20, 1959, as a result of a chemical explosion during a decontamination operation at the radiochemical processing plant in Bldg. 3019).[59,60] At the time of the accident, the pilot plant was in shutdown status with the exception of the decontamination of the evaporator section. After attempts to decontaminate the evaporator with a decontamination agent followed by water and 30% HNO_3 were unsuccessful, 200 L (50 gal) of decontaminant (a then unknown mixture of alkaline salts, amines, hydroxy acids, phenol, surface active agents and water) were introduced into the evaporator and boiled for 2 h. After boiling, the decontaminant was run out through the remotely operated drain leaving a "heel" of about 15 L (4 gal). This heel could be drained only through a hand-operated valve. Skipping the water wash and neutralization recommended by the manufacturer, 270 L (70 gal) of 20% HNO_3 was added to the evaporator which still contained about 15 L (4 gal) of decontaminant. The mixture was boiled for about 2 h concentrating the HNO_3. The remotely operated drain valve was then opened, and an explosion occurred while draining. Although a definite cause of the explosion was not determined, investigators have deduced possible causes as either a reaction of nitric acid with the decontamination agent or a collection of tributylphosphate (TBP) and dilutent solvents plus a substantial portion of radiation degradation products of TBP and the solvent.

The amount of plutonium released outside of the processing building was estimated to be about 0.6 g (only residual radioactive materials remaining in the processing equipment were involved). This resulted in the contamination of nearby buildings, several vehicles, and roadways and grounds in an area of about 1.6 ha (4 acres). The immediate area was evacuated, and steps were taken to avoid excessive exposure to radioactivity of persons entering the contaminated area. Because of the nature of plutonium hazards, all reasonable measures were taken to remove or "fix" contamination so that the possibility of plutonium particles becoming airborne was virtually eliminated. No one was injured by the explosion. Damage to processing equipment as a direct result of the explosion amounted to $10,000; decontamination costs were estimated at about $350,000.

4.6.2.2 Accidents involving release of nonradioactive materials

Large quantities of nonradioactive chemicals are stored and used (Table 2.8 provides a representative summary of organic chemical purchases annually through Chemical Stores). In addition to these, large quantities of inorganic chemicals and petroleum products are also purchased and consumed.

Regulations promulgated by EPA require that spills of oil and "hazardous amounts" of designated "hazardous chemicals" be reported either to the U.S. Coast Guard or to the EPA. For purposes of this discussion, spills are differentiated from accidental releases in that spills reach (or may be reasonably expected to reach) water resources, while accidental releases would not. For example, rupture of a tank within a diked area from which runoff is controlled and can be contained or treated would not constitute a spill, whereas release of the same material in an area from which runoff is not controlled would constitute a spill. Although "hazardous quantities" have been established for a number of specific chemicals, no specific quantity has been established for oil. The only quantity-related criteria generally applied to oil is the presence or absence of a visible sheen on the surface of the receiving water.

The Department of Environmental Management (DEM) is responsible for responding to all accidental releases of oil or chemicals and for providing pertinent related information to DOE. During the 4-year period from 1978 to 1981, DEM responded to a total of 60 accidental releases, 37 involving oil and 23 involving other chemicals. Only 6 of these releases were reportable as spills; 5 others resulted in noncompliance with national pollutant discharge elimination system permit limitations for oil and grease (2 occurrences) or pH (3 occurrences). Of the reportable oil spills, 2 involved undertermined quantities of transformer mineral oil or hydraulic fluid; the other 3 involved hydraulic fluid [75 L (20 gal)], diesel fuel [190 L (50 gal)], and machine coolant [380 L (100 gal)]. The chemical spills included sulfuric acid [60 L (16 gal)], calcium hydroxide [7 kg (15 lb)], and an undetermined quantity of cement.

4.6.3 Selected Postulated Accidents

4.6.3.1 Bulk Shielding Reactor

In the maximum accident postulated for the Bulk Shielding Reactor (BSR), the following assumptions are made:

1. that the melting of 50% of the fuel immediately following 28 months of continuous operation (equivalent to an average fuel element life of 14 months at an average power level of 2 MWt) would be involved;
2. that the containment building would remain intact;
3. that all of the noble gases, 50% of the iodine, and 2% of the nonvolatile fission products would be released from the melted fuel and would be immediately and uniformly mixed with the building air (however, in the internal dose analysis for the iodine, some credit is taken for the scrubbing action of the water in the reactor pool); and
4. that the building ventilation system would continue to function so that all building leakage is inward and all building air is exhausted through filters for particle and iodine removal at a rate of 2.3 m^3/s (5000 ft^3/min).[61]

The filter system at the BSR, the same type as that used at the Oak Ridge Research Reactor, consists of a roughing filter, an absolute filter, a charcoal filter, and a final roughing filter. Tests performed, as installed at the Oak Ridge Research Reactor, yielded a decontamination factor for iodine of about 600. Because the iodine release would occur under water, a decontamination factor of 1000 was assumed for iodine. Filters are capable of removing 99.95% of all particles larger than 0.3 μm, equivalent to a decontamination factor of 2000. Although action of the pool water and adsorption by the building and duct surfaces could increase the decontamination factor by a factor of 1.5 to 2.0, a conservative decontamination factor of 2000 is assumed for nonvolatile fission products. A decontamination factor of 1 is assumed for the noble gas fission products.

The predicted maximum doses to an individual located about 1 km (0.6 mile) downwind from the 3039 stack are about 25 mSv (2.5 rems) total external dose and about 2 mSv (200 mrems) total internal dose.

4.6.3.2 High Flux Isotope Reactor

In the maximum credible accident postulated for the High Flux Isotope Reactor (HFIR), the following assumptions are made:

1. that the melting of not more than 50% of the reactor fuel following 15 d of operation at 100 MWt would be involved;
2. that 100% of the noble gases, 50% of the iodines, and 2% of the other fission products would be released from the fuel;
3. that 25% of the released fission products would escape from the primary containment and would be rapidly removed from the region over the pool by the special building hot exhaust system;
4. that the other 75% would be removed more slowly by the hot off-gas system; and
5. that the released fission products would be discharged following filtration.[62]

Based on (1) tests conducted on the Oak Ridge Research Reactor filter system, which is similar to but somewhat less elaborate than that at the HFIR, and (2) the fact that the iodine is released underwater and must pass through the off-gas ducts before reaching the filters, a decontamination factor of 2000 was assumed for iodine. An overall decontamination factor of 4500 was assumed for the nonvolatile fission products. And it was assumed that 100% of the noble gas fission products would be released from the stack.

The points of predicted maximum exposure to iodine and noble gas (beta and gamma) are within 1 km (0.6 mile) of the HFIR stack but are not coincident. The predicted maximum whole body exposures to noble gas beta and gamma radiation are about 350 mSv (35 rems) and 500 mSv (50 rems) respectively. The maximum predicted iodine (thyroid) dose is about 52 mSv (5.2 rems). At the nearest point on the boundary of the ORR, predicted maximum exposures are 110 mSv (11 rems) beta and 130 mSv (13 rems) gamma for a whole body total of 240 mSv (24 rems), which is slightly below the limit of 250 mSv (25 rems) specified by 10 CFR 100. The predicted iodine dose to the thyroid at the same location is 28 mSv (2.8 rems).

4.6.3.3 Health Physics Research Reactor

Because the Health Physics Research Reactor (HPRR) can be operated in either a burst or a continuous steady-state mode, two potential accidents are analyzed.[63] The maximum credible accident is considered to result from the addition of sufficient excess reactivity causing a burst of 10^{19} fissions resulting in physical destruction of the reactor core. This accident is predicted to result in a total external dose of not more than 150 mSv (15 rems) at the nearest access point about 900 m (3000 ft) from the reactor. Maximum internal doses resulting from iodine and strontium are predicted to be about 52 mSv (5.2 rems) to the thyroid and 2.2 mSv (220 rems) to the bone respectively. A less severe accident is a meltdown of the core because of failure of the control system to scram the reactor. Meltdown is assumed to occur at the end of a 2-h run at 1 kWt following a long sequence of similar runs on a daily basis. This incident is predicted to result in an internal exposure of about 3 mSv (300 mrems) to the thyroid of a person at a distance of about 900 m (3000 ft) from the reactor.

4.6.3.4 Oak Ridge Research Reactor

The postulated maximum hypothetical accident assumes that the Oak Ridge Research Reactor core operating at 45 MWt suffers a 100% meltdown in which 100% of the noble gases and 50% of the iodines are released.[64] It is also assumed that the noble gas daughters of 100% of the iodines are also released (this assumption results in counting the iodine daughters twice, thereby providing a slight additional degree of conservatism but simplifying the calculations). Because the release takes place under water, the escape of nonvolatile fission products is assumed to be negligible. The pool is assumed to have a decontamination factor of 3 for iodine. The filters consistently demonstrated a decontamination factor of 100 or more in semiannual testing; therefore the filter factor is taken as 100.

Maximum iodine doses are estimated to be about 160 mSv (16 rems) under most representative conditions and 100 mSv (10 rems) under inversion conditions. The downwind distances to the points of maximum exposure are about 1 km (0.6 mile) and 6 km (3.7 miles) respectively. The initial whole body dose rate within the building would be about 7 Sv/min (700 rems/min); however, the internal dose rate from ^{131}I would exceed 75 Sv/min (7500 rems/min). Personnel in the reactor bay would very likely become casualties unless they escaped before the fission gases became mixed with the atmosphere in the building.

The initial dose rate at 1 m (3 ft) from the building wall would be about 3 Sv/min (300 rems/min) and would decrease to 70 mSv (7 rems/min) at 100 m (330 ft). Within 150 to 200 m (500 to 650 ft) of the building, the controlling external dose is that delivered by direct radiation from the building.

External doses at the site boundary [about 3 8 km (2.4 miles)] are estimated to be about 150 mSv (15 rems) for infinite exposure under inversion conditions. About 50 mSv (5 rems) of this exposure would be received in the first 2 h. Under most representative conditions the external dose at the same location would be less than 20 mSv (2 rems) even for infinite exposure.

4.6.3.5 Tower Shielding Reactor II

The postulated maximum credible accident[65] for the Tower Shielding Reactor II involves a partial melting of the reactor core following an incident in which the reactor is dropped with the resultant loss of all water from the pressure vessel. Even though heat loss calculations indicate that convection heat losses and available heat capacity would preclude melting, an instantaneous release of fission products from a melted portion of the core is assumed. Release of 100% of the noble gases, 50% of the iodines, and 1% of the controlling bone-seeking nonvolatile nuclides directly to the atmosphere without deposition on fuel plate or pressure vessel surfaces is also assumed. Burnup of the ^{235}U in the fuel elements is assumed to be 1.5%, which is equivalent to 3000 MWh of operation.

Based on fission product inventories for two operating modes (1 MWt for 8 h/d and 1 MWt for 1000 h), the fractions of the core which could melt without exceeding doses of 3 Sv (300 rems) to the thyroid and 250 mSv (25 rems) to bone at a distance of 1000 m (3300 ft) were calculated for lapse and inversion conditions. Iodine inhalation was determined to be the controlling exposure mechanism. Under inversion conditions and continuous operation for 1000 h, 3.6% of the core could melt without exceeding a thyroid dose of 3 Sv (300 rems) at 1000 m (3300 ft). This would result in a bone dose of about 30 mSv (3 rems). Under lapse conditions the fraction melting could increase to 80%. For operation at 1 MWt for only 8 h/d, the allowable core-melting fractions increase to 8.9% and to 200% under inversion and lapse conditions respectively.

4.6.3.6 Floods

The watershed that would affect ORNL during flood conditions is described in Sect. 3.2 and consists of White Oak Lake, WOC, and Melton Branch, located mainly on the south and west of ORNL (Fig. 4.2). Studies made recently identify potential effects of flooding on the ORR.[52]

Effects due to a maximum severity flood. Potential effects from floods are recognized as a possibility because of the 140-cm (55-in.) annual rainfall per year. Observations of flood conditions go back to 1826, but measurements of runoff and high water elevation have been made only since ORNL began operations in 1943. Since 1943, five rainstorms have produced flooding conditions that caused minor damage. These observations, together with other studies, form the basis for three conclusions:

1. Based on the measurements made and on area-wide meteorology,[66] it was concluded that rainstorms, with the estimated return period of from 50 to 100 years, have not occurred in the area during the existence of ORNL. For example, the latest reported flooding occurrence resulted from 9.7 cm (3.8 in.) of rain that fell over a 48-h period on June 7–8, 1978. This produced overbank flooding and runoff volumes that exceeded measurement capacity.

2. As a result of the requirement that WOC must handle large volumes of water, a new spillway and monitoring equipment are to be installed at White Oak Dam to accommodate maximum design flow of 57 m^3/s (2000 cfs) and a high water elevation of 229.5 m (753.0 ft).[67] This equipment choice is based on estimated flows for a 25- to 50-year flood. Steps have been taken since 1979 to prevent the failure of White Oak Dam.[41] A rock berm and sand filter were recently completed on the downstream slope to increase its stability.
3. Computer analysis of regional meteorological data have allowed ORNL to estimate the impacts due to flood conditions of maximum severity. Runoff volumes and high water levels along WOC were calculated and the extent of flooding overlaid on topographic maps to ascertain which areas of ORNL would be affected.[52] The runoff rates of these postulated floods ranged from a factor of 1.1 (for the 100-year flood) to 15.3 (for the maximum probable flood) when compared with the highest measured flood runoff that occurred in November 1973.

Building impacts. About 40 buildings would be affected by a 500-year flood.[52] Details on the water level in each building and its potential impacts are not available. However, it would be anticipated that flooding could produce leaching of contaminated areas, and resultant contamination of the floodwaters to unknown concentrations would be carried downstream. The flooding could also result in water damage to equipment and furniture in the buildings and require cleanup to remove deposited silt and mud after the water recedes.

Solid waste disposal area. Floods probably would have little effect on radioactive buried wastes because most of the SWDAs are outside of the maximum probable floodplain. A small area of SWDA No. 6 and of SWDA No. 1 would be covered during the maximum probable flood; however, it is unlikely that enough sediment transport would occur to remove the 0.91-m (3-ft) cover from a trench (thereby exposing or removing the buried waste). Inundation would temporarily increase transport from the trenches because of increases in groundwater flow.

Gunite tanks in 3507 area. The bottom of the six Gunite tanks are below the 239.6-m (786-ft) elevation, which is the elevation that water would reach in a 100-year flood. Therefore, there is a potential significant hazard from tank failure due to such a flood and such possible failure mechanisms as tank bottom failure, tank sidewall failure, and tank flotation. After the Gunite tanks have been emptied of their radioactive contents when decommissioned, process water can be added to them to prevent flood-induced tank failure or tank flotation. However, any water added to the tanks for this purpose would have to be disposed of subsequently as contaminated water.[68]

New hydrofracture facility. The design elevation of the floor of the waste pit of the new hydrofracture facility is 234 m (768 ft). The maximum probable flood that has been estimated for the Clinch River is also 234 m (768 ft) at the discharge of WOC. A flood of this magnitude would not be expected to have any effect on the hydrofracture facility. All structures of the facility will be well above this flood stage.[69]

Intermediate-level waste system. The design elevation of the sumps of the ILW facilities are as follows: evaporator addition, 240.2 m (788 ft); ILW collection tank, 237.7 m (780 ft); concentrate surge tank, 240.8 m (790 ft); waste storage tanks (Melton Valley), 233.2 m (765 ft); waste collection tank (transuranic), 257.9 m (846 ft). The maximum probable flood [234 m (768 ft) at the discharge of WOC] would be a few feet above the elevation of the sumps of the waste storage tanks in Melton Valley, but no adverse effects are expected. All other structures in the waste-handling system will be well above this flood stage. A flood of greater magnitude would result in a higher water level around the Melton Valley waste storage tanks but should not damage the tanks or affect their integrity. The tanks would not float under any credible flood conditions.[70,71]

Based upon the foregoing analysis, the risks associated with the occurrence of severe flood conditions are considered acceptable.

4.6.3.7 Earthquakes

To present problems of damage or release of radioactivity, an earthquake with a Modified Mercalli (MM) intensity of VII or greater would have to occur in the ORNL area. MM intensity

VII may be described as causing slight damage in buildings such as those at ORNL (see Sect. 3.1.2.3). The estimated frequency of this type of event at ORNL is from 50 to 100 years. In critical installations, seismic design criteria are used to prevent damage from events such as this. As a result, only slight damage to property and limited release of radioactivity are to be expected. Based on the low probability of occurrence and on the limited consequences, it is concluded that earthquakes do not present a significant risk to ORNL facilities.[52]

4.6.3.8 Tornadoes

A study of tornado occurrence indicates that because of the proximity of the Cumberland Mountains and the broken terrain in the vicinity, the probability of the incidence of a tornado at a given point in the Oak Ridge area is once in about 2500 years. On May 2, 1952, a small tornado passed through the ORR but no damage was sustained.

The consequences resulting from the occurrence of a tornado are unique for two reasons: first, both the primary and secondary containment systems may be severely damaged resulting in the direct release of radioactive materials, and second, the wind velocities are adequate to disperse dense materials such as oxide powders over extremely large areas. The majority of the buildings at ORNL were not designed to withstand tornado forces and would be severely damaged or destroyed. Although the primary containment systems, such as hot cells or glove boxes, might survive the wind forces, they could be severely damaged by the collapse of the building.

Because of the large inventory of actinide elements in the Transuranium Processing Facility (TRU),[72] the most serious consequences would be expected if a tornado severely damaged this facility. The inventory of transuranium elements normally contained in about 20 glove boxes in the TRU is estimated to have a radiological hazard equivalent to about 100 kg (220 lbs) of plutonium. This facility is currently being reviewed under SARS to assess the potential damage from a tornado.

4.7 DECONTAMINATION AND DECOMMISSIONING

4.7.1 The National Surplus Facilities Management Plan

In its 1979 report to the president, an interagency review group recommended that an improved national program for nuclear waste management be defined as a high priority national need.[73] Subsequently, the president defined this need and reiterated the role of DOE as the lead agency for the management and disposal of radioactive wastes.[74] As part of the National Waste Management Program, DOE has established the Surplus Facilities Management Program (SFMP),[75–77] which is part of the Remedial Actions Program Office under the assistant secretary for nuclear energy, Office of Nuclear Waste Management. ORNL is one of the organizations participating in the SFMP. The primary function of SFMP is the safe management and decommissioning of DOE-owned surplus facilities. The program seeks to ensure that adequate restrictions on the use of deactivated facilities are implemented and that safeguards and quality assurance procedures are developed that would allow the safe disposition or reuse of the facilities by the government as appropriate in the future.

Implementation of the SFMP has accelerated the development of policy regarding decontamination and decommissioning, which continues to evolve as specific facility considerations receive attention. An extensive bibliography on decommissioning and site remedial actions cites such developments.[78]

4.7.2 Program Implementation at ORNL

The national SFMP designates 15 projects at ORNL as candidates for decontamination and decommissioning (D&D) (Table 4.29). These projects are no longer needed for their intended purposes and should be considered for either decommissioning or adapting to other uses.

In a review of the ORNL D&D program, Bell notes:

> "A systems management approach will be used to accomplish the D&D program at ORNL. In this approach the D&D program will be treated as a major system made up of numerous subsystems (the individual D&D projects). Since the projects have interrelated requirements, assets, and liabilities, the systems management approach is expected to save redundant expenditures of manpower and money. Initially, this concept will include establishment of a central program office, an early program definition and planning effort, conceptual engineering studies on high priority projects, development of a technical information base, research and development activities, and analysis of interfaces with other ORNL programs such as waste management."[79]

This program, employing the systems management approach, has been proposed to DOE. Its implementation is expected to span several decades and cost over $100 million.

Options for ultimate disposition of facilities range from in situ protective storage to complete removal of the facility from the site.[80] For instance, appropriate decommissioning alternatives, defined by the NRC *Regulatory Guide 1.86*, are the following:

- mothballing,
- in-place entombment,
- removal of radioactive components and dismantling,
- conversion to a new nuclear system or a fossil fuel system, and
- permanent dedication of a site and its facility, or any part of the facility, to nuclear application.[81]

In response to the national plan, ORNL has recently completed decommissioning the Building 3026-C radiochemical waste system. Also recently completed were two engineering feasibility studies (decommissioning of the ILW transfer line and decommissioning of the Metal Recovery Facility, Building 3505), two planning studies (*Radiological Characterization of Selected Sites and Facilities* and *Removal and Disposal of MSRE Fuel Salts*), and an environmental assessment of the decommissioning of the ILW transfer line. The decontamination of the Curium Facility will be completed in late FY 1982.

Initiation of actions to decontaminate and decommission other facilities listed in Table 4.29 are contingent on the availability of an adequate ORNL solid waste disposal system. Numerous uncertainties in the costs of proceeding with decontamination and decommissioning operations, particularly those associated with solid waste disposal, preclude the immediate definition of project plans. However, preliminary plans and procedures for decommissioning a number of the specific sites have been prepared.

4.7.3 Environmental Effects of Decontamination and Decommissioning

The decommissioning of nuclear facilities requires a determination of the need for an EIS for actions or proposals with significant impact on the human environment, as prescribed by the NEPA of 1969. DOE, as the responsible agency for such actions with ORNL facilities, acts in conformance with procedures described in "DOE Guidelines for Compliance with the National Environmental Policy Act," published in 44 CFR Pt. 2136, July 18, 1979. If an EIS is deemed as

Table 4.29. Current surplus radioactive facilities at ORNL

	Facility/project	Description
1.	ILW transfer line	Transfer line between ILW and hydrofracture
2.	Metal Recovery Facility	Building 3505
3.	Curium Source Fabrication Facility	Building 3028
4.	Fission Product Development Laboratory (FPDL)	Building 3517
5.	Waste Holding Basin	Site 3513
6.	Molten Salt Reactor Experiment	Building 7503
7.	Gunite storage tanks	W-5 to W-10, Site 3507
8.	Old hydrofracture facility	Shale fracturing plant, Site 7852
9.	Waste storage tanks	WC-1, WC-11, WC-15, WC-17, W-1, W-2, W-3, W-4, W-13, W-14, W-15, TH-1, TH-2, TH-3, TH-4
10.	Radioisotope process facilities	Storage gardens 3026-D and 3033; carbon-14 process system; Waste Evaporator Facility, Building 3506; Fission Product Pilot Plant Building 3515
11.	Shielded transfer tanks	Solid Waste Storage Area No. 5
12.	Oak Ridge Research Reactor experimental facilities	ORRR water-air heat exchanger, Building 3087; ORRR-GCR A9-B9 experiment facilities; ORRR-MSR loop; ORRR-Marine Ship Loop; Pneumatic tube irrad. facility; ORRR-GCR Loops I and II, Building 3042
13.	Homogeneous Reactor Experiment	Building 7500
14.	Low Intensity Test Reactor	Building 3005
15.	ORNL Graphite Reactor	Building 3001

Source: J. H. Coobs, Operations Division of the Oak Ridge National Laboratory.

not necessary, a finding of no signficant impact (i.e., a conclusion that the potential or proposed action will not have significant environmental consequences) is issued. Otherwise, a notice of intent will be published, stating that an EIS will be prepared. Detailed definition of these procedures is given in the current version of the SFMP plan.[77] Assessment of the environmental consequences of a specific decommissioning program include the following areas of assessment:

- impact on land resources,
- occupational radiation exposure,
- nonoccupational radiation exposure,
- industrial safety considerations,
- nonradiological considerations,
- sociological-economic impacts, and
- program-related resource commitments.

Proposals for decontamination and decommissioning require a careful analysis of the ramifications of each of these types of impacts before operations are initiated. Analytic procedures, as well as methodology for evaluating alternatives to the proposed action, are discussed in ref. 80. Work in each of the facilities listed in Table 4.29 may have caused some radioactive contamination of the nearby area during the period of its operation. Removal of residual trace amounts of radionuclides may require excavation and backfilling operations. Site borings and collection of soil samples may be needed to determine the extent of contamination in surrounding soils, and a pathway analysis based on information obtained may be required to determine the amount of soil removal that may be required. Such data will be needed for each facility in the program to characterize residual environmental contamination.

During the operational phase, contaminants present at the site will be packaged for disposal. A strong quality assurance program will be implemented to ensure that these operations provide adequate containment. Solid wastes will be placed in SWDA No. 6. This facility is expected to be usable without expansion until 1988–1990. Liquid wastes produced from decontamination procedures will be processed as LLW or ILW as appropriate (see Sect. 2.5.7). Gaseous wastes may be released either to one of the existing gaseous waste systems or stacks (see Sect. 2.5.6) or to the atmosphere directly after filtering.

The current condition of the candidate facilities for decontamination and decommissioning varies with respect to continued integrity and hence to their potential for environmental impact. As decontamination and decommissioning of individual facilities at ORNL is authorized, assessments will be required of the feasibility of decontaminating various items of equipment or areas to the extremely low allowable limits for release. Careful evaluation of the decontamination effort required to achieve these levels is needed to ensure that the environmental impact of the decontamination effort is not more severe than would result from the adoption of other alternatives.

REFERENCES FOR SECTION 4

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APPENDIX A

ORNL FACILITIES DESIGNATION

Facility Number	Name
1000	Engineering
1053A	Estimating Engineering Office
1053B	Estimating Engineering Office
1054	Engineering Model Shop
1057	100-Meter Meteorological Tower
1503	Plant Sciences Laboratory
1504	Aquatic Ecology Laboratory
1505	Environmental Sciences Laboratory
1506	Controlled Environment and Animal Building
2000	Solid State Laboratory Annex
2000	Quality Assurance and Inspection
2001	Information Center Complex
2003	Process Water Control Station
2007	Health Physics Calibration Laboratory
2008	Health Physics Technology Internal Dosimetry Laboratory
2009	Cafeteria Storage Building
2010	Cafeteria
2011	Mechanical Properties Laboratory No. 2
2013	West Maintenance Service Center
2016	West Portal
2018	Electrical and Air-Conditioning Service Center
2019	Solar Energy Laboratory
2024	Information Center Complex A
2024	Quality Assurance and Inspection
2026	High-Radiation-Level Analytical Laboratory
2029	Information Center Complex Annex C
2030	Mobile Office Unit
2069	Change House
2093	Environmental Storage
2500	Guard and Fire Headquarters
2506	Fabrication Shop and Timekeeping
2510	Air Compressor Building
2517	Personnel Development and Systems Department Offices
2518	Plant and Equipment Division Offices
2519	Steam Plant
2521	Sewage Treatment Plant
2522	Fuel Oil Tank
2523	Decontamination Laundry
2525	Fabrication Department Shop A

Facility Number	Name
2528	Coal Research Laboratory
2531	Radioactive Waste Evaporator Building
2536	Sewage Research Building
2567	Craft Support Group Offices
2621	Tool Stores
2628	Fire Protection Maintenance and Storage Shop
3000	13.8 kV Substation
3001	Graphite Reactor
3002	Filter House
3003	Solid State Accelerator Facility
3004	Water Demineralizer
3005	Low-Intensity Testing Reactor
3010	Bulk Shielding Reactor Facility
3012	Rolling Hill
3013	Geological Disposal Laboratory
3017	Chemical Technology Division Annex
3019A	Radiochemical Processing Pilot Plant
3019B	High-Level Radiation Analytical Laboratory—A
3024	Fabrication Department Shop B
3025E	Physical Examination Hot Cells—A
3025M	Solid State Division Laboratories
3026C	Radioisotope Development Laboratory—B
3026D	Dismantling and Examination Hot Cells
3028	Radioisotope Production Laboratory—A
3029	Radioisotope Production Laboratory—B
3030	Radioisotope Production Laboratory—C
3031	Radioisotope Production Laboratory—D
3032	Radioisotope Production Laboratory—F
3033	Radioisotope Production Laboratory—F
3033A	Radioisotope Production Laboratory Annex
3034	Radioisotope Area Services
3036	Isotope Area Storage and Service Building (Temporary)
3037	Operations Division Office
3038	Radioisotope Laboratory
3039	Central Radioactive Gas Disposal Facility
3042	Oak Ridge Research Reactor
3044	Special Materials Machine Shop
3047	Isotope Technology Building
3074	Interim Manipulator Repair Facility
3085	Pump House—Oak Ridge Research Reactor
3087	Heat Exchanger—Oak Ridge Research Reactor
3092	Off-Gas Facility
3095	Reactor Area Equipment Building
3102	Heat Exchanger No. 2—Oak Ridge Research Reactor
3103	Cooling Tower No. 3—Oak Ridge Research Reactor
3106	Cell Ventilation Filters (for Bldgs. 4501, 4505, and 4507)
3114	Shock Tube Laboratory
3115	Solid State Offices
3127	Plutonium Storage Vault
3130	Waste Op[illegible]ions Control Center

Facility Number	Name
3500	Instrumentation and Controls
3502	East Research Service Center
3503	High-Radiation-Level Chemical Engineering Laboratory
3504	Geosciences Laboratory
3505	Fission Product Development Laboratory Annex
3506	Radioisotope Production Laboratory—G
3508	Chemical Technology Alpha Laboratory
3517	Fission Product Development Laboratory
3518	Process Waste Water Treatment Plant
3523	Controls Research
3525	High-Radiation-Level Examination Laboratory
3534	Liquid Metal Cleaning Facility
3537	Hydrogen and Oxygen Distribution Station
3539	Process Waste Pond No. 1 (North)
3540	Process Waste Pond No. 2 (South)
3544	Process Waste Treatment Plant
3546	Instrument and Controls Office Annex
3550	Research Laboratory Annex
3581	Solvent Storage
3587	Instrument Laboratory Annex
3592	Coal Conversion Facility
3603	Environmental Study Center
4000	13.8 kV Substation
4500	Central Research and Administration
4501	High-Level Radiochemical Laboratory
4505	Experimental Engineering Section
4507	High-Radiation-Level Chemical Development Laboratory
4508	Metals and Ceramics Laboratory
4509	Compressor House
4510	Cooling Tower
4511	Cooling Tower
5000	Main Portal
5500	High Voltage Accelerator Laboratory
5505	Transuranium Research Laboratory
5506	East Portal Building
5507	Electron Spectrometer Facility
5554	Electric Substation (for Bldg. 5505)
6000	Holified Heavy Ion Research Facility (HHIRF)
6001	Cooling Tower (for Bldg. 6000)
6002	ORELA Office Annexes A, B, C, and D
6003	Modular Building for Offices
6005	Gas Compressor House (for Bldg. 6000)
6007	Joint Institute for Heavy Ion Research
6010	Electron Linear Accelerator
6025	Engineering Physics Office/Laboratory Building
6551	West Reservoir (on Haw Ridge)
6552	East Reservoir (on Haw Ridge)
7001	General Stores
7002	Garage and Ironworking Shop
7003	Welding and Brazing Shop
7005	Lead Shop

Facility Number	Name
7006	Paint Stores
7007	Paint Shop
7009	Carpenter Shop
7010	Dry Lumber Storage
7012	Central Mechanical Shops
7013	Acid, Chemical, and Flammable Liquid Storage
7018	Salvage and Reclamation Facility
7040	Gas Cylinder Storage
7070	Storage Shed
7500	Nuclear Safety Pilot Plant
7503	Molten-Salt Reactor Experiment Building
7505	MIT Practice School
7506	CPAF Contractor Headquarters
7507	Substores
7509	Molten-Salt Reactor Office Building
7516	Field Service Shop (for 7500 Area)
7555	Diesel Generator House (for Bldg. 7503)
7561	Valve Pit (for Bldg. 7500)
7600	Containment Building
7601	Office Building
7602	Engineering Systems—CFRP
7603	Experimental Engineering—CFRP
7605	Storage Building
7606	South Research Service Maintenance Building
7607	River Pump Station
7608	Component Development—CFRP
7700	Tower—Tower Shielding Facility
7709	Health Physics Research Reactor
7710	DOSAR Facility—HPRR
7712	DOSAR Low-Energy Accelerator
7900	High-Flux Isotope Reactor
7902	Cooling Tower (for Bldg. 7900)
7910	Office Building (for Bldg. 7900)
7914	Equipment and Parts Storage Building
7915	Operations Storage Building
7920	Transuranium Processing Plant
7930	Thorium-Uranium Recycle Facility

APPENDIX B

GEOLOGIC FORMATIONS OF THE OAK RIDGE, TENNESSEE, AREA; EARTHQUAKE HISTORY OF EAST TENNESSEE; DESCRIPTION OF SOIL SERIES ON THE OAK RIDGE RESERVATION

B.1 ROME FORMATION[1]

The Rome formation is composed of interbedded sandstone, siltstone, shale, and dolomite. The bulk of the formation in the Oak Ridge area is siltstone and shale. Sandstone beds, which range in thickness from 7 to 35 cm (3 to 14 in.), are more abundant in the upper one-half of the formation than in the lower.

The sandstone is composed of light gray to light brown, fine- to medium-grained quartz and is cemented with silica or iron oxide. The sand is so well cemented in places that it appears quartzitic. Generally, the weathered surfaces of the sandstone are dark brown or reddish brown.

Siltstone in the Rome is generally light to dark brown and greenish brown, thin bedded, and has irregular bedding surfaces with concentrations of small flakes of mica.

A striking characteristic of the Rome is its banded coloration, primarily caused by the shale beds, which are green, maroon, red, violet, purple, yellow, tan, and brown. Very small flakes of mica are common along the bedding surfaces.

Northwest of Pine Ridge a belt of shale occurs which heretofore has not been assigned a definite stratigraphic position. It is faulted above and below, has no obvious lithologic similarity to the formations in the area, and lacks identifiable fossils. The shale is dominantly maroon, red, and tan, fairly silt-free clay. It is interbedded with lesser amounts of brown, purple, and green, more silty clay. The maroon and red shale beds may be a potential source of brick clay because they are very similar to the shale of the Pennington formation of Mississippian age that is used in several places in southwestern East Tennessee for brick and pottery. The surface over the shale is characteristically strewn with 5- to 15-cm-diam (2- to 6-in.) cobbles of dense bluish white to blue chalcedony, which is probably derived from weathering of calcareous beds interbedded with the shale. Many of these cobbles exhibit cryptozoanlike structures on the exterior. Wad (a hydrous manganese oxide mineral) occurs locally as nodules in the shale, and a few fine- to medium-grained, maroon and brown thin-bedded sandstone beds are present.

The shale is thought to be an older part of the Rome formation not exposed in the belts southeast of Pine Ridge; perhaps the shale corresponds to the Apison shale member of the Rome, which crops out in southwestern East Tennessee.

The typical sandstones and siltstones of the Rome are characterized by abundant primary features such as ripple marks, rill marks, swash marks, mud cracks, and, locally, raindrop imprints.

The lower contact of the Rome is not exposed in the Oak Ridge area; it is always in fault relationship with younger rocks that lie underneath it. The upper contact with shale of the Conasauga group is gradational and was chosen arbitrarily, based primarily on topography and the coloration of the shales (the shales of the Conasauga are not as brightly colored as those of the Rome formation).

The Rome formation underlies ridges that are typically narrow, steep sided, and broken by many closely spaced wind and water gaps that give the ridges a "comby" appearance.

The residual soil of the Rome is generally less than 4.5 m (15 ft) thick and is composed of sandy, silty, light-colored clay containing scattered siltstone and sandstone fragments.

No fossils were found in the Rome of the Oak Ridge area, but those found in the formation elsewhere show that its age is youngest Early Cambrian. The total thickness of the formation is not present in the Oak Ridge area, but probably 240 to 800 m (800 to 2600 ft) of the upper part of the Rome is represented. The thickness of the older part of the Rome has not been determined.

B.2 CONASAUGA GROUP[1]

The Conasauga is primarily calcareous shale interlayered with limestone and siltstone. The shale of the Conasauga ranges from pure clay shale to silty shale and is brown, tan, buff, olive green, green, and dull purple. Dark gray, dense to crystalline, nodular, thin-bedded, silty limestone is interbedded with the shale and siltstone in the lower two-thirds of the group. Siltstone, which is brown, reddish brown buff, and tan, is present throughout the lower four-fifths of the group and is abundant in the layers underlying a line of knoblike hills on the northwestern sides of the valleys underlain by the Conasauga.

Alternating beds of shale and light gray, dense to crystalline, regularly bedded limestone are present about 150 m (500 ft) below the top of the group. These beds are overlain by about 90 m (300 ft) of massive, light to medium gray, dense to coarsely crystalline or oolitic limestone. The upper limestone beds of the Conasauga are used in many places in East Tennessee as a source of quarry stone for road aggregate; most of this limestone is fairly pure, and the oolitic beds are composed of nearly pure calcium carbonate.

The contact between the limestone of the Conasauga group and the dolomite of the Knox group is gradational from dolomitic limestone to dolomite containing stringers of limestone.

The Conasauga group underlies valleys between ridges formed by the Rome formation and the Knox group. The surfaces of these valleys are characteristically irregular, with many gullies and small hills. The most prominent topographic feature is the line of knobs on the northwestern sides of the valleys.

Residuum derived from shale in the Conasauga is generally thin. Weathering has penetrated to a depth of about 6 m (20 ft) in the layers where shale predominates, but the weathered part retains the appearance of the original rock except that most of the limestone has been removed. The residuum derived from the massive limestone is characteristically orange red and contains little or no chert.

The thickness of the Canasauga group is difficult to measure because of a number of minor folds and faults, but it is estimated to be 450 m (1500 ft) or more. The age of the Conasauga is Middle and Late Cambrian.

B.3 KNOX GROUP[1]

The Knox is composed primarily of massive, siliceous dolomite. The group can be divided into five formations on the basis of lithologic variations.

The general variation in lithology is from massive, dark gray, crystalline, very cherty dolomite at the base to generally less massively bedded, lighter gray, dense to finely crystalline, less cherty dolomite on the top. Thin beds of light gray, dense limestone are present in the upper part, and thin beds of relatively pure sandstone occur about 300 m (1000 ft) above the base of the group. Outcrops of the dolomite are not abundant because of the rapid weathering and deep soil cover; however, on the northwestern sides of ridges underlain by the group, erosion has removed the soil cover to an extent that outcrops are fairly common.

The amount and type of chert left by weathering varies from formation to formation within the group; and because outcrops of the dolomite are not abundant, residual chert is used as a basis for differentiating the group. Because of the varying amounts of chert retained in the residuum, the rate of erosion varies from formation to formation, producing a distinctive topography that is an aid in mapping.

The upper contact of the Knox group is disconformable; that is, it is a surface once exposed to erosion, then covered by sediments, with no significant variation between the dip and strike of the layers beneath the erosional surface and those above. The relief on this surface is rather high in some places. The Knox group–Chickamauga limestone contact is usually distinct because of the sharp contrast between the dolomite and the overlying basal beds of the Chickamauga; also, springs are common along or near the contact, especially in East Fork Valley.

The Knox weathers to form a deep residual mantle held in place by the abundant chert on the surface. The surface of the bedrock beneath the soil mantle is very irregular; outcrops generally represent the tops of pinnacles of bedrock projecting through the soil.

The Knox group underlies broad ridges generally having fairly gentle slopes on the southeastern side and steeper slopes on the northwestern side. Variation in resistance to erosion leads to the development of a saddle shape in profile when viewed parallel to the strike. The dolomite of the Knox is very soluble and caverns are common, some of which are large. Sinkholes are a persistent topographic feature of the group.

Fossils are not common in the Knox group, but small coiled gastropods were found in a limestone bed in the upper part of the group on the northern side of McKinney Ridge. The age of the Knox is Late Cambrian and Early Ordovician. The total thickness is about 900 m (3000 ft).

B.4 CHICKAMAUGA LIMESTONE[1]

The Chickamauga limestone underlies Bethel Valley, East Fork Valley, and a narrow belt northwest of Pine Ridge.

Lithologically, the Chickamauga is extremely variable, although the entire sequence is calcareous. In the two major valleys underlain by the formation, East Fork Valley, where a complete section is present, and Bethel Valley, where the upper 150 m (500 ft) or more have been faulted out, the stratigraphic succession of beds within the formation is dissimilar.

In East Fork Valley, the lowermost beds of the Chickamauga are composed of discontinuous thin layers of bentonite material; gray clay shale with obscure bedding; thin-bedded, maroon, calcareous siltstone up to 15 m (50 ft) thick; and gray, calcareous, micaceous siltstone. The lateral continuity of these basal beds is irregular, and in places this sequence is absent. Locally, the basal layers contain fragments of chert derived from the underlying Knox group. A sequence of limestone about 450 m (1500 ft) thick lies above these layers. The limestone is dominantly light to medium gray and bluish gray, dense to finely crystalline, shaly, and thin bedded, and contains variable amounts of chert. These layers usually contain fragmentary, small fossil brachiopods, bryozoans, corals, and crinoid stems. The character of these beds changes along the strike, and similar lithologies recur in various zones, making division into units difficult. Near the top of this limestone sequence are two bentonite beds which lie about 15 m (50 ft) apart stratigraphically. Above the upper bentonite is a 12-m (40-ft) sequence of yellow and maroon, calcareous siltstone beds, at the top of which is an apparently small disconformity. Bluish gray limestone, which is coarsely crystalline, extremely fossiliferous, relatively pure, and more massively bedded than the underlying limestones, lies above the disconformity. Unlike the layers of shaly limestone below, this lithology is relatively homogeneous along the strike.

The coarsely crystalline limestone grades upward into the Reedsville shale, a calcareous, tan to orange-brown, fissile, thin-bedded, fossiliferous shale, which is the uppermost unit of the Chickamauga limestone. This unit is 60 to 75 m (200 to 250 ft) thick.

In Bethel Valley, lithologic differences within the formation are more distinct, and the stratigraphic sequence is more easily defined than in other parts of the area. The residual mantle is generally thinner, and outcrops of the beds are more common than in East Fork Valley. Also, the beds are persistent in character along strike, and each unit has more distinguishing features. The Chickamauga in Bethel Valley can be divided into at least eight units.[2] Three of these units consist of redbeds: one about 35 m (120 ft) above the base, another near the middle of the formation, and another at or near the top. These redbeds apparently are not represented in East Fork Valley, although the thin, discontinuous redbeds at the base of the formation in this belt may corresp d to the lower redbeds of Bethel Valley.

In other respects, the beds of gray, shaly limestone in Bethel Valley are similar to those of East Fork Valley in color, bedding characteristics, and chert and fossil content.

In East Fork Valley, the Chickamauga limestone–Sequatchie formation contact is placed below the lowest occurrence of maroon, calcareous siltstone. Generally, the contact is covered by residuum and has to be approximated (in most areas).

The soil produced by weathering of the Chickamauga typically consists of yellow, light reddish orange, or red clay containing variable amounts of chert. Chert is abundant enough in the lower layers to cause development of a line of low hills on the northwestern sides of the valleys. This is more pronounced in Bethel Valley, where the basal material is composed of alternating siltstone beds and beds of blocky chert.

The surfaces of the valleys underlain by the formation are irregular; the more silty and cherty layers underlie low ridges and hills. Sinkholes are present, but these are not as numerous or as large as those in the Knox group.

Fossils, including brachiopods, bryozoans, gastropods, cephalopods, crinoid stems, corals, and trilobites, are common throughout the formation.

The age of the Chickamauga limestone is Middle and Upper Ordovician. The boundary between Middle and Upper Ordovician rocks in this area is drawn at the base of the Reedsville shale. The thickness of the Chickamauga in East Fork Valley is about 730 m (2400 ft) and in Bethel Valley, about 530 m (1750 ft).

REFERENCES FOR APPENDIX B

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Table B.1. Annotated list of earthquakes that have affected the Oak Ridge Reservation or the eastern Tennessee vicinity

Date	Geodetic coordinates °N	Geodetic coordinates °W	Epicenter area	Maximum MM intensity at epicenter	Estimated MM intensity at Oak Ridge	Notes
1811, Dec 16	36.5	89.6	New Madrid, Mo.	XII	V–VI	Strongest shocks of a great series collectively known as the New Madrid Earthquake. Topographic changes effected over an area of 3000 to 5000 sq mile in Mississippi Valley.
1812, Jan 23	36.6	89.6	New Madrid, Mo.	XII	V–VI	
Feb. 7	36.6	89.6	New Madrid, Mo.	XII	V–VI	
1843, Jan. 4	35.2	90.0	Western Tennessee	VIII	III–IV	Shock felt over 12 states, including the entire Tennessee Valley.
1844, Nov 28	36.0	84.0	Knoxville, Tenn.	VI	V	25 mi from Oak Ridge area
1861, Aug. 31	36.6	78.5	Virginia	VI	III–IV	Described as "heavy shock" in the Oak Ridge area.
1886, Aug. 31	32.9	80.0	Charleston, S.C.	IX–X	V–VI	The Great Charleston Earthquake felt over the entire eastern U.S.
1895, Oct. 31	37.0	89.4	Charleston, Mo.	XI	III–IV	Shock felt over 23 states, including the entire Tennessee Valley.
1897, May 31	37.3	80.7	Giles County, Va.	VII	III–IV	Shock felt throughout east Tennessee. Heaviest shock in historic time in southern Appalachia.
1902, May 29	35.1	85.3	Chattanooga, Tenn.	V	?	Not reported to have been felt in the Oak Ridge area.
Oct. 18	35.0	85.3	Chattanooga, Tenn.	V	?	Not reported to have been felt in the Oak Ridge area.
1904, Mar. 4	35.7	83.5	Maryville, Tenn.	V	II–III	Low intensity except at epicenter.
1905, Jan. 27	34.0	86.0	Gadsden, Ala.	VII	II	Large "felt" area, but probably very low intensity shock.
1913, Mar 28	36.2	83.7	Strawberry Plains, Tenn.	VII	V–VI	One of the strongest shocks in southern Appalachia.
Apr. 17	35.3	84.2	Ducktown, Tenn.	V	?	Not reported to have been felt in the Oak Ridge area.
1914, Jan 23	35.3	84.2	Southeastern Tennessee	V	?	Only felt reports are from the epicenter, so probably local.
1916, Feb. 21	35.5	82.5	Asheville, N.C.	VI	III–IV	Felt over whole state of Tennessee, especially mountains of east Tennessee
Oct. 18	33.5	86.2	Easonville, Ala.	VII	III	Felt over seven state area, but only light shock in Oak Ridge
1918, June 21	36.0	84.1	Lenoir City, Tenn.	V	IV	15 mi from Oak Ridge area
1920, Dec. 11	36.9	85.0	Rockwood, Tenn.	V	III	35 mi from Oak Ridge area
1921, Dec. 15	35.8	84.6	Kingston, Tenn.	V	III–IV	Shock of "considerable intensity" only 15 mi from Oak Ridge area.
1924, Oct 20	35.0	82.6	Pickens County, S.C.	V	II	Large felt area, but little effect in eastern Tennessee.
1927, Oct 8	35.0	85.3	Chattanooga, Tenn.	IV–V	II	Not reported to have been felt in the Oak Ridge area
1928, Nov 2	35.8	82.8	Madison County, N.C.	VII	III	Large felt area, including all of eastern Tennessee.
1930, Aug. 30	35.9	84.4	Kingston, Tenn	V	V	5 mi northwest of Oak Ridge Reservation
1938, Mar. 31	35.6	83.6	Little Tennessee River Basin	III	I–III	Centered in mountains and felt widely in eastern Tennessee
1940, Oct. 19	35.0	85.0	Chattanooga, Tenn.	V	?	Not reported to have been felt in the Oak Ridge area
1941, Sept 8	35.0	85.3	Chattanooga, Tenn	IV–V	?	Not reported to have been felt in the Oak Ridge area
1945, June 14	35.0	84.5	Cleveland, Tenn.	V	II	Felt area over southeast Tennessee and northwest Georgia

Table B.1. Annotated list of earthquakes that have affected the Oak Ridge Reservation or the eastern Tennessee vicinity (continued)

Date	Geodetic coordinates °N	Geodetic coordinates °W	Epicenter area	Maximum MM intensity at epicenter	Estimated MM intensity at Oak Ridge	Notes
1946, Apr. 6	35.2	84.9	Cleveland, Tenn.	III	?	No reports of shock outside of the city.
1947, Dec. 27	35.0	85.3	Chattanooga, Tenn.	IV	?	Not reported to have been felt in the Oak Ridge area.
1954, Jan. 1	36.6	83.7	Knoxville, Tenn.	V–VI	IV–V	Large shock area including all of eastern Tennessee; no damage at Oak Ridge.
Jan. 22	35.4	84.4	McMinn County, Tenn.	V	?	No reports of shock outside of the county.
1956, Sept. 7	35.5	84.0	Corbin, Ky.	VI	IV–V	Two shocks, 14 min apart, felt over most of southern Appalachia.
1957, June 23	35.9	84.3	Knox County, Tenn.	V	IV	5 mi from Oak Ridge area.
1959, June 12	35.3	84.3	Tellico Plains, Tenn.	IV	II–III	Widely felt over eastern Tennessee and western North Carolina.
1960, Apr. 15	35.8	83.9	Knoxville, Tenn.	V	IV	20 mi from Oak Ridge area.
1968, Nov. 9	38.0	88.5	Southern Illinois	VII	II–III	Felt over 400,000-sq mile area including [illegible] states and areas of Canada
1969, July 3	36.1	83.7	Knoxville, Tenn.	V	III–IV	30 mi from Oak Ridge area.
Nov. 19	37.4	81.6	Southern West Virginia	VI	II–III	Large felt area but small intensity.
1971, July 12	35.9	84.3	Knoxville–Oak Ridge, Tenn.	III–IV	III–IV	Shock felt with full intensity in Oak Ridge area; no personal injuries or property damage reported.
1973, Oct. 5	35.5	83.7	Maryville, Tenn.	IV–V	III–IV	25 mi from Oak Ridge area.
Nov. 3	35.5	83.7	Maryville, Tenn.	V–VI	IV–V	75 mi from Oak Ridge area.
1975, Feb. 10	36.1	83.6	Knoxville, Tenn.	?	?	Not reported to be felt in Oak Ridge, 60 mi from Oak Ridge
May 2	36.07	84.41	Roane Co., Tenn.	?	III	10 mi from Oak Ridge area.

Sources

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"Part I (1699–1850)," *J. Tenn. Acad. Sci.* 29(3): 224–233 (1954)
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"Part III (1901–1925)," *J. Tenn. Acad. Sci.* 32(2): 91–105 (1957)
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2. Project Management Corporation, *Preliminary Information on Clinch River Site for LMFBR Demonstration Plant*, Aug. 23, 1972, pp. 73–82.

3. The following publications of the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service (formerly, U.S. Coast and Geodetic Survey),

a. *United States Earthquakes, 1928–1935* (collected annual reports), No. COM-73-11456 (Reprint).
b. *United States Earthquakes, 1936–1940* (collected annual reports), No. COM-73-11457 (Reprint).
c. *United States Earthquakes, 1941–1945* (collected annual reports), No. COM-73-11447 (Reprint).
d. *United States Earthquakes, 1946–1972* (individual annual reports).
e. *Preliminary Determination of Epicenters, 1972* (monthly listing).
f. *Earthquake History of the United States*, Publication 41-1 (Revised through 1970), Washington, D.C., 1973, pp. 21–58.

Table B.2. Characteristics of the soil series on the Oak Ridge Reservation

Soil series	Brief profile description	Physiographic position	Soil drainage	Slope range (%)	Parent material
Bland	Reddish-brown silt loam surface, underlain by weak-red silty clay at 8 in. Weathered bedrock is at 20 to 40 in. Class 1 rockiness is common over most areas. Very erodable; surface soil has been removed over much of the area by sheet erosion.	Upland	Well drained	5 to 60	Calcareous siltstone (muddy limestone). Chickamauga Unit Ochb
Bodine	Pale-brown very cherty silt loam surface underlain at 12 in. by strong-brown very cherty silty clay loam. Variegated yellow, brown, red, and gray very-cherty silt loam substratum occurs at 30 in. Depth to weathered cherty dolomitic limestone bedrock ranges from 6 to 20 ft, but cherty beds are common below a depth of 26 in. Occurs on the more cherty hill crests along Copper Ridge and Chestnut Ridge.	Upland	Excessively drained	5 to 60	Cherty dolomite or limestone Knox Dolomite Chickamauga Unit Ocha Chickamauga Unit Ochc
Claiborne	Dark-brown silt loam surface about 8 in. thick over a brown silty clay loam transition layer which grades into a yellowish-red silt or clay at 16 in. Small dark-stained chert fragments are generally present throughout the profile. Bedrock occurs at a depth of 10 to 40 ft.	Upland	Well drained	5 to 30	Dolomitic limestone
Colbert	Dark yellowish-brown silt loam surface over a very firm yellowish-brown clay. Weathered argillaceous limestone bedrock is at 24 to 48 in. Rock outcrops are common. Top soil usually removed from nonforested areas by sheet erosion.	Upland	Moderately drained	2 to 7	Argillaceous limestone Chickamauga limestone

Table F.2. Characteristics of the soil series on the Oak Ridge Reservation (continued)

Soil series	Brief profile description	Physiographic position	Soil drainage	Slope range (%)	Parent material
Dewey	Brown silt loam surface over red silty clay or clay subsoil. Profile is relatively cherty-free. Weathered bedrock is at 15 to 40 ft. Occurs intermittently along the broader, smoother, more chert-free ridge crests.	Upland	Well drained	3 to 30	Dolomite Knox Dolomite
Dunning	Dark grayish-brown silty clay loam surface which grades to a silty clay at 6 in. A very dark grayish-brown firm clay subsoil is at 12 in., which becomes mottled with depth. Extensive surface cracking occurs during dry summer months. Thickness of alluvium over limestone rock ranges from 3 to 6 ft. Most extensive area is located along the northern base of Copper Ridge.	Depressions and narrow bottoms	Poorly drained	3	Local alluvium
Emory	Dark reddish-brown loam surface underlain at 14 in. by a weakly developed reddish-brown silty clay loam subsoil. Alluvial deposit is 4 to 10 ft. thick.	Narrow bottom, toe slopes, and depressions	Well drained	2 to 5	Local alluvium chiefly from limestone Knox Dolomite Chickamauga Limestone
Fullerton	Grayish-brown cherty silt loam over yellowish-red cherty silty clay or cherty clay underlain at 36 in. by red cherty silty clay variegated with yellowish-brown and strong brown. Depth to bedrock usually ranges from 8 to 25 ft.	Upland	Well drained to excessively drained	4 to 50	Cherty dolomite or limestone Chickamauga Unit Ochc
Greendale	Brown silt loam surface over yellowish-brown silt loam subsoil that becomes somewhat finer textured with depth, grading to a silty clay loam. Free of mottling to a depth of 30 in. or more.	Toe slopes, alluvial fans, and narrow drainageways	Well drained	2 to 5	Local alluvium from cherty

Table B.2. Characteristics of the soil series on the Oak Ridge Reservation (continued)

Soil series	Brief profile description	Physiographic position	Soil drainage	Slope range (%)	Parent material
Hamblen	Brown silt loam that becomes slightly mottled at 15 in. and becoming progressively more mottled with depth. A mottled dark grayish-brown layer occurs at 24 in. Depth to bedrock varies from 4 to 20 ft. Sometimes called Hamblen in areas where the alluvium originates primarily from sandstone and shale areas.	Bottoms and local alluvium	Imperfectly to moderately well drained	0 to 3	General alluvium Local alluvium from mixture of sandstone, shale, and limestone
Hartsells	Yellowish-brown loam surface over yellowish-brown loam subsoil. Depth to weathered bedrock is generally 24 to 30 in. Occurs intermittently on the broader ridge crests on Haw Ridge.	Upland	Well drained	5 to 12	Medium-grained sandstone Rome Formation
Jefferson	Yellowish-brown loam surface over yellowish-brown or brownish-yellow moderately friable clay loam subsoil that becomes slightly mottled with yellow and gray at 36 in. Depth of the colluvial deposit ranges from 3.5 to 8 ft. deposit is underlain by shale or sandstone residuum.	Foot slopes and colluvial benches	Well drained	4 to 30	Colluvium from sandstone Rome Formation
Landisburg	Light yellowish-brown silt loam over yellowish-brown silty clay loam subsoil. Fragipan layer at 28 in. Depth of the colluvial deposit varies from 3 to 10 ft. and is underlain by cherty dolomitic limestone residuum. Developed in soil deposits transported from cherty Fullerton and Clarksville soils.	Foot slopes and colluvial benches	Moderately well drained	2 to 12	Colluvium from cherty dolomite and limestone

Table B.2. Characteristics of the soil series on the Oak Ridge Reservation (continued)

Soil series	Brief profile description	Physiographic position	Soil drainage	Slope range (%)	Parent material
Leadvale	Grayish-brown silt loam surface over yellowish-brown silty clay loam subsoil. Fragipan at 24 in. Colluvial deposit is generally 2.5 to 5 ft. thick and is underlain by shale residuum. Developed in soil deposits transported from Sitz and Sequoia soils.	Foot slopes and colluvial benches	Moderately well drained	3 to 12	Colluvium and local alluvium from acid shale Conasauga Shale Chickamauga Unit Ochb
Lehew	Weak-red loam surface underlain at 8 in. by weak-red shaly loam substratum. Weathered bedrock is 20 to 40 in. deep. The weak-red color is not uniform, many brownish-yellow bands are interwoven.	Upland	Excessively drained	5 to 60	Interbedded sandy shale and siltstone
Litz	Yellowish-brown silt loam surface over yellowish-red shaly silt clay loam or shaly silt clay loam subsoil. Weathered bedrock is at depths of about 12 to 24 in. Gully-erosion common in areas that had been cultivated prior to AEC purchase.	Upland	Well drained to excessively drained	5 to 30	Acid shale Consauga Shale Units Ecb and Ece Chickamauga Unit Ocha
Minvale	Brown to dark yellowish-brown silt loam surface over yellowish-red silty clay subsoil. Depth of colluvial deposit varies from 3 to 8 ft, generally underlain by dolomitic limestone residuum. Develops in colluvial material generally transported from Fullerton Upland soils.	Foot slopes and colluvial benches	Well drained	4 to 20	Colluvium from cherty dolomite and limestone Chickamauga Unit Ocha
Montevallo	Dark grayish-brown silt loam surface underlain at 6 in by brown silt loam soil material mixed with grayish colored shale fragments. Soil depth is 10 to 20 in.	Upland	Well drained	5 to 30	Fissle shale Conasauga Unit Ece

Table B.2. Characteristics of the soil series on the Oak Ridge Reservation (continued)

Soil series	Brief profile description	Physiographic position	Soil drainage	Slope range (%)	Parent material
Muse	Yellowish-brown silt loam surface over strong brown silty clay loam or silty clay subsoil. Depth to colluvial deposit varies from 2.5 to 6 ft. and is underlain by acid shale residuum.	Foot slopes	Well drained	3 to 20	Colluvium from acid shale
Muskingum	Yellowish-brown or brown silt loam surface underlain at 9 in. by brownish-yellow silt loam subsoil. Depth to shale bedrock is 20 to 40 in. Class-2 and Class-3 rockiness are common.	Upland	Excessively drained	8 to 75	Shale or siltstone Rome Formation
Newark	Dark grayish-brown silt loam surface over gleyed subsurface layers that become finer textured with depth. The grayish-brown subsurface layers are mottled with yellow and brown. Water table generally is within 2 ft of the surface. Depth of bedrock is generally greater than 5 ft. Occurs primarily in Whiteoak Creek flood plain. Sometimes called Prader in areas where alluvium originates primarily from sandstone and shale soils.	Bottom	Poorly drained	0 to 2	General alluvium from mixture of sandstone, shale, and limestone
Sensabaugh	Brown friable fine sandy loam surface that grades into a yellowish-brown very friable loam at 12 in. Free of mottling to a depth of 30 in or more. Alluvial deposit varies from 2.5? to 6 ft. Depth of bedrock is seldom less than 5 ft.	Local alluvium along narrow drainageways	Well drained	2 to 5	Local alluvium from sandstone

Table B.2. Characteristics of the soil series on the Oak Ridge Reservation (continued)

Soil series	Brief profile description	Physiographic position	Soil drainage	Slope range (%)	Parent material
Sequoia	Brown silt loam or silty clay loam surface over yellowish-red silty clay subsoil that grades into yellowish-red shaly silty clay at 20 to 22 in. Weathered shale bedrock generally occurs at 20 to 40 in. usually occurs on the broader smoother hill tops.	Upland	Well drained	3 to 12	Yellowish-red acid shale Consauga Unit Ecb Chickamauga Unit Ochh
Talbott	Brown silty clay loam over yellowish-red very firm clay subsoil that grades into a yellowish-red clay, mottled with yellow and brown at 25 in. Depth to weathered bedrock ranges from 3 to 5 ft. Occurs on relatively chert-free units in areas where rock outcrops are less common.	Upland	Well drained	3 to 20	Argillaceous limestone Chickamauga limestone

Sources:

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APPENDIX C

GROUNDWATER QUALITY AT SELECTED SITES IN ANDERSON AND ROANE COUNTIES

Table C.1. Groundwater quality data observed in Anderson and Roane counties near ORNL site

Station No.[a]	3610170-84205600	3611550-84021600	3544520-84394500	3552250-84263000
Date of sample	5/23/77	5/16/77	6/3/77	5/24/77
Specific conductance, micromhos	340	575	375	400
pH, standard units	7.7	7.2	7.5	7.8
Temperature, °C	17.0	17.0	17.0	16.0
Color, platinum cobalt units	0	0	0	0
Turbidity, JTU	2	25	2	1
Hardness (Ca, Mg), mg/L	64	320	150	140
Noncarbonate hardness, mg/L	0	8	0	0
Dissolved calcium (Ca), mg/L	19	90	51	43
Dissolved magnesium (Mg), mg/L	3.9	23	5.9	7.9
Dissolved sodium (Na), mg/L	60	6.5	14	29
Percent sodium	67	4	17	31
Sodium adsorption ratio	3.3	0.2	0.5	1.1
Dissolved potassium (K), mg/L	1.6	2.6	1.7	2.7
Bicarbonate (HCO_3), mg/L	210	380	200	230
Carbonate (CO_3), mg/L	0	0	0	0
Alkalinity ($CaCO_3$), mg/L	170	310	160	190
Carbon dioxide (CO_2), mg/L	6.7	38	10	5.8
Dissolved sulfate (SO_4), mg/L	0.6	0.4	5.0	6.3
Dissolved chloride (Cl), mg/L	13	13	4.2	7.9
Dissolved fluoride (F), mg/L	0.2	0.3	0.0	0.1

Table C.1. Groundwater quality data observed in Anderson and Roane counties near ORNL site (continued)

Station No.[a]	3610170-84205600	3611550-84021600	3544520-84394500	3552250-84263000
Dissolved silica (SiO_2), mg/L	17	10	17	16
Dissolved solids (residue at 180°C), mg/L	210	334	208	211
Dissolved solids (sum of constituents), mg/L	219	336	197	226
Total nitrate (N), mg/L	0.0	0.0	1.1	0.24
Total nitrite (N), mg/L	0.05	0.0	0.0	0.0
Total phosphorus (P), mg/L	0.19	0.01	0.02	0.0
Total phosphorus (PO_4), mg/L	0.58	0.03	0.06	0.0
Dissolved iron (Fe), mg/L	310	2400	10	10
Dissolved manganese (Mn), mg/L	80	860	0	10
Total organic carbon (C), mg/L	3.2	6.8	5.6	2.8

[a]The 15-digit station number identifies the latitude and longitude of the sampling location.

Source: U.S. Dept. of Interior, Water Resources Data for Tennessee Water Year 1977, U.S. Geological Survey Water-Data Report TN-77-1, 1978.

Table C.2. Results of chemical and physical tests of groundwater quality at the Clinch River Breeder Reactor site[a]

Sample[b]	B-1	B-27	B-27	B-29	B-37	B-37	B-41	A	B	C	D	E	F	G	H
pH, standard units	7.3	7.9	8.7	7.2	7.1	7.1	7.1	8.0	8.1	8.2	8.3	8.5	8.2	8.7	4.9
Conductivity, microsiemens	300	450	500	475	475	550	375	300	230	168	217	349	205	334	240
Silica (SiO_2)	1.6	1.7	1.7	1.7	1.8	2.0	1.5								
Iron (Fe)	0.28	0.92	0.46	1.1	1.0	1.5	0.52	0.07	0.21	0.12	0.24	0.13	0.09	0.14	9.5
Total hardness as $CaCO_3$	232	88	32	130	308	314	178	167	121	95	119	199	109	188	46
Calcium (Ca)	48	22	7	36	53	62	50	58	41		28	64	38	39	10
Magnesium (Mg)	27.2	7.8	3.4	9.7	42.8	38.9	13.1	5.4	4.6		12.0	9.5	3.5	22.0	5.1
Sodium (Na)	9	80	90	100	14	21	28								
Potassium (K)	2	10	10	5	6	9	4								
Bicarbonate (HCO_3)	173	363	280	385	385	468	261	179	135	114	136	20[illegible]	132	192	
Carbonate (CO_3)			43									8		12	
Sulfate (SO_4)	5.1	9.7	3.8	4.1	3.6	2.8	4.6	4	15	8	10	3	2	5	26
Chloride (Cl)	7.9	13.9	15.9	9.9	7.9	7.9	17.9	6.8	5.2	1.5	2.0	6.8	2.0	3.2	17.0
Fluoride (F)		1.74	1.74		0.26		0.52							0.1	
Nitrate (N)	0.85	1.4	0.70	0.8	1.4	1.1	0.73	9.1	3.3	1.2					
Turbidity, JTU	26	55	28	81	52	110	27								
Total dissolved solids	301	564	490	512	421	497	328								

[a]All results in mg/L except pH, conductivity and turbidity.

[b]Samples were obtained from observation wells located in the Clinch River Breeder Reactor area about 6.4 km (4 mi) west of ORNL.

Source: Clinch River Breeder Reactor Plant Environmental Report, vol. 1, Table 2.5-20, Docket No. 50-537, Project Management Corporation, April 1975.

Table C.3. Chemical analyses of water from auger wells in solid waste disposal areas (mg/L)

Composite sample No.	Date of collection	Well No.	SiO_2	Al	Fe	Li	Mn	Sr	Ca	Cu	Mg	Zn	Na	B	K
1	Dec.19, 1958	138,139,152,157	8.6	0.0	0.07	0.1	1.2	0.1	68	0.0	5.5	1.0	2.1	0.0	0.8
2	Dec.17, 195[illegible]	132,133,145,135 137	8.4	0.1	0.00	0.2	0.22	0.1	89	0.0	12	0.5	4.0	0.0	1.1
3	Dec.18, 1958	147,148,149,150	9.4	0.2	0.01	0.2	2.0	0.1	88	0.0	8.2	0.5	4.4	0.0	0.8
4	Jan.15, 1959	158,169,160,161	8.3	0.0	0.45	0.2	0.22	0.1	82	0.0	6.4	0.5	3.5	0.0	0.8
5	Dec.30, 1958	127,130	9.1	0.1	0.88	0.2	0.22	0.1	69	0.0	7.5	0.5	4.0	0.0	0.7

Composite sample No.	Pb	Cr	$CO_3^{=}$	HCO_3^-	$SO_4^{=}$	Cl^-	F^-	NO_3^-	$PO_4^{\equiv}$	Br^-	I^-	Total dissolved solids	Hardness as $CaCO_3$[a]	Color (Color units)	pH (pH units)	Specific conductance (μS at 25°C)
1	0.0	0.0	0.0	221	8.7	1.3	0.0	1.2	0.0	0.0	0.0	208	193	5	7.5	353
2	0.0	0.0	0.0	263	55.	1.9	0.2	2.1	0.0	0.0	0.0	305	272	5	7.7	491
3	0.0	0.0	0.0	306	10.	1.0	0.1	0.3	0.0	0.0	0.0	276	258	10	7.7	472
4	0.0	0.0	0.0	256	27.	1.8	0.2	1.4	0.0	0.0		263	239	5	7.4	429
5	0.0	0.0	0.0	227	15.	1.5	0.1	0.9	0.0	0.0	0.0	222	204	5	7.1	378

[a]Includes hardness of all polyvalent cations reported.
Source: K. E. Cowser, T. F. Lomenick, and W. M. McMaster, Status Report on Evaluation of Solid Waste Disposal at ORNL:I ORNL-3035, February 1961.

APPENDIX D

METEOROLOGICAL DATA (FOG DAYS, TEMPERATURE, PRECIPITATION, AND WIND) AND NOISE-LEVEL DATA IN THE OAK RIDGE, TENNESSEE, VICINITY

Table D.1. Average number of days with heavy fog at selected sites in the Oak Ridge, Tennessee vicinity[a] (by month)

Site	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Weather Service Office[b] (1/1/51–12/31/64)	1	1	1	1	2	2	3	4	4	8	6	2	34
Melton Hill Dam (1/13/64–10/31/76)	4	4	4	5	7	10	10	12	15	14	12	8	106
Bull Run Creek[c] (1/11/64–10/31/76)	2	2	1	1	4	3	7	9	8	8	6	3	54

[a]Heavy fog has been defined as fog which reduces horizontal visibility to: (1) 400 m (0.25 mile) or less at the weather service office and (2) 500 m (0.31 mile) or less at the Melton Hill and Bull Run sites.

[b]Oak Ridge.

[c]TVA steam plant.

Source: Exxon Nuclear Company, Inc., "Nuclear Fuel Recovery and Recycling Center Environmental Report," XN-FR-33, Rev. 0, Docket No. 50-564, December, 1976.

Table D.2. Temperature record (°C) for Oak Ridge, Tennessee (1947–1980)

Month	Mean daily maximum	Mean daily minimum	Monthly mean	Record maximum	Record minimum
January	8.4	-1.6	2.9	23.9	-22.8
February	10.2	-0.8	4.6	26.1	-17.2
March	14.8	2.4	8.8	29.4	-17.2
April	21.4	7.9	14.7	32.8	- 4.4
May	26.1	12.5	19.0	33.9	- 1.1
June	29.7	17.2	22.9	38.3	3.9
July	30.8	19.1	24.8	40.6	10.0
August	30.4	18.5	24.3	37.8	10.6
September	27.5	14.8	21.1	38.9	0.6
October	21.7	8.4	14.7	32.2	- 6.1
November	14.4	2.4	8.4	28.3	-17.8
December	9.1	-1.1	4.2	23.3	-19.4
Annual	20.3	8.3	14.2	40.6	-22.8

[a]Means based on record for period 1941–1970.

[b]To convert from degree Celsius (°C) to degree Fahrenheit (°F) see inside back cover.

Source: National Oceanic and Atmospheric Administration, "Local Climatic Data, 1980, Oak Ridge, Tennessee," U. S. Department of Commerce, 1981.

Table D.3. Precipitation record (cm) for Oak Ridge, Tennessee (1947–1980)

Month	Water equivalent				Snow, ice pellets	
	Mean	Maximum	Minimum	24-h maximum	Maximum	24-h maximum
January	14.07[a]	33.71	4.72	10.80	24.4	21.1
February	12.06	26.59	2.13	7.47	43.7	23.1
March	15.57	31.0[illegible]	5.41	12.04	53.3	30.5
April	10.87	24.66	2.24	15.85	0.8	0.8
May	10.77	26.49	2.03	11.20		
June	10.46	20.55	2.16	9.40		
July	13.74	48.95	3.94	12.47		
August	9.68	26.57	1.37	19.00		
September	9.19	23.11	1.04	8.71		
October	7.34	17.65	Trace	6.76	Trace	Trace
November	11.71	31.04	3.48	13.44	16.5	16.5
December	14.22	26.19	1.70	13.00	37.6	27.4
Annual	139.7	19[illegible].9	[illegible]5.07		108.0	

[a]Multiplier factors for converting International System of Units (SI) to English units are located on inside back cover.

Source: National Oceanic and Atmospheric Administration, "Local Climatic Data, 1980, Oak Ridge, Tennessee," U. S. Department of Commerce, 1981.

Table D.4. Wind record (m/s) for Oak Ridge, Tennessee

Month	Mean wind speed[a]	Prevailing direction[b]	Peak wind speed (gust)[c]
January	2.1[d]	SW	26
February	2.2	ENE	21
March	2.4	SW	21
April	2.5	SW	22
May	2.0	SW	21
June	1.9	SW	22
July	1.7	SW	22
August	1.7	E	24
September	1.7	[illegible]	17
October	1.6	E	17
November	1.8	E	20
December	2.0	SW	22
Annual	2.0	SW	26

[a]Sixteen-year record through 1964.

[b]Thirteen-year record.

[c]Twenty two-year record through September 1979.

[d]Multiplier factors for converting International System of Units (SI) to English units are located on inside of back cover.

Source: National Oceanic and Atmospheric Administration, "Local Climatic Data, 1980, Oak Ridge, Tennessee," U. S. Department of Commerce, 1981.

Table D.5. Ambient noise levels [dB(A)], Bethel Valley Road,[a] during morning commuter traffic volume peak, March 3, 1982[b]

Time (EST)	Distance (km)[c] 0.0	0.8	1.6	2.4	3.2	4.0	4.8	5.6	6.4	7.2	8.0	8.9	9.7
0715	70/70[d]												
0720		75/85											
0730			90/100										
0735				100/105									
0740					100/105								
0745						100/110							
0750							100/110						
0752								100/110					
0755									100/105				
0800										80/90			
0802											80/90		
0807												80/90	
0810													70/85

[a]Located on ORR in both Anderson and Roane counties, Tennessee.
[b]Ambient temperature = 5.6°C, atmospheric pressure = 98.5 kPa.
[c]Distance eastward from Main Portal of ORNL toward the Comparative Animal Research Laboratory.
[d]Low/high values represent the range of sound levels measured at height of 1 m and distance of 1 m from edge of pavement.

Source: H. Hubbard, Industrial Safety and Applied Health Physics Division, ORNL, personal communication to D. N. Secora, Energy Division, ORNL, August 6, 1982.

Table D.6. Ambient noise levels [dB(A)], Bethel Valley Road,[a] during afternoon commuter traffic volume peak, March 3, 1981[b]

Time (EST)	Distance (km)[c] 0.0	0.8	1.6	2.4	3.2	4.0	4.8	5.6	6.4	7.2	8.0	8.9	9.7
1[illegible]													75/80[d]
1615												75/85	
1620											80/[illegible]		
1625										80/95			
1630									80/95				
1635								80/90					
1640							75/85						
1645						75/80							
1650					75/80								
1652				70/75									
1700			65/75										
1705		70/80											
1710	75/85[d]												

[a]Located on ORR in both Anderson and Roane counties, Tennessee.
[b]Ambient temperature = 10.6°C, atmospheric pressure = 98.9 kPa.
[c]Distance eastward from Main Portal of ORNL toward the Comparative Animal Research Laboratory.
[d]Low/high values represent the range of sound levels measured at height of 1 m and distance of 1 m from edge of pavement.

Source: H. Hubbard, Industrial Safety and Applied Health Physics Division, ORNL, personal communication to D. N. Secora, Energy Division, ORNL, August 6, 1982.

Appendix E

DRAFT DOE ORDER 5820 ON LOW-LEVEL RADIOACTIVE WASTE MANAGEMENT (Formerly *AEC Manual*, Chap. 0511)

E.1 PERFORMANCE OBJECTIVES

The performance objective is to ensure that the low-level waste management system for U.S. Department of Energy (DOE) sites is established and maintained in a manner that protects the site workers and the public. A health and safety performance requirement is that the annual dose from radionuclides shall not exceed limits established by the Environmental Protection Agency.

E.2 SITE SELECTION

1. General Geological Considerations
   a. The disposal site shall be located where geologic hazards will not jeopardize performance objectives.
2. Projected Size
   a. The disposal site shall be of sufficient area and depth to accommodate the projected volume of waste, an administrative area, and a three-dimensional buffer zone of sufficient size to allow unrestricted human use beyond its boundary.
3. Location of Burial Zone
   a. The disposal site shall allow waste to be buried either completely above or below the transition between the unsaturated and saturated zones.
4. Flooding
   a. The disposal site shall be located where flooding will not jeopardize performance predictions.
5. Erosion
   a. The disposal site shall be located where erosion from wind and water will not jeopardize performance predictions.
6. Subsurface Hydrology
   a. The disposal site shall be located where subsurface hydrology will not jeopardize performance predictions.
7. Earth Materials and Water Chemistry
   a. The disposal site shall be selected with consideration given to those characteristics of earth materials and water chemistry which favor increased residence times and/or attenuation of radionuclide concentrations.
8. Other Considerations
   a. The disposal site shall be selected with consideration given to current and projected population distributions.

b. The disposal site shall be selected with consideration given to current and projected land use and resource development.

c. The disposal site shall be selected (to the extent consistent with other criteria) with consideration given to location of waste generation, access to all-weather highways and rail routes, and access to utilities.

d. The disposal site shall be selected consistent with federal laws and regulations and shall not be located within areas that are protected from such use by federal laws and regulations.

E.3 SITE DESIGN

1. General

a. All engineering design and construction activities shall conform with established Engineering Standard Practices and with applicable federal codes and regulations.

b. For all disposal site activities (design, operations, closure), a quality assurance program as outlined in ANSI/ASMW NQA-1 shall be instituted and followed.

2. Site Characterization

a. Data obtained during site selection shall be evaluated, and that additional data necessary to design a disposal site shall be determined, acquired, and evaluated.

b. The site design shall be based on the volume and on the characteristics of the site selected such that during the required performance period of the site, contaminent releases will result in exposures lower than established federal limits.

3. Monitoring

a. A system that will monitor and verify site performance shall be designed and installed.

4. Receiving and Acceptance Area

a. The site design shall include a receiving and acceptance area for the purpose of inspecting and verifying waste receipts.

5. Site Transportation Routes

a. Roadways and/or railways within a disposal site shall be convenient to disposal excavations, shall allow for unrestricted flow of incoming and outgoing traffic, and shall be designed to support the maximum size and weight of vehicles and equipment expected.

b. Vehicular traffic over closed trenches which could jeopardize the integrity of the trench cap shall be avoided.

c. The parking area for site employees, visitors, etc., shall be located in an unrestricted area.

6. Waste-Handling and Treatment Facilities

a. Waste-handling and treatment facilities shall be located and designed for ease of handling waste and for minimization of (1) radiation exposure to personnel and (2) contamination of the disposal site.

7. Disposal Area

a. The disposal area shall be designed to minimize wind erosion and the effects of surface runoff water.

b. The disposal area shall be designed to enhance the natural physical characteristics of the area.

c. The disposal area and trenches shall be designed to minimize the migration of radionuclides.

d. Where required to meet performance objectives, trench covers shall be designed to minimize water infiltration and the contact time of water and waste.

e. A two-dimensional grid system shall be designed to locate all disposal excavations on a map of the disposal site which is referenced to a U.S. Geological Survey (USGS) or a National Geodetic Survey benchmark.

8. Disposal Unit Design

a. Disposal trenches shall be designed and constructed consistent with the site-specific hydrology, soil characteristics, and projected waste receipts such that performance objectives can be met.

9. Support System

a. An administrative facility shall be furnished that is adequate in size and design to provide for the projected needs of that disposal site.

b. Decontamination facilities for personnel, vehicles, and equipment shall be provided.

c. An equipment storage facility of adequate size shall be provided to accommodate projected storage needs.

d. Adequate fire suppression systems shall be provided for all structures and the disposal area.

e. Adequate utilities shall be provided as required.

f. A security system shall be provided that will inhibit unauthorized entry into the disposal site and unauthorized removal of material or equipment from the disposal site.

g. Where so indicated by projected waste receipts, a criticality alarm system shall be installed on the trench or trenches designed to accept such waste.

E.4 SITE OPERATION

1. General

a. It shall be the practice at each low-level waste disposal site that in all aspects of shallow land burial of low-level radioactive waste, good housekeeping and operating practices shall be employed.

b. It shall be the practice of each disposal site management to develop operating procedures that will ensure the health and safety of site personnel, the security of the site, and the protection of the surrounding environment.

c. It shall be the practice that those techniques and procedures that minimize the land area required for radioactive waste disposal shall be utilized to the extent that personnel health and safety and protection of the environment is not compromised (consistent with a cost/benefit analysis).

d. It shall be the practice to develop response plans for emergency conditions, both radiological and nonradiological, that could occur at a low-level waste disposal site. All responsible personnel shall be familiar with said emergency response plans, and the plans are to be tested on an annual frequency to ensure adequate response.

e. Prompt information on emergency events shall be reported to the responsible DOE field office. A list of names, addresses, and phone numbers (office and home) of all persons qualified and authorized to act as emergency coordinators for the site shall be prepared and shall be readily available at the disposal site. One person shall be named as primary coordinator, and the others shall be listed in the order in which they will assume responsibility as coordinator. The responding coordinator shall immediately take action to notify the responsible DOE field office of the emergency and to keep that office advised of developments as they occur.

f. Anomalous occurrences at the waste disposal site shall be reviewed, and corrective measures shall be implemented and documented as required.

g. It shall be the practice to assess disposal site operations and operating procedures continually. Recommendations, along with justifications for improvements, are to be made to the responsible management and are to be implemented after concurrence is received and funding is made available for such action.

h. It shall be the practice to conduct all disposal site operations in such a manner as to minimize the need for long-term control of that disposal site.

2. Administrative

a. Each DOE facility conducting low-level radioactive waste disposal shall have one designated individual who shall be responsible for all operations conducted at that site.

b. Each low-level waste disposal site manager shall establish an independent review system to review operating procedures and site operations.

c. Each low-level radioactive waste disposal site shall institute and maintain a safety assurance program as specified in DOE Order 5481.1, "Safety Analysis and Review System."

3. Site Operations

a. Each disposal site manager shall develop acceptance criteria for receipt of both onsite and offsite generated waste as necessary.

b. Low-level radioactive waste, as received at a disposal site, shall be subject to verification to ensure that said waste meets the requirements as established above. If any waste shipment fails to satisfy the waste receipts requirements as determined by receiving verification, appropriate actions shall be taken as developed in the safety documentation.

c. The location of all shallow land disposal sites shall be identified on the surface by permanent markers from which the boundaries of all disposal excavations can be located. The markers, along with the total area of the facility, shall be permanently recorded on a map of the area which is referenced to a USGS or a National Geodetic Survey benchmark.

d. The location of each waste shipment within at least a two-dimensional grid, along with its documentation information, shall be recorded in a manner that will allow permanent retrieval of the information.

e. To reduce the potential for criticality, limits on fissile materials shall be approved and documented for each low-level radioactive waste disposal site.

f. At least one person who has received site-approved first aid training shall be available on each working shift. Equipment and facilities for medical treatment shall be readily available at or near the disposal facility.

g. Based on site-specific needs, each site shall have and maintain the equipment that is necessary for proper and efficient site operations.

h. All personnel engaged in disposal site activities shall be monitored with appropriate equipment whenever leaving the disposal site area. All vehicles or equipment leaving a low-level waste disposal site area shall be monitored for radioactive contamination. If radioactive contamination is found on personnel or equipment, appropriate action is to be taken.

i. Acceptable contamination limits within a disposal facility shall be established and documented. Facilities and equipment not leaving the disposal site shall be surveyed on an established frequency consistent with the risk anticipated and shall be decontaminated as required.

j. The management of each DOE low-level waste disposal site shall institute a quality assurance program that will ensure full compliance with DOE directives and approved site-specific procedures.

k. All buildings, facilities, and equipment shall be kept in such condition as to ensure sound operations and a safe working environment.

l. Thermoluminescent dosimeter or equivalent packets shall be arrayed around the site perimeter at such spacing that any direct radiation will be detected.

m. All low-level radioactive waste disposal sites shall have the services of a radiological laboratory with capabilities for qualitative or quantitative analyses.

n. All activities at a low-level radioactive waste disposal site shall be conducted in such a manner as to reduce the potential for contamination of the site-monitoring system.

o. All low-level waste that could be readily dispersed by wind shall be contained to prevent dispersion.

p. Waste shall be handled, stored, and disposed in a manner that will prevent unfavorable reactions or interactions among the contents of the various waste packages.

q. Chelating agents and biodegradable waste shall be incinerated when practical to reduce to an insignificant level the potential for interaction of nuclides and the formation of unstable complexes that may increase the mobility of radionuclides.

r. The intrusion of animals or vegetation into the disposed waste shall be controlled.

s. Records shall be maintained of data obtained from all monitoring systems. These data shall be tabulated, analyzed, and presented in an annual environmental report as required by DOE Order 5484.1.

4. Site Maintenance

a. Disposal site features, such as drainage systems and disposal excavation caps, shall be inspected on an established frequency, and corrective action shall be taken when required.

b. When any airborne activity measurement at the site boundary is equal to or greater than the concentration guides for uncontrolled areas specified in DOE Order 5480.1, Chap. XI, "Requirements for Radiation Protection," the source of the activity is to be determined, and corrective action is to be taken.

c. When detectable levels of radiation or nonradioactive material over and above background levels are found to be migrating from the site, a study is to be initiated to determine the probable cause of such migration and to determine if corrective action is necessary.

5. Support

a. Shipment papers initiated by the generators shall accompany the waste during shipment and shall contain all data necessary for historical records.

b. Shipment paper data shall be submitted to the Waste Management Branch of DOE-ID for inclusion in the Solid Waste Information Management System, or other information system that may be developed in the future, for permanent storage or retrieval of such information.

c. Records shall be maintained at a central location and at the disposal facility. These records shall contain a description of the disposed waste and the location of the waste shipment within the disposal facility.

d. For incoming shipments from offsite generators, the disposal site manager shall receive notification of such shipments at least 5 d prior to its scheduled arrival.

e. Records of all waste receipts and all other significant activities shall be retained as specified in a site-established records retention system.

6. Generator Responsibilities

a. Each generator of low-level radioactive waste shall continually review those processes that generate low-level waste and shall determine and implement modifications or procedures that will reduce the amount of waste being generated.

b. Low-level radioactive waste shall be segregated, treated, and packaged in accordance with the waste acceptance criteria established at the site where that waste will be disposed.

E.5 SITE CLOSURE

1. Closure Plans

a. Prior to initiation of operations at a new site, or prior to closure at an existing site, a comprehensive closure plan shall be submitted to the responsible DOE field office for approval.

b. Monitoring data collected during operational and trench closure phases will be evaluated using predetermined assessment techniques and standards to determine if the site has performed as expected. If detrimental discrepancies are found, final site closure plans will be modified to correct them.

2. Quality Assurance

a. A quality assurance program will be established to cover all phases of closure activities.

3. Monitoring

a. A monitoring program shall be established that will provide the data needed to determine the degree of contaminant migration from the original disposal locations.

b. A monitoring program that assesses the effectiveness of trench closure shall be implemented concurrent with the operational phase site-monitoring program.

c. A program will be established that will analyze the monitoring data and, if needed, provide a mechanism for increased monitoring effort and implementation of appropriate remedial action.

4. Backfill and Cap

a. Following waste burial operations, all surface backfill material shall be compacted to a density equal to or greater than the surrounding undisturbed soil.

b. A trench cap shall be placed over the buried waste immediately after the trench has been filled and the substrate has been compacted. Where required, this trench cap shall then be covered with a layer of erosion-resistent material that will protect the cap from wind and water.

c. A cover system shall be designed and implemented for final site closure consistent with site design parameters. This cover shall be designed to minimize water infiltration, soil erosion, and penetration by burrowing animals and deep-rooted plants.

5. Soil Stabilization

a. A soil stabilization program shall be implemented that will retard the erosion rate of the site cap.

6. Contaminated Soil

a. Surface soil of the disposal site shall meet acceptable radioactive concentration standards by the end of the closure operation.

7. Equipment and Facilities

a. Equipment and facilities no longer needed shall be decontaminated and removed or appropriately disposed.

8. Drainage System

a. An integrated design shall be developed to transport all excess precipitation from the site rapidly.

b. When required, a drainage system shall be installed that will intercept hydrologic pathways that potentially could conduct water to the site and redirect the flow from the site.

9. Security and Safety

   a. A security program shall be implemented that is designed to detect and prevent unauthorized entry into the disposal site or unauthorized removal of material or equipment.

   b. A passive, permanent form of site security such as a long-lasting chain link fence equipped with appropriate warning signs shall be installed.

   c. Personnel participating in the closure operations shall be made familiar with radiological health and safety procedures that may be applicable to their occupation.

   d. Response plans shall be developed, and facilities and equipment shall be available to handle both radiological and nonradiological emergencies. All such plans shall be readily available at the disposal facility.

10. Records

   a. Periodic reports detailing the status of the closure effort shall be submitted to DOE. The report shall describe the closure operations and environmental monitoring data and shall discuss both significant accomplishments and problems encountered during the reporting period.

   b. Permanent records of the closure provisions shall be maintained concerning the type, amount, burial date, and location of waste deposited at the site. A copy of these records should be stored safely on or near the site. Duplicates should be stored at one or more locations.

E.6 SITE POSTCLOSURE

1. Monitoring

   a. Regular monitoring that can detect radionuclide migration shall be provided during the period of institutional control.

2. Site Surveillance

   a. Site surveillance shall be conducted on a regular basis to detect any problems that may result during site postclosure. Records of discrepancies and corrective actions shall be included in the annual report of site activities. Any required corrective maintenance shall be promptly performed.

   b. A quality assurance program shall be established to cover all phases of postclosure activities.

3. Response Mechanisms

   a. A response mechanism will be in a place that will facilitate appropriate remedial action if significant radionuclide movement is detected.

E.7 WASTE GENERATION REDUCTION EFFORTS

Each field office's waste management plan should include a comprehensive site-specific plan (for implementation in FY 1984) to reduce the volume of low-level and transuranic waste requiring storage and disposal. The plan should address methods for implementation including charging for part of the cost of waste storage or disposal to the waste generator, technical and administrative controls on waste generation and segregation, etc.

APPENDIX F
ECONOMIC EFFECTS OF ORNL OPERATIONS

F.1 INTRODUCTION

The total economic effects resulting from operation of Oak Ridge National Laboratory (ORNL) are substantially greater than those attributable to the direct cost of operation. Additional (i.e., secondary) effects can be estimated through a multiplier relationship: the ratio of total economic activity to direct operating expenditures. The direct effect, known as the final-demand change, represents the change introduced into the economy by ORNL expenditures. The secondary effect is the sum of the additional economic activity generated in the region by these expenditures.

Through ORNL operations the initial economic effect is represented by expenditures for (1) equipment and materials purchased from manufacturers and distributors and (2) labor. Local and nonlocal direct suppliers in turn purchase goods and services from secondary suppliers (e.g., wholesalers). The secondary suppliers in turn rely on other suppliers farther removed from ORNL. These successive rounds of interindustry purchases and sales are the secondary economic effects of ORNL activity.

The size of the local regional multiplier depends on the proportion of direct and indirect input requirements that can be supplied by the region's economy, which in turn depends on the specific needs of ORNL operations activities and the ability of the regional economy to competitively supply the inputs. Conceptually, therefore, the multiplier is different for every specific combination of ORNL activities and sites in the nation.

F.2 IMPACT REGION

The region selected for the evaluation of ORNL employment and procurement impacts during 1981 was the Knoxville Bureau of Economic Analysis (BEA) economic area. This area, comprising 24 counties, corresponds to the Knoxville Standard Metropolitan Statistical Area as well as to other counties tied to this economic center on the basis of journey-to-work patterns.[1] Total population (employment) in the Knoxville BEA economic area totalled 876,000 (266,000) in 1960, 905,000 (305,000) in 1970, and is expected to reach 1,073,000 (436,000) by 1985.[2]

F.3 COMPUTATION METHOD: LOCAL INDIRECT AND INDUCED EFFECTS

ORNL payroll disbursements and procurement within the Knoxville BEA economic area create significant (additional) indirect and induced impacts through input output linkages in the local economy. Thus, any methodology for assessing ORNL economic impacts must explicitly recognize interindustry effects. The input output methodology describes the flows of goods and services to markets and between industries in a region. Each industry in the economy has a particular set of inputs required to produce its output; these requirements generally differ from those of other industries. The input output model describes the structure of the economy and may be used to analyze the implications of the changes in one portion of the economic effects that are set off by the final-demand change. Implicit in this process is a multiplier that relates total change to a specific initial change.

Industry-specific gross-output multipliers that capture indirect and induced impacts (within an input output framework) are available for the Knoxville BEA economic area from the Regional Industrial Multiplier System (RIMS) and were employed in the assessment of ORNL economic impacts.[3] RIMS also provides a method for converting impacts measured by output changes into earnings (income) and employment impacts. Each industry from which ORNL purchases goods and services requires inputs that are converted to an output. For example, the manufacture of electric motors requires, as some of its inputs, copper, electricity, labor, and transportation. When the electric motors are completed (and become an output), they may be purchased by ORNL, or they may become inputs to others such as the copper industry and the electric appliance industry. Some of these suppliers and some consumers are located in the region of interest; others are not.

To RIMS, direct impacts such as ORNL expenditures for payroll and local procurement must first be stated in terms of final demands for locally produced goods and services (industry by industry). Because payroll and local procurement expenditures required different treatment in this respect, each will be discussed separately below.

F.4 LOCAL PAYROLL EXPENDITURES

During 1981, 4906 individuals were employed at ORNL (including ORNL operations at Y-12 and K-25) and received $128,153,000 in annual compensation.[4] These numbers represent the direct effect of ORNL employment on the Knoxville BEA economic area.

Combined direct, indirect, and induced-consumption effects of this same employment were determined as follows. First, the annual compensation figure above was deflated to 1967 dollars, the price basis of RIMS. Second, total personal consumption expenditures of ORNL employees were assumed to represent 77.7% of this total compensation.[5] Of this amount, 90% was estimated to be spent within the Knoxville BEA economic area, the impact region selected for the study.[6]

To determine the combined direct, indirect, and induced effects of this local consumption, RIMS requires that these expenditures be allocated as final demands across 56 local industrial sectors [defined by Standard Industrial Classification (SIC) codes]. This was accomplished by (1) determining the distribution of personal consumption expenditures across the 85 sectors of the 1972 national input output table, (2) aggregating these numbers to a distribution vector consistent with the 56 sectors of RIMS, and (3) multiplying (for each of these sectors) the total local personal consumption expenditures of ORNL employees by the product of that sector's location quotient and consumption share [from (2) above].[7]

The resulting final-demand vector was then used to calculate changes in local output and income (earnings) stemming from the local personal consumption expenditures of ORNL employees. These direct plus indirect plus induced effects are calculated industry by industry in RIMS and are then summed across sectors. The $57.3-million additional income effect of the $128.1 million ORNL payroll was obtained by inflating this latter income sum to 1981 dollars. The equivalent output effect of ORNL employee local consumption is equal to $177.6 million. Finally, the additional employment impact of ORNL employee spending (3,697 workers) was obtained from the equivalent earnings figure ($57,332,000) by multiplying this latter number by an appropriate employment/earnings ratio for the impact area.[8]

F.5 LOCAL PROCUREMENT EXPENDITURES

The effect of ORNL procurement (including ORNL operations at Y-12 and K-25) on income in the Knoxville BEA economic area was determined as follows. A listing of total materials (to include services) procurement by commodity type for calendar year 1981 was obtained for each ORNL buyer (buyer 3 through buyer 99). These procurement expenditures included both direct charges and stores expenditures. In addition, data were obtained on ORNL purchases of utility services during 1981. During 1981, total purchases were approximately $120,164,000 (consisting of $111,270,000 in materials and services procurement and $8,894,000 in utility purchases). Approximately 21.4% of materials and services procurement of ORNL buyers is purchased locally in the

Knoxville BEA economic area ($23,820,000). Based on a listing of utility purchases by ORNL for electricity, treated water, and natural gas, approximately $8,287,000 of locally produced utility services were purchased during 1981. Thus, the estimate of total ORNL procurement in the local area during 1981 was $32,107,000.

The total effect of local procurement expenditures on both local income and employment were determined as follows. First, 21% of the $32,107,000 in total local procurement was allocated to the wholesale and retail trade final-demand sector of RIMS as trade margin.[9] Second, purchases from all other local sectors were ascertained by (1) assigning commodity purchases of each buyer to RIMS sectors, (2) adjusting these purchases to reflect only that portion produced locally, and (3) deflating the resulting final demands to 1967 dollars.[10]

The resulting final-demand vector for ORNL procurement was then used to calculate direct plus indirect plus induced output and income (earnings) impacts similar to those determined above for ORNL payroll expenditures. In 1981 dollars, the direct plus indirect plus induced-income effect of ORNL local procurement is $27.2 million. This total income effect of local ORNL procurement was then allocated to direct and indirect plus induced components (i.e., $10.9 million and $16.3 million respectively).[11]

The associated output effect is equal to $78.9 million. Finally, the total employment impact on the Knoxville BEA economic area of ORNL procurement is equal to 1756 workers (702 + 1054), and was determined from the direct and additional (indirect plus induced) income effects in a manner similar to that described above for payroll expenditures.

F.6 IMPACTS BEYOND THE KNOXVILLE BEA ECONOMIC AREA

ORNL payroll expenditures affect areas outside the Knoxville BEA economic area in two ways. First, 10% of ORNL employee personal consumption expenditures was estimated to be spent in retail establishments outside the Knoxville area.[12] Second, of the $89.6 million assumed to be spent locally, only $73.3 million is produced locally.[13] Thus, $16.3 million of local consumption creates income and employment impacts outside the Knoxville economic area. When combined, $26.3 million of ORNL employee consumption leaves the region and creates income and employment impacts elsewhere. Based upon the direct and indirect plus induced income and employment patterns observed for the Knoxville economic area (Table 4.24), this $26.3 million creates $20.6 million of extra income and 1326 additional jobs in other areas of the United States (Table 4.25).

Of the $120.2 million of ORNL procurement expenditures, $32.1 million was spent within the Knoxville BEA economic area.[14] Thus, $88.1 million was spent outside the impact area and created significant income and employment impacts throughout the remainder of the United States. Based upon the implied multipliers for procurement in the Knoxville BEA economic area (Table 4.24), these expenditures result in $68.1 million in extra income and 4392 additional jobs.

REFERENCES FOR APPENDIX F

1. For a definition of BEA economic areas and a description of both their development and use for regional economic analyses, see R. J. Olsen, et al., *Multiregion: A Simulation-Forecasting Model of BEA Economic Area Population and Employment*, ORNL/RUS-25, Oak Ridge National Laboratory, Oak Ridge, Tenn., October 1977, Chap. 2.

2. These figures are from Henry W. Herzog, Jr., et al., *Long-Term Projections of Population and Employment for Regions of the United States*, ORNL/TM-7641, Oak Ridge National Laboratory, Oak Ridge, Tenn., August 1981, pp. 276–77.

3. See *Industry-Specific Gross Output Multipliers for BEA Economic Areas*, Regional Economic Analysis Division, Bureau of Economic Analysis, U.S. Dept. of Commerce, January 1977. The regionalization step in RIMS reconciles the technical requirements of each industry with the capacity of the region to supply the required inputs. The technical requirements are replaced by regional direct coefficients reflecting the actual purchases of inputs from suppliers within the study region. This step is accomplished with the use of the location quotient, which is a double ratio of the following form:

- industry employment in the study region/total employment in the study region
- industry employment in the nation/total employment in the nation.

County Business Patterns data are used to estimate these location quotients. If the location quotient for a given input is zero, no production is carried on in the region. Thus, all the required input must be imported, and the regional direct effect is zero. If the location quotient is equal to or greater than one, production in the region is assumed to be sufficient to supply the study industry, and the regional direct effect is equal to the national direct requirement. In cases where the location quotient is greater than zero but less than one, the region is assumed to supply some of the input requirement, the proportion being equal to the value of the location quotient.

4. 1981 payroll information is provided in Table 3.35.

5. This percentage represents the ratio of personal consumption expenditures to wage and salary disbursements at the national level in 1979. See Table 2.1, *Survey of Current Business*, Bureau of Economic Analysis, U.S. Department of Commerce, July 1981.

6. This percentage spent locally was based upon the location quotient for wholesale and retail trade in the Knoxville BEA economic area (0.90).

7. See Table A, *Survey of Current Business*, Bureau of Economic Analysis, U.S. Department of Commerce, February 1979. Additional information on the percent distribution of personal consumption expenditures for agricultural products was obtained from the 1972–1973 Consumer Expenditure Survey, Bureau of Labor Statistics, 1973. For sector 54 in RIMS, wholesale and retail trade, local final demand was set equal to that sector's consumption share (0.19) times the total local personal consumption expenditure of ORNL employees. This procedure is consistent with the treatment of trade margins in input-output-based models such as RIMS. Location quotients exceeding one were set equal to unity during these calculations.

8. The ratio of employment to earnings in 1978 for Tennessee was obtained from "Regional and State Projections of Income, Employment, and Population to the Year 2000," *Survey of Current Business*, Bureau of Economic Analysis, U.S. Department of Commerce, November 1980, Table 4.

9. This allocation was based on RIMs methodology for the treatment of trade margins. See RIMS, p. 12.

10. The adjustment was based on location quotients for the Knoxville BEA economic area. In addition, total demands for local goods and services were constrained not to exceed the total amount purchased locally ($32,107,000). Because this constraint was binding within our location quotient analysis, our estimate of the effects of local procurement should be interpreted as an upper bound.

11. See RIMS, pp. 15–16.

12. See reference six and the associated discussion in the text.

13. See reference seven and the associated discussion above relevant to local payroll expenditures.

14. See the section above on local procurement expenditures.

SYMBOLS AND CONVERSION FACTORS[a]

Prefix	Symbol	Multiplication Factor		
peta	P	1,000,000,000,000,000	=	10^{15}
tera	T	1,000,000,000,000	=	10^{12}
giga	G	1,000,000,000	=	10^{9}
mega	M	1,000,000	=	10^{6}
kilo	k	1,000	=	10^{3}
hecto	h	100	=	10^{2}
decka	da	10	=	10^{1}
deci	d	0.1	=	10^{-1}
centi	c	0.01	=	10^{-2}
milli	m	0.001	=	10^{-3}
micro	μ	0.000,001	=	10^{-6}
nano	n	0.000,000,001	=	10^{-9}
pico	p	0.000,000,000,001	=	10^{-12}
femto	f	0.000,000,000,000,001	=	10^{-15}

Quantity	Symbol	Quantity	Symbol	Quantity	Symbol
are	a	gallon	gal	pound	lb
becquerel	Bq	gram	g	pound/in.^{2}	psi
British thermal unit	Btu	gray	Gy	roentgen	R
coulomb	C	hour	h	roentgen absorbed dose	rad
curie	Ci	inch	in.	roentgen equivalent man	rem
day	d	joule	J	second	s
degree Celsius	°C	liter	L	siemens	S
degree Fahrenheit	°F	minute	min	sievert	Sv
foot	ft	meter	m		
		pascal	Pa		

To convert from	to	multiply by
	Length	
m	ft	3.281
cm	in.	0.3937
cm	ft	0.03281
km	mile	0.6215
	Area	
ha	acre	2.471
km^2	mile^2	0.3861
	Volume	
L	gal	0.2642
m^3	ft^3	35.31
	Mass	
kg	lb	2.205
tonnes, 1000 kg	ton, 2000 lb	1.102
	Rate	
L/s	gpm (gal per min)	15.85
m^3/s	cfm (ft^3 per min)	2.119×10^3
m^3/s	Mgd (million gal per day)	3.051×10^6
	Other	
Bq	Ci	2.703×10^{-11}
°C	°F	1.8 + 32
Gy	rad	100
kJ	Btu	0.9479
kPa	psi	0.1451
mC/kg	R	3.876
S	mho	1
Sv	rem	100

Exponential notation (example): 1.5E5 = 1.5×10^5.

[a] *ASTM Standard for Metric Practice*, E 380-79, American Society for Testing and Materials, Philadelphia, 1980.