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Buried TRU Wastes and TRU-Contaminated Soils at ORNL Remedial Action Program Sites: Program Strategy and Long-Range Planning

J. R. Trabalka

Environmental Sciences Division
Publication No. 2935

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OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
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REMEDIAL ACTION PROGRAM

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TRU WASTE PROGRAM
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The ORNL Remedial Action Program was created to meet new regulatory requirements and ensure adequate protection of human health and the environment by providing appropriate corrective measures at over 150 contaminated sites. Potentially 65 or more ORNL sites contain buried transuranic (TRU) wastes and/or TRU-contaminated soil resulting from waste disposal operations. These fall into 5 major categories: Low-Level-Waste (LLW) Lines and Leak Sites (28 sites); LLW Storage Tanks (24 sites); LLW Seepage Pits and Trenches (7 sites); New Hydrofracture Facility (NHF) (1 site); and Solid Waste Storage Areas (SWSAs) (5 sites). The NHF has been included pending resolution of concerns about its status as a greater-confinement-disposal operation.

The TRU-contaminated material varies considerably from site to site, consisting of soils, sludges, LLW system components, NHF grout sheets, and a wide variety of solid wastes. Information on waste inventories is incomplete or fragmentary; few historical records exist for the SWSAs, in particular. Significant uncertainty is also associated with TRU-waste burial locations in the SWSAs. At all sites, the radionuclide inventories are dominated by fission and activation products rather than by TRU nuclides. These factors significantly affect site stabilization strategies and costs. A potential approach to such problems at ORNL is to design for control and decay in situ of intermediate-lived fission and activation products (during a 100- to 300-year period of institutional control). This should provide a more-than-sufficient period for evaluation of the effectiveness of environmental processes and passive remedial measures in controlling the migration of the less-mobile transuranics, as well as the time needed for development of technologies for more permanent site stabilization.

The complexity of the ORNL situation (geohydrology, site and waste diversity), regulatory compliance requirements under the corrective action provisions of the Resource Conservation and Recovery Act, and the magnitude of potential resources needed for remedial measures (≥$1 billion) dictated that a strategy unique to ORNL conditions guide necessary actions and ensure efficient application of resources. This will involve an intensive 5-year series of remedial investigations and assessments oriented toward groupings of ORNL waste sites, followed by an integrative feasibility study to determine the scope of needed corrective actions. The long-term strategy is oriented very pragmatically toward the concepts of in situ stabilization and facility decontamination for reuse, wherever practicable.

1. INTRODUCTION

The Oak Ridge National Laboratory (ORNL), established in 1943 as part of the World War II Manhattan Project for nuclear weapons development, is located approximately 50 km west of Knoxville, Tennessee, in the south-central portion of the federally owned Oak Ridge Reservation, a 240-km^2 area which is principally controlled by the U. S. Department of Energy (DOE). The post-war role of ORNL quickly changed to development of civilian uses of nuclear materials and technologies and now encompasses a wide range of energy applications, most of which are nonnuclear in scope. A wide variety of liquid and solid radioactive wastes, generated on-site or received from other sites (for example, Mound Laboratory wastes containing significant quantities of ^{3}H), have been disposed during the 44-year existence of ORNL. The major ORNL sources of wastes (and, later, surplus facilities) were: Radioisotope production facilities; experimental reactors; hot cells and pilot plants (chemical separations and fuel reprocessing development); research laboratories (physical, chemical, and biological); accelerators; and analytical laboratories. Waste produced at sites other than Oak Ridge contributed a significant fraction of both the volume and the radionuclide inventory of solid waste buried in Solid Waste Storage Areas (SWSAs) 4 and 5 during the period from 1955 to 1963 in which these sites were designated as the Southern Regional Burial Ground by the Atomic Energy Commission [National Academy of Sciences (NAS) 1985].

Over 40 years of ORNL operations have produced a diverse legacy of contaminated surplus facilities, environmental research areas, and inactive waste disposal areas that are potential candidates for remedial action. The ORNL Remedial Action Program (RAP) represents a comprehensive effort to meet new regulatory requirements and ensure adequate protection of on-site workers, the public, and the environment by providing appropriate corrective measures at over 150 of these sites, which are contaminated with radioactive, mixed, or hazardous chemical wastes. A structured path of program planning, site characterization, continued site maintenance and surveillance, interim corrective action, alternatives assessment, technology development, engineering design, and eventual site closure or decommissioning is required to meet these objectives (Berry et al., in press; Trabalka and Myrick, in press).

The ultimate objective of site closure or decommissioning is to provide long-term containment of residual contaminants by placing each site into a permanently stabilized state, requiring only periodic monitoring and minimal maintenance to ensure proper performance in protecting human health and environment (Trabalka and Myrick, in press). Currently, however, this desirable goal may not be practicable for many contaminated sites (see Sect. 4.1), particularly those containing transuranic (TRU) wastes as defined in DOE Order 5820.2 (DOE 1984). Thus, important facets of the RAP involve the identification and characterization of sites where TRU wastes are currently buried, emplaced, or stored, followed by development of appropriate performance objectives and criteria and stabilization alternatives for these sites. The long-term strategy of the RAP has been very pragmatically oriented toward the concepts of in situ stabilization and facility decontamination for reuse, wherever practicable.

There are potentially 65 or more ORNL sites containing TRU-contaminated soil resulting from waste disposal operations and/or buried TRU wastes, grouped into 5 major categories: (I) Low-Level-Waste (LLW) Lines and Leak Sites; (II) LLW Storage Tanks; (III) LLW Seepage Pits and Trenches; (IV) New Hydrofracture Facility (NHF); and (V) Solid Waste Storage Areas (SWSAs). The LLW Lines and LLW Storage Tanks were a major part of the early liquid waste management system (that is, for transferring, collecting, and storing LLW liquids and sludges prior to disposal). Many of the components included in this category were taken out of service because of leakage and resulting soil contamination. In situ stabilization of TRU-waste residuals in the LLW Lines and the LLW Storage Tanks could be accomplished in conjunction with the stabilization of proximate TRU-contaminated soils--hence their inclusion here. The LLW Seepage Pits and Trenches were used for direct disposal of liquid wastes (and some sludges) into the ground, prior to development of the Hydrofracturing technique for direct waste injection into deep geologic formations (NAS 1985). This latter approach for liquid waste disposal has itself been abandoned (at least temporarily). The underground grout sheets beneath the NHF have been included (provisionally) because this site's earlier classification as a greater-confinement-disposal operation is currently in question (see Sect. 3.1). The SWSAs were used primarily for solid waste disposal (that is, shallow-land trench burials), but a portion of SWSA 5 has been devoted to aboveground and belowground retrievable storage (Bates 1983; Coobs and Gissel 1986). This report documents the current status of information on these ORNL TRU-contaminated sites and long-range planning by the RAP to meet the objectives outlined above.

2. REGULATORY INFLUENCES ON REMEDIAL ACTION PLANNING AND IMPLEMENTATION

2.1 IMPACT OF RCRA SECTION 3004(u) AT ORNL

From the inception of the RAP, the overall strategy followed the guidance given in the DOE Orders covering surplus facilities management (Order 5820.2; DOE 1984), the Comprehensive Environmental Response, Compensation, and Liability Act [CERCLA; Order 5480.14 (DOE 1985a)], and the National Environmental Policy Act (NEPA) because the Resource Conservation and Recovery Act (RCRA) was believed to apply only to a limited number of sites (that is, active surface impoundments). As part of this strategy, individual sites were being addressed according to estimated priorities for site characterization, remedial action, and decommissioning or closure planning. Integration of individual remedial actions was to be provided through a comprehensive site wide environmental assessment, leading to development of an environmental impact statement (EIS) for remedial actions in the entire White Oak Creek watershed. This primarily CERCLA- and NEPA-oriented approach formed the basis for both long-range and current-year planning (Bates et al. 1986), and had been presented to representatives from appropriate regulatory agencies (State of Tennessee and EPA-Region IV) for consideration.

However, in April 1986, the EPA expressed concern about the length of time required to implement the DOE Orders, and has subsequently elected to enforce regulatory requirements for remedial actions through its RCRA authority rather than its CERCLA authority (Trabalka and Myrick, in press). Under this authority, any new RCRA permit for a hazardous waste management unit (such as the new ORNL Hazardous Waste Storage Facility, Building 7652) must adhere to the corrective action requirements of the 1984 RCRA Amendments [Sect. 3004(u)]. Remedial actions will be required for <u>all</u> continuing releases of hazardous waste or constituents from <u>any</u> solid waste management unit, <u>regardless of when the waste was placed there.</u> Such units include tanks (and transfer lines), surface impoundments, waste piles, land-treatment units, landfills, underground injection wells, and certain spill sites. Most ORNL RAP sites and all of the TRU-contaminated sites potentially fall into these categories.

Proposed enforcement of the RCRA Sect. 3004(u) provisions involves a series of steps (Trabalka and Myrick, in press). The most significant of these are a Remedial Investigation [acronyms: RI(CERCLA) and RFI(RCRA); equivalent to Phase II in DOE Order 5480.14], followed by a Corrective Measures Study [CMS; corresponds to the Feasibility Study (FS) conducted under CERCLA and to Phase III in the DOE Order]. These provide the basis for determining the extent of contamination problems and the scope of needed corrective actions. This process begins with identification of sites either known to exhibit continuing releases or having the potential to do so.

The timing for the RI/FS sequence is not defined, but must be negotiated with EPA and State regulatory authorities through the RCRA permit application process. However, it was apparent from discussions and correspondence with regulatory authorities that the long-term scheduling proposed under the initial RAP strategy (or the DOE CERCLA Order) was unacceptable. Based on the requirements of RCRA Sect. 3004(u), a modified RAP implementation strategy has been developed (Sect. 5) that is responsive to regulatory concerns, yet is believed to be technically defensible in light of the complexity of the ORNL situation. Because of the large number of sites to be considered and the hydrogeologic complexity of the ORNL area, however, it became apparent that treating sites individually in the tightened regulatory framework would result in an unmanageable situation. Thus, the new strategy is oriented toward Waste Area Groupings (WAGs), as described below.

2.2 WASTE AREA GROUPINGS (WAGs)

Since a strong coupling generally exists between the shallow groundwater and surface drainage systems at ORNL (Hydrofracture injection zone excepted; see Sect. 3.1), it becomes important to group individual sites or aggregates of such units into discrete WAGs, based on observable surface drainage characteristics. The WAGs are generally defined by watersheds that contain contiguous and similar assemblages of operating facilities and remedial action sites, including waste management units. Under the WAG concept, ORNL sites can be placed within 20 such groupings (Fig. 2.1), 8 of which are believed to contain TRU-contaminated sites (Table 2.1). For example, WAG 7, LLW Pits and Trenches Area, containing inactive seepage pits, trenches, and associated waste transfer lines, is a collection of contiguous subdrainages that together contain similar wastes (Table 2.1).

2.2.1 Site and Regulatory Relationships

Table 2.1 identifies the subset of ORNL RAP sites that are known or potential TRU-contaminated locations, the WAGs developed for use in Remedial Investigations, and the current assessment of the regulations that are applicable to each site. The regulatory summary includes required actions under RCRA [units subject to requirements for active sites as well as those potentially governed by the corrective action provisions of Sect. 3004(u)]; the applicable DOE Orders that govern radioactive waste management, remedial actions, and decommissioning (5480.14 and 5820.2); and the Underground Injection Control (UIC) regulations of the Safe Drinking Water Act.

Rather than to enforce the provisions of CERCLA either at either radioactive-waste sites or mixed-waste sites (for the radioactive constituents), the administrator of EPA Region IV has instead chosen to invoke "omnibus" provisions of RCRA, Sects. 3005(c) and 3008(g), to include radioactive materials in the RI/FS process. Thus, the RAP is currently responding primarily to EPA RCRA and UIC regulations and to DOE Order 5820.2 in remedial action planning. However, because radionuclides appear to be the principal contaminants at ORNL sites, future regulation under a CERCLA program (or perhaps dual regulation under CERCLA and RCRA) seems highly probable, despite the current RCRA emphasis.

Also provided in Table 2.1 are modified Hazard Ranking System (mHRS) scores developed in 1986 in responding to the DOE CERCLA Order (5480.14). These scores are not available for all sites because many ORNL sites appear to be covered by DOE Order 5820.2 or by RCRA regulations. All of the sites listed in Table 2.1 are currently covered by RCRA Section 3004(u) requirements. Although the mHRS scores in Table 2.1 permit rough

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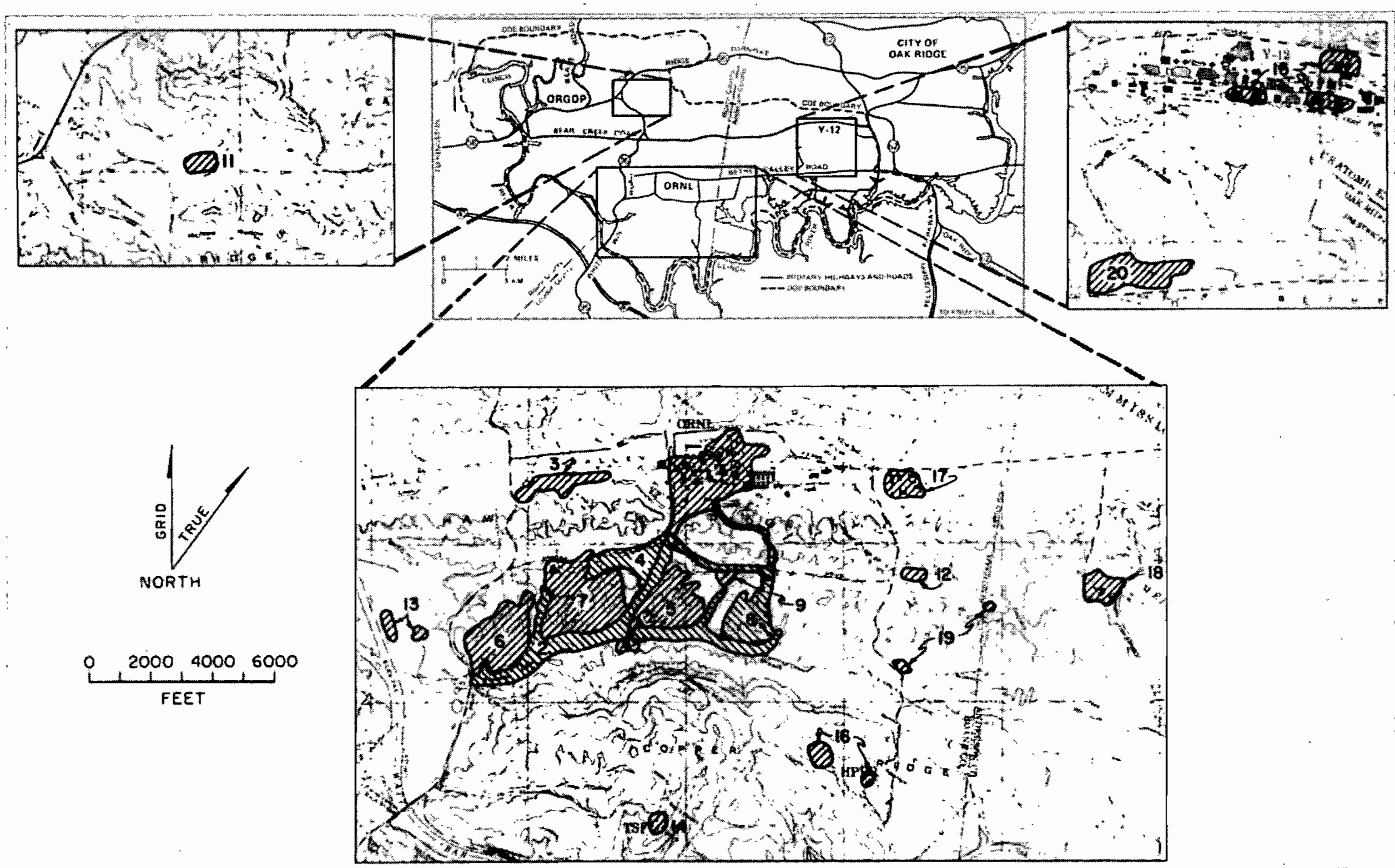

Fig. 2.1. Locations and boundaries of ORNL Waste Area Groupings.

Key to Fig. 2.1

1: Main Plant Area

2: White Oak Creek and White Oak Lake

3: Solid Waste Storage Area 3

4: Solid Waste Storage Area 4

5: Solid Waste Storage Area 5

6: Solid Waste Storage Area 6

7: Low-Level-Waste Pits and Trenches Area

8: Melton Valley Area

9: Homogeneous Reactor Experiment Area

10: Hydrofracture Injection Wells and Grout Sheets
(wells denoted by triangles)

11: White Wing Scrap Yard

12: Closed Contractors' Landfill

13: Environmental Research Areas

14: Tower Shielding Facility

15: ORNL Faciliites at Y-12

16: Health Physics Research Reactor Area

17: ORNL Services Area
(no Remedial Action Program sites)

18: Consolidated Fuel Reprocessing Area
(no Remedial Action Program sites)

19: Hazardous Waste Facilities
(no Remedial Action Program sites)

20: Oak Ridge Land Farm

Table 2.1. Regulatory relationships and environmental surveillance for TRU-contaminated sites at ORNL[a]

Site category / Waste Area Grouping / Site description	Regulatory relationship: RCRA 40 CFR pt 265	RCRA Sect. 3004(u)	DOE Orders 5480.14	DOE Orders 5820.2	Environmental surveillance measures
I. LLW LINES AND LEAK SITES					
1: Main Plant Area					Contaminated groundwater from line and tank leak sites collected and treated in WAG 1; surface water monitored at several locations; perimeter groundwater-monitoring wells to be installed in WAG 1 in FY 1987; preliminary remedial action studies ongoing
Bethel Valley: 3019 and Isotopes Areas; Central Ave. (20 leak sites)	X	X	X(4.8)[b]		
4: SWSA 4, 5: SWSA 5, 7: LLW Pits and Trenches Area, and 8: Melton Valley Area					See later entries for SWSAs 4, 5, and 7; perimeter groundwater-monitoring well installation to be completed in FY 1988 for WAG 8
Melton Valley lines and 8 leak sites in 4 WAGs	X	X	X(4.8)[b]		Surface water monitoring for combined releases from WAGs 8 and 9; 200 m of pipeline removed from flood-plain area; 2 leak sites entombed
II. LLW STORAGE TANKS					Closure planning mandated by 1986 RCRA tank regulations
1: Main Plant Area					See first entry for WAG 1 details
(W-5, W-6, W-7, W-8, W-9, W-10)	X	X		X	Tank sampling to be completed in FY 1987, along with decommissioning/closure plan
W-1, W-2, W-3,	X	X		X	
W-4, W-11, W-15,	X	X		X	
W1-A, WC-15, TH-2	X	X		X	
5: SWSA 5					See later entry for SWSA 5
New Hydrofracture tanks (W-24, W-25, W-26, W-27, W-28, W-29, W-30, W-31)	X	X		X	Tank sampling and analysis of sludge removal and treatment options in FY 1987

Table 2.1. (Continued)

Site category / Waste Area Grouping / Site description	Regulatory relationship: RCRA 40 CFR pt 265	RCRA Sect. 3004(u)	DOE Orders 5480.14	DOE Orders 5820.2	Environmental surveillance measures
II. LLW STORAGE TANKS (Continued)					
9: Homogeneous Reactor Experiment Area					Perimeter groundwater-monitoring well installation in WAG 9 in FY 1988
HRE tanks (7560, 7562)	X	X		X	Tank sampling in FY 1987; surface-water monitoring for combined releases from WAGs 8 and 9
III. LLW SEEPAGE PITS AND TRENCHES					All are asphalt capped; cap extension and groundwater diversion and monitoring at Trench 7
7: LLW Pits and Trenches Area					Perimeter monitoring wells for WAG 7 to be installed in FY 1988
Pit 1 (7805)		X	X(5.6)[b]		In situ vitrification studies for site stabilization ongoing
Pits 2, 3, and 4 (7806, 7807, 7808)		X	X(7.2)[b]		
Trench 5 (7809)		X	X(7.2)[b]		
Trench 6 (7810)		X	X(6.7)[b]		
Trench 7 (7818)		X	X(7.2)[b]		
IV. NEW HYDROFRACTURE FACILITY (7860)					
10: Hydrofracture Injection Wells and Grout Sheets					
Subsurface grout sheets		X[c]	X[c]		RCRA Remedial Investigation underway; deep monitoring wells sampled periodically; FY 1987 injection-well closure planning
V. SOLID WASTE STORAGE AREAS					
1: Main Plant Area					Also see first entry in table
SWSA 1 (2624)		X	X(4.4)[b]		Regular erosion control
SWSA 2 (4003)		X	X(1.1)[b]		Soil coring in 1977 indicated no measurable contamination

Table 2.1. (Continued)

Site category / Waste Area Grouping / Site description	Regulatory relationship: RCRA 40 CFR pt 265	RCRA Sect. 3004(u)	DOE Orders 5480.14	DOE Orders 5820.2	Environmental surveillance measures
V. SOLID WASTE STORAGE AREAS (Continued)					
3: SWSA 3					Perimeter groundwater-monitoring well installation in WAG 3 in FY 1987
SWSA 3 (1001)		X	X(7.2)[b]		Fenced and grass-covered; runoff diversion
4: SWSA 4					Perimeter groundwater-monitoring wells for WAG 4 in FY 1987
SWSA 4 (7800)		X	X(7.2)[b]		Fenced and grass-covered; surface runoff and groundwater controls; trench-grouting studies ongoing; surface-water monitoring
5: SWSA 5					Perimeter groundwater-monitoring well installation in WAG 5 in FY 1987
SWSA 5 (7802)		X	X(7.2)[b]		Fenced and grass-covered; drainage ditches; some trench corrective measures; surface-water monitoring

[a]Key to abbreviations:

HRE	Homogeneous Reactor Experiment
LLW	low-level waste
RCRA	Resource Conservation and Recovery Act
SWSA	Solid Waste Storage Area
TRU	transuranic
WAG	Waste Area Grouping.
40 CFR pt 265	Title 40, U. S. Code of Federal Regulations, Part 265

[b]Modified Hazard Ranking System score (Source: Nix et el. 1986).
[c]Also regulated under the Underground Injection Control Program (Safe Drinking Water Act).

comparisons between ORNL sites, comparisons between sites at ORNL and at some other DOE facilities may not be possible (Nix et al. 1986; Sleeman 1986). This involves what appear to be basic problems in applying the hazard ranking methodology to individual sites when (1) these are located at facilities that contain a large number of sites and (2) radionuclides are the principal contaminants present. This has led to differing interpretations of the use of contaminant observations in sediments and surface waters downstream from a facility in assigning scores in the "Targets" subcategory of the mHRS.

At facilities such as ORNL, it is very difficult to quantify individual source contributions to contamination downstream because overall releases are a complex mixture of effluents from both currently operational and RAP sites and the bulk of downstream contamination (for example, in Clinch River and Watts Bar Reservoir sediments) is principally attributable to historical sources which do not necessarily coincide with current sources. In addition, contamination observed downstream near the public drinking water intake closest to ORNL represents a mixture of materials derived from 3 different DOE installations located on the Oak Ridge Reservation (ORNL, the Oak Ridge Gaseous Diffusion Plant, and the Y-12 Plant). The presence of some contaminants is attributable to releases from only one of these installations while others may have been released (to highly varying degrees) from all three. Individual contributions from ORNL waste disposal sites thus have to be inferred.

In its initial scoring, ORNL chose to exclude downstream contaminant observations from consideration, pending development by DOE of guidance for dealing with such issues (Nix et al. 1986). The mHRS score for some individual waste disposal sites, as well as the aggregate score for all ORNL sites combined, could be high enough to place on the CERCLA National Priorities List if the assumption is made that some fraction of the very low radionuclide levels observed at public water supply intakes downstream is attributable to current waste site releases. Yet the maximum annual radiation dose to a member of the general public living outside the Oak Ridge Reservation is <<25 mrem/year (Sect. 4.2) indicating that even the aggregate of ORNL sites does not pose a current threat to human health and environment! This leads to the question whether an mHRS score that has been derived in this manner is artificially high, simply because the analytical technology for radionuclides permits their detection and quantification in environmental media at extremely low levels relative to hazardous chemicals (including known carcinogens). Simplistic use of the mHRS appears to generate results that are contrary to logic; mHRS scores should therefore be interpreted and used with caution.

2.2.2 <u>Environmental Surveillance Activities</u>

Although some WAGs may share boundaries (Fig. 2.1), each comprises distinct small drainage areas into which similar contaminants were introduced. In some cases, there has been hydrologic interaction among the units within a WAG, thus making some units hydrologically inseparable. The approach of grouping waste management units allows perimeter monitoring of both groundwater and surface water at inflow and discharge points for each hydrologic entity (i.e., WAG) in a time frame that is much shorter than that required to isolate and define each unit individually. This allows a response which is protective of human health and the environment to be developed in an appropriate time period. Based upon such monitoring data, further studies, principally directed toward the groundwater subsystem, can address individual sites or units within a WAG or contaminant plumes that extend beyond the perimeter of a WAG (Trabalka and Myrick, in press).

Thus, many aspects of environmental surveillance, including preliminary characterization, maintenance and surveillance, interim corrective actions, monitoring, and the RI/FS process itself, are now or will be oriented toward this geographic (and hydrogeologic) scale. Site characterizations will be performed for each WAG to identify significant sources of releases and evaluate both the need for interim corrective measures and the options for long-term stabilization actions (see Sect. 5). Past and planned environmental monitoring and remedial activities associated with individual site categories and WAGs are summarized in Table 2.1.

A system of required water quality monitoring wells was installed in fiscal year (FY) 1985 at all active RCRA sites at ORNL (that is, surface impoundments). Although an extensive network of wells had also been constructed for studies of radionuclide migration in groundwater at a number of ORNL waste disposal sites (see, for example, Webster 1976, Bates 1983, Olsen et al. 1983, Spalding and Boegly 1985, Coobs and Gissel 1986), these were constructed prior to the development of RCRA standards for groundwater-monitoring well construction and placement. Much more comprehensive information on site geohydrologic characteristics and well development (materials, procedures) is now required to meet the new RCRA standards. This also involves the placement of a rigorous network of hydrostatic head and piezometer wells to define the groundwater flow regime well in advance of the construction of groundwater monitoring wells.

Thus, a comprehensive program was initiated at the inception of the RAP in FY 1985 to develop the information that is needed to establish a satisfactory perimeter monitoring network of RCRA-quality wells in all ORNL WAGs for the RI/FS. Over 300 hydrostatic head and piezometer wells have been installed to date. Projected completion dates for the perimeter network of over 250 water quality monitoring wells are given by WAG in Table 2.1; the placement of intra-WAG wells will be determined during the RI/FS.

Radionuclides (primarily ^{3}H and fission and activation products) and some hazardous chemicals are monitored routinely at many surface-water stations in the stream system which drains the ORNL area (Fig. 2.2 and Table 2.1; Martin Marietta Energy Systems 1986; ORNL 1986a, 1986b, 1986c; Oakes et al. 1987). Other monitoring stations, particularly those associated with small tributaries or individual seeps within WAGs, are occupied on a periodic or infrequent basis. Concentrations of TRU radionuclides are routinely monitored at only one location, White Oak Dam, which is located near the ORNL site boundary and the terminus of the White Oak Creek drainage (Martin Marietta Energy Systems 1986; ORNL 1986a, 1986b, 1986c; Oakes et al. 1987). All TRU-waste sites are upstream from this location (Fig. 2.2; also see Sect. 3.1), and since their discharges become mixed and integrated before reaching White Oak Dam, it is not currently possible to distinguish individual site trends in TRU releases with time or their relative contributions to overall TRU releases.

The entire surface-water monitoring system at ORNL is currently being expanded and upgraded (Berry et al., in press). New monitoring locations

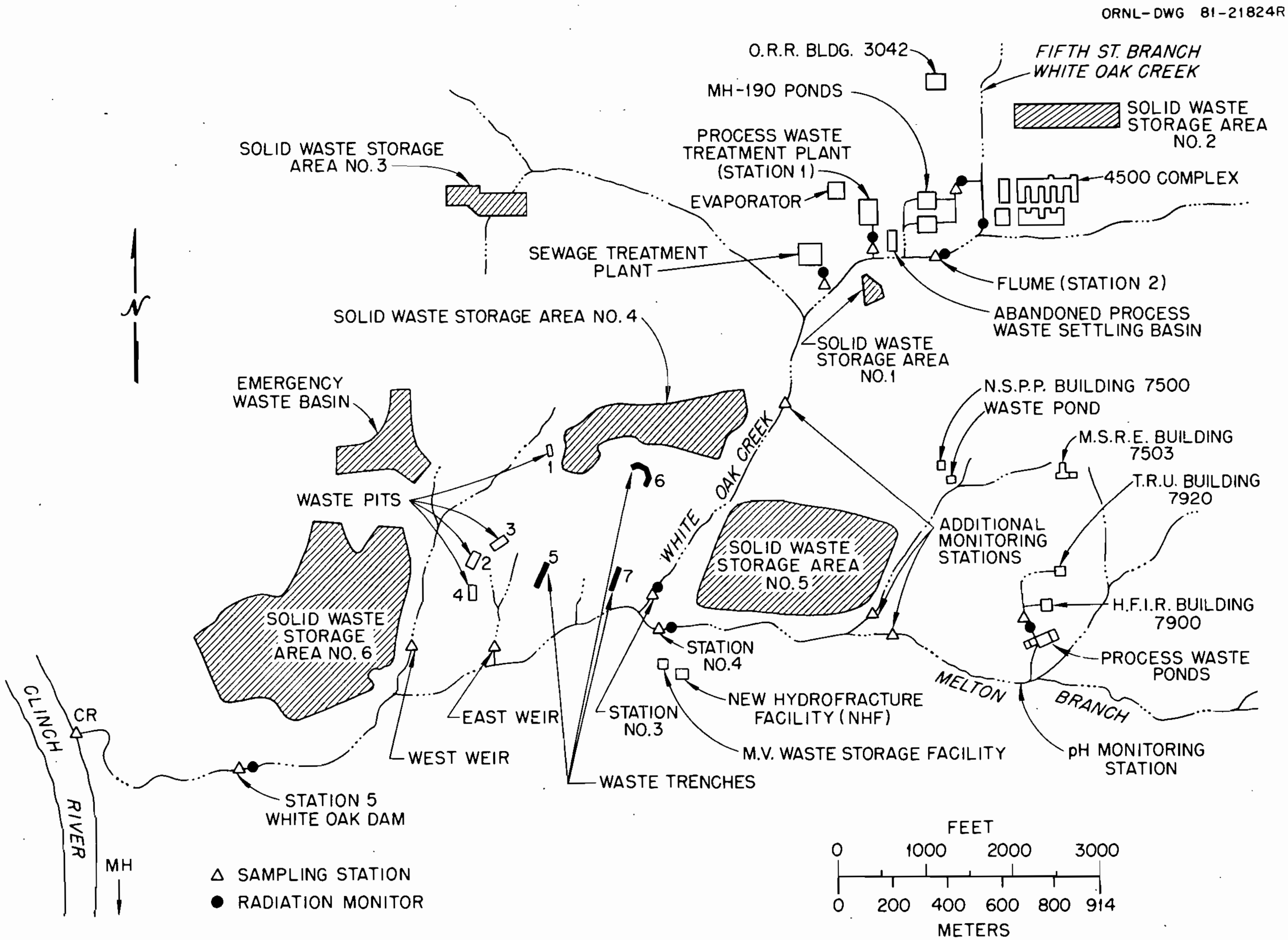

Fig. 2.2. Location plan for White Oak Creek sampling stations and radiation monitors.

will be added during the execution of the RI/FS as appropriate WAG perimeter-station locations are identified. However, new criteria for continuous monitoring of effluent streams which have been proposed by DOE (DOE 1986) could also increase greatly both the costs and technological requirements for operation of many ORNL stations. Thus, it may not be feasible to provide accurate estimates of the long-term costs of monitoring until the expected redefinition of the existing system during the RI/FS has been completed.

Releases from ORNL operations since 1943 have resulted in radionuclide contamination of sediments in White Oak Creek and in the Clinch River and Watts Bar Reservoir. Radionuclides are detectable in reservoir sediments $\geq$40 km downstream from the ORNL area of the Oak Ridge Reservation (Oakes et al. 1982). The principal contaminants contributed by ORNL appear to be ^{60}Co, ^{90}Sr, ^{137}Cs, and $^{239,240}Pu$. Based on data reported by Oakes et al. 1982, it is estimated that the inventories of ^{137}Cs, ^{90}Sr, and $^{239,240}Pu$ in the Clinch River/Watts Bar Reservoir system are <300 Ci (1 Ci is equal to 3.7×10^{10} Bq), <10 Ci, and <2 Ci, respectively. Concentrations of ^{137}Cs in sediments sampled during the most recent survey in 1977 reached 600 pCi/g (dry weight) and levels >50 pCi/g were recorded in an appreciable number of core segments (Oakes et al. 1982).

3. ENVIRONMENTAL CONDITIONS AND WASTE SITE CHARACTERISTICS

3.1 ORNL PERSPECTIVE

The ORNL area is characterized by a humid, temperate (sometimes classified as subtropical) climate and receives an annual average precipitation of 130 cm. Greater than 95 percent of precipitation occurs as rainfall, with peak amounts in December through March and in July (Coobs and Gissel 1986). The water table occurs at shallow depths, and the uppermost aquifers in the groundwater system are generally thought to outcrop to surface streams before leaving the Oak Ridge Reservation boundary. Stream flow is seasonally large and periods of accumulative winter precipitation often lead to a high water table in late March (NAS 1985). Flooding can also be a local problem, and the relatively large amount of rainfall reduces the distance between groundwater recharge and discharge points as well as the length of the groundwater residence time (NAS 1985; Coobs and Gissel 1986). The groundwaters are neutral to slightly alkaline (pH 7 to 8.5) and enriched in Ca, Mg, and bicarbonate ions. The two cations are only slightly diluted in surface waters and thus interfere with ^{90}Sr sorption on soils and sediments. The overall effect of these combined factors is to enhance the mobility of weakly sorbed contaminants such as ^{3}H and ^{90}Sr and to aggravate the management of such constituents in the ORNL environment (NAS 1985). The nature of the deeper groundwater flow regime (that is, at 300-m depths corresponding to the Hydrofracture grout sheets) is now the subject of intense scrutiny (Trabalka and Myrick, in press).

The TRU-contaminated sites at ORNL are located in two parallel valleys that are oriented northeast-southwest and separated by Haw Ridge (Coobs and Gissel 1986). Bethel Valley is on the north side of Haw Ridge, and is drained by White Oak Creek (WAG 2 in Fig. 2.1; see Sect. 2.2.2), a small tributary of the Clinch River (which also forms the southern boundary of the DOE Oak Ridge Reservation). The flow pattern of White Oak Creek is from Bethel Valley to Melton Valley through a gap in Haw Ridge, and then through the southwest portion of Melton Valley (past WAG 4, SWSA 4, and then WAG 7, LLW Pits and Trenches Area) to the Clinch River (Fig. 2.1). The northeast portion of Melton Valley is drained by the Melton Branch tributary of White Oak Creek, which receives effluents from WAGs 8, 9, and 5 (in sequence) before it joins White Oak Creek between WAGs 4 and 7, 1 km southeast of Haw Gap (Figs. 2.1 and 2.2).

Waste Area Groupings 1 and 3 are located in Bethel Valley (Fig. 2.1), which is underlain by limestones (primarily) of the Chickamauga Formation (Coobs and Gissel 1986). Fractures and solution cavities in the Chickamauga limestones make predictions of transport difficult, but generally serve to enhance the movement of groundwater (and dissolved waste constituents). This tendency is enhanced even more in WAG 1, Main Plant Area, by the existence of numerous anthropogenic features (for example, gravel-filled pipeline trenches) which become preferred-flow pathways for rapid transport of waste constituents from groundwater to nearby tributaries of White Oak Creek (Trabalka and Myrick, in press).

The remaining WAGs which contain TRU-contaminated sites are located in Melton Valley, which is underlain by the Conasauga Group [interbedded shale, siltstone, and limestone units with varying degrees of permeability and with a total thickness of approximately 600 m; (NAS 1985)]. Wastes in

WAGs 4, 5, 7, 8, and 9 were either accidentally leaked from LLW Lines and/or LLW Storage Tanks, disposed or emplaced [solid wastes in shallow land burial trenches in the Solid Waste Storage Areas (SWSAs)], or purposefully released as waste liquids or sludges (LLW Seepage Pits and Trenches) into soils and/or highly weathered materials comprising the uppermost member of the Conasauga Group in each WAG. Because the geologic units dip to the southeast, each member of the formation outcrops in a linear sequence. For example, the Pumpkin Valley shale occurs at the surface in WAG 4, SWSA 4, but underlies other members to increasingly greater depths at other locations, extending to >350 m below the surface in WAG 10, Hydrofracture Injection Wells and Grout Sheets. In other WAGs (5, SWSA 5, for example) two or more members, including the Maryville Limestone, may occur at the surface (Coobs and Gissel 1986).

Soils in the ORNL area are characterized as silty, with considerable clay content and a pH ranging from 4.5 to 5.7 (Coobs and Gissel 1986). The weathered zone in Bethel Valley areas underlain by Chickamauga Limestone is thin, generally less than 3 m. The depth of weathering in areas underlain by the Conasauga Group is related to topography: Thinning from ridge tops to low-lying areas. In WAG 4, the weathered zone ranges from 1.2 to 4.9 m, while in WAG 5, it ranges from <1 to 12 m. The principal minerals in the weathered Chickamauga materials are kaolinite and illite, and in the Conasauga Group: Illite, smectite, and vermiculite (NAS 1985). Although these minerals have excellent sorptive properties for some radionuclides (^{137}Cs, in particular; Spalding and Boegly 1985), the complex, fractured nature of some of the surface members and the relatively high porosity of weathered zones, coupled with unfavorable features of some waste disposal practices (see Sect. 4.2; Bates 1983; NAS 1985; Coobs and Gissel 1986), permit appreciable releases of poorly sorbed radionuclides such as ^{3}H and ^{90}Sr.

The subsurface grout sheets in WAG 10, generated by New Hydrofracture Facility (NHF) operations, were produced by injecting a waste-grout slurry between layers of Pumpkin Valley shale, the lowermost member of the Conasauga Group underlying the NHF (which is located physically in WAG 5, SWSA 5). It was originally believed that the low permeability of the Pumpkin Valley shale and the depth of the injection zone (on the order of 300 m), combined with the integrity of the solidified grouts, would serve to limit migration of waste constituents on meaningful time scales (NAS 1985), thus representing greater-confinement disposal. However, records indicating that a number of injections at the New Hydrofracture Facility may have had an unacceptably low grout content and observations of ^{90}Sr at concentrations of several microcuries/L in deep-monitoring wells located near the periphery of the grout sheets have raised serious questions about this interpretation and led to the need for a Remedial Investigation to determine the potential for migration beyond the injection zone (Trabalka and Myrick, in press).

3.2 TRANSURANIC WASTE AND SITE CHARACTERISTICS

3.2.1 Waste and Site Associations

Detailed descriptions of the individual sites and associated waste disposal practices have been provided elsewhere (Webster 1976; Bates 1983;

Myrick 1984; Myrick et al. 1984; NAS 1985; Spalding and Boegly 1985; Coobs and Gissel 1986; Nix et al. 1986; Trabalka and Myrick, in press) and thus will not be repeated here. The material presented in this report is a summary of existing information which has been focused on specific details pertinent to remedial action planning at TRU-contaminated sites.

The characteristics of the TRU-contaminated materials vary widely between sites (Table 3.1). These materials consist of soils and sludges (primarily) at the LLW sites, along with transfer line and tank components in the first two site categories; stacked layers of NHF grout sheets emplaced about 300m below the surface (NAS 1985); and a wide range of solid wastes in the SWSAs, along with soil contaminated in situ by releases from disposed wastes (Webster 1976; Bates 1983; Coobs and Gissel 1986).

3.2.2 Waste Inventories

Information on the the identities and quantities of waste constituents at known or potential TRU-contaminated sites is also presented in Table 3.1. This is often incomplete, fragmentary, or otherwise limited, leading to conservative overestimates of inventories. Few historical records exist for the SWSAs, in particular, and the records for SWSAs 3, 4, and (parts of) 5 were destroyed by fire (Coobs and Gissel 1986).

Although inventories of hazardous chemical constituents are poorly characterized at all sites (Table 3.1), sludges generated in the LLW systems and the NHF grouts [which were partially derived from some of these sludges (Weeren and Mackey 1980)] are expected to be toxic by characteristic as defined by RCRA regulations because of their heavy metal content (Trabalka and Myrick, in press). The contents of both TRU and other radioactive constituents are quite well characterized in the NHF grouts and in some of the LLW Storage Tank sludges, but this is not the case for wastes from other sites, particularly for those from the LLW Lines and Leak Sites. The LLW Storage Tanks contain significant residual liquids and sludges to be disposed, but only the sludges fit the current TRU-waste definition. The LLW Lines are very poorly characterized currently, but some probably contain TRU-sludge residuals. Leak sites (primarily from LLW Lines) represent numerous, relatively localized patches of contaminated soil; only a few of these have been characterized as TRU-wastes to date.

Despite the absence of documentation on hazardous chemical inventories, radionuclides are expected to be the primary hazardous materials present at the majority of ORNL sites. Thus, it is believed that the potential radioactive hazard will generally overshadow the chemical hazard at all of these sites (Trabalka and Myrick, in press). In addition, the radionuclide inventories at all sites are dominated by fission products (^{90}Sr and ^{137}Cs), tritium, and activation products (for example, ^{60}Co) rather than by the transuranics (Table 3.1). This has major implications for site stabilization strategy (Sect. 4.1).

It is currently estimated that the total NHF grout inventories of TRU contaminants (2100 Ci) are approximately an order of magnitude greater than the totals for the LLW Storage Tanks, the LLW Pits and Trenches, and the SWSAs, respectively (Table 3.1). The inventories in the latter three categories appear to be roughly comparable to one another and approximately

Table 3.1. TRU-waste characteristics at ORNL sites[a,b]

Site category / Waste Area Grouping / Description	Contaminant	Inventory [Ci (kg)]	Volume $(m^3)^c$
I. LOW-LEVEL WASTE (LLW) LINES AND LEAK SITES			
1: Main Plant Area, 4: SWSA 4, 5: SWSA 5, 7: LLW Pits and Trenches Area, and 8: Melton Valley Area			
Contamination in inactive lines and in soil at 28 leak sites in Bethel and Melton Valleys	HZ	NA	NA
	^{90}Sr, ^{137}Cs, ^{244}Cm, and TRU	NA[d]	NA
II. LLW STORAGE TANKS			
Sludges in 24 tanks	HZ	NA	NA
1: Main Plant Area			
[W-5, W-6, W-7, W-8, W-9, W-10]	^{90}Sr	19,000	
	^{137}Cs	2,500	
	TRU	<100 est.	350
W-2	^{90}Sr	10	
	^{137}Cs	10	
	TRU	7.0	2.0
W-3	^{90}Sr, ^{137}Cs, and TRU	NA[d]	16
W-4	^{90}Sr	100	
	^{137}Cs	100	
	TRU	4.2	22
[W-11, W-15, W1-A, WC-15, TH-2]	^{90}Sr, ^{137}Cs, ^{233}U, Th, U, Unident., and TRU	NA[d]	≤40

Table 3.1. (Continued)

Site category / Waste Area Grouping / Description	Contaminant	Inventory [Ci (kg)]	Volume (m^3)[c]
II. LLW STORAGE TANKS (Continued)			
5: SWSA 5			
New Hydrofracture Facility tanks with second. containment [W-24, W-25, W-26, W-27, W-28, W-29, W-30, W-31]	^{90}Sr	30,000	
	^{137}Cs	1,000	
	^{232}Th	(<10,000 est.)	
	^{238}U	(<10,000 est.)	
	TRU	190	190
9: Homogeneous Reactor Experiment Area			
HRE storage tanks [7560, 7562]	Unident. and TRU	NA[d]	$\leq$46
III. LLW SEEPAGE PITS AND TRENCHES			
7: LLW Pits and Trenches Area			
Sludges and soils at all 7 sites	HZ	NA	NA
Pit 1	^{137}Cs	230	
	^{239}Pu	0.021	
	TRU	NA	NA
Pits 2, 3, & 4	^{90}Sr	42,000	
	^{137}Cs	180,000	
	^{239}Pu	29	
	TRU	NA	NA
Trench 5	^{90}Sr	<97,000	
	^{137}Cs	210,000	
	^{239}Pu	10	
	TRU	NA	NA
Trench 6	^{90}Sr	150	
	^{137}Cs	670	
	^{239}Pu	0.013	NA
	TRU	NA	NA

Table 3.1. (Continued)

Site category Waste Area Grouping Description	Contaminant	Inventory [Ci (kg)]	Volume (m^3)[c]
III. LLW SEEPAGE PITS AND TRENCHES (Continued)			
7: LLW Pits and Trenches Area (Continued)			
Trench 7	^{90}Sr	48,000	
	^{137}Cs	230,000	
	^{233}U	3.2	
	^{238}U	0.040 (120)	
	^{239}Pu	12	
	TRU	39 est.	12[e]
IV. NEW HYDROFRACTURE FACILITY			
10: Hydrofracture Injection Wells and Grout Sheets			
Subsurface grout sheets [waste, cement, fly ash, and clay mixture emplaced at 300-m depth]	HZ	NA	
	^{90}Sr	640,000	
	^{137}Cs	84,000	
	^{232}Th	>4.0 (>40,000)	
	^{238}U	>20 (>60,000)	
	Unident.	21,000	
	TRU	2,100	11,000
V. SOLID WASTE STORAGE AREAS			
Solid wastes and soils in all SWSAs	HZ[f]	NA	NA
1: Main Plant Area			
SWSA 1[g]	^{90}Sr and Unident.	<3,000[h]	<1,100[h]
SWSA 2[g]	^{239}Pu and Unident.	NA[i]	NA[i]
3: SWSA 3			
SWSA 3[g]	^{3}H, ^{90}Sr, Unident., and TRU	<50,000[h]	20,000[h]

Table 3.1. (Continued)

Site category / Waste Area Grouping / Description	Contaminant	Inventory [Ci (kg)]	Volume (m^3)[c]
V. SOLID WASTE STORAGE AREAS (Continued)			
4: SWSA 4			
SWSA 4 [Trash, scrap, carcasses, soil, rubble, filters, oils, asbestos, lumber, equipment, shielding, and containerized materials]	^{3}H, ^{60}Co, ^{90}Sr, ^{137}Cs, Th, U, Unident., and TRU	<110,000[h]	53,000[h]
5: SWSA 5			
SWSA 5 [Trench areas with materials as in SWSA 4 ; other TRU (and ^{233}U) container burial areas, with some containers buried non-retrievably]	^{3}H, ^{60}Co, ^{90}Sr, ^{137}Cs, Th, U, ^{244}Cm, Unident., and TRU	<210,000[h]	100,000[h]

[a]Source: Trabalka and Myrick, in press (Table A-2 data and references).

[b]Key to table abbreviations:

est.	estimated value, based on data in references cited
HRE	Homogeneous Reactor Experiment
HZ	hazardous chemicals
LLW	low-level waste
NA	not available
SWSA	Solid Waste Storage Area
TRU	transuranic radionuclides, half-lives $\geq$20 years
Unident.	unidentified radionuclides.

[c]Waste volume reported applies to all contaminants present unless otherwise noted.

[d]Applies to all radionuclide contaminants listed.

Table 3.1. (Continued)

[e]Estimate is for sludge volume only.

[f]Consists of Pb, other toxic metals, and hazardous solvents.

[g]See SWSA-4 entry for description of solid wastes buried.

[h]Values reported are the estimated total waste inventories and volumes disposed (that is, the sum of LLW and TRU wastes buried). Records for individual radionuclides or waste fractions are not available (see Sect. 3.2 of this report).

[i]The presence of either LLW or TRU waste residuals at this site has not been confirmed. The bulk of its contents were reportedly exhumed and transferred to SWSA 3 prior to 1950. However, some accounts indicate that not all wastes were removed (Webster 1976; Bates 1983).

approximately two orders of magnitude larger than the totals for the LLW Lines and Leak Sites.

The total inventories and volumes of buried TRU wastes and contaminated soils at ORNL have been estimated previously (King 1981a, 1981b, 1985; Row 1983) for the Integrated Data Base (DOE 1985b) and other DOE documents (DOE 1980a, 1981). Post-1970 data on the fraction of total solid waste burials (from 1971 to 1973) associated with TRU wastes (then defined as ^{233}U + ^{239}Pu*) were extrapolated to the 1943-1970 period and combined with post-1970 records to generate an estimate of 6200 m^3 buried (King 1981a, 1981b). Accountability records were used to estimate the mass and activity of TRU wastes associated with this buried material (King 1981a, 1981b; Row 1983). This estimate (3.5 kg of ^{233}U and 1.7 kg of ^{239}Pu, totalling 5.2 kg) was later revised at the end of calendar year 1982 to 5.6 kg (272 Ci) by the addition of 358 g and 135 Ci, respectively (Row 1983). However, the derivation of the revised values was not documented (for example, the TRU radionuclides were not identified). Although the original estimate may have been revised to incorporate contributions from ingrowth of TRU daughter products and/or ^{238}Pu, it is also quite conceivable that isotopes of Am and of Pu other than ^{239}Pu (with physical half-lives >20 years) are either not included or not accurately represented by these totals. The result in either case would be a significant underestimate of the TRU activity and radiotoxicity of materials buried in the ORNL SWSAs.

The total volume of contaminated soils resulting from solid waste burials was estimated to range from a low value equal to twice the volume of buried TRU waste to a high value equal to 10 times the total volume of solid waste disposed at ORNL (for example, times values given in Table 3.1 for the SWSAs). The high estimate [1,600,000 m^3 (DOE 1981; Row 1983)] was later lowered to 10 times the volume estimate for disposed TRU wastes [that is, to approximately 60,000 m^3 (DOE 1985b; King 1985)], to reflect better the fraction of the total contaminated volume associated exclusively with TRU materials.

However, the original high estimate was made with the knowledge that TRU wastes were buried in the same solid waste disposal areas as LLW prior to October 1970. "In some cases, the alpha[-emitting] wastes were put in separate trenches and covered with concrete but this was not practiced consistently" (King 1981b). Maps indicate that approximately 1/3 to 1/2 of the disposal areas in the principal SWSAs (3, 4, and 5) were used for trench burial of alpha wastes (Webster 1976; Bates 1983; Coobs and Gissel 1986). Reports on early waste disposal practices at ORNL indicate that concrete was typically used to cap alpha-emitting-waste trenches in SWSAs 3 and 4. The practice of segregating and capping the alpha-contaminated wastes was reportedly discontinued between 1958 and 1970, during the operational life of SWSA 5 (Webster 1976). However, field surveys in SWSA-4 burial areas that were mapped as containing alpha wastes in concrete-covered trenches located very few trenches that were actually concrete capped. Thus, it is currently difficult to judge how successful site characterization studies will be in isolating TRU-waste burial

*In the current context, ^{239}Pu refers solely to the single isotope. However, in Table 3.1, ^{239}Pu represents the sum of ^{239}Pu and ^{240}Pu activities, which are analytically indistinguishable using alpha spectrometry.

trenches from other alpha-waste or LLW trenches. This has major implications for site stabilization strategies and costs.

An additional 1000 m^3 of contaminated soil containing 0.3 kg (8 Ci) of ^{233}U and ^{239}Pu was estimated by King (1981a) to have resulted from liquid waste disposal operations. The ^{233}U and ^{239}Pu content was based on the assumption that soil concentrations were comparable to those derived from early "minimum volume" estimates of TRU contamination in the SWSAs [that is, by using (5.2 kg/18,000 m^3) x 1000 m^3], but the data which led to the volume estimate were not documented. Although the contaminated-soil volume estimate seems plausible as an upper limit, the associated TRU activity appears to have been significantly underestimated (probably by more than an order of magnitude; see entries for LLW Pits and Trenches Area in Tables 3.1 and 3.2 and in Nix et al. 1986). Development of realistic estimates must await the outcome of site characterization studies (see Sect. 5.1).

With the exception of the NHF grout sheets, estimates of buried TRU-waste and TRU-contaminated-soil inventories at ORNL are highly uncertain (Table 3.2). The RAP estimates of the total contaminated soil volume in the SWSAs are comparable to the Row (1983) estimate of 1,600,000 m^3. However, the potential error in the fractional amount of buried waste and contaminated soil that would constitute certifiable TRU waste is quite large, and greater than indicated by the data in Table 3.2 because the back-extrapolation method used by King (1981a, 1981b) to obtain the buried TRU-waste component did not provide an uncertainty estimate. As it stands, the uncertainty in the estimated TRU-waste volume in the SWSAs is so large that the aggregate volume for other site categories (NHF grout sheets excepted) is over an order of magnitude smaller than this uncertainty. New or revised estimates have not been attempted; better information awaits the completion of ongoing and planned site characterization studies by the RAP over the next five years (Sect. 5.1). In the interim, the previous estimates (summarized in Table 3.2) have been used in making hypothetical assignments of remedial action costs (Sect. 5.2).

Table 3.2. TRU-waste summary for ORNL sites[a]

Site category / Waste Area Grouping / Waste description	Contaminant	Inventory [Ci (kg)]	Volume (m^3)
I. LOW-LEVEL WASTE (LLW) LINES AND LEAK SITES			
1: Main Plant Area, 4: SWSA 4, 5: SWSA 5, 7: LLW Pits and Trenches Area, and 8: Melton Valley Area			
Contamination in inactive lines and in soil at 28 sites in 5 WAGs	TRU	NA	NA
II. LLW STORAGE TANKS			
1: Main Plant Area, 5: SWSA 5, and 9: Homogeneous Reactor Experiment Area			
Contamination in or near 24 inactive tanks in 3 WAGs:			
Sludges	TRU	>200	≤670
Soils around leaking tanks	TRU	NA	NA
III. LLW SEEPAGE PITS AND TRENCHES			
7: LLW Pits and Trenches Area			
Sludges and soils at all 7 sites	^{239}Pu	51 (0.62)	
	TRU	NA	≤1000 est.
IV. NEW HYDROFRACTURE FACILITY (7860)			
10: Hydrofracture Injection Wells and Grout Sheets			
Subsurface grout sheets at 300-m depth	TRU	2,100	11,000

Table 3.2. (Continued)

Site category Waste Area Grouping Waste description	Contaminant	Inventory [Ci (kg)]	Volume (m^3)
V. SOLID WASTE STORAGE AREAS (SWSAs)			
1: Main Plant Area, 3: SWSA 3, 4: SWSA 4, and 5: SWSA 5			
Buried TRU wastes	^{233}U and ^{239}Pu[b]	270 (5.6)[b]	6,200[b]
Total solid wastes disposed in SWSAs	LLW and TRU	<370,000	170,000
Contaminated soil proximate to wastes	TRU	NA	12,000 to 60,000[c]
	LLW and TRU	NA	≤1,600,000[d]

[a]Key to table abbreviations:

est. estimated value, yet to be verified.
LLW low-level waste; fission and activation products and actinides (including transuranics present in concentrations <100 nCi/g)
NA not available
TRU transuranic radionuclides with half-lives ≥ 20 years, present in concentrations ≥100 nCi/g
WAG Waste Area Grouping

[b]Historical estimates (King 1981b; Row 1983; DOE 1985b; King 1985) obtained through the use of accountability records (inventories) and back-extrapolations (volumes). These estimates cannot be verified at this time and should be used with caution (see Sect. 3.2.2 of this report).

[c]Historical estimates (DOE 1985b; King 1985) which are based on multiples (2 to 10 x) of the buried TRU waste volume estimate (see preceding footnote). This estimate also assumes that TRU-contaminated soils are totally isolable from LLW and LLW-contaminated soils.

[d]Historical estimate (DOE 1981; Row 1983), approximately equal to 10 times the total volume of solid wastes disposed in the SWSAs.

Table 3.2. (Continued)

This represents the maximum volume of contaminated soil that would require handling as potential TRU waste prior to post-exhumation assay if TRU-waste burial trenches are not geographically isolable from LLW trenches before exhumation (see Sects. 3.2.2 and 4.1 of this report). This estimate could be lowered to 500,000 to 800,000 m^3 if TRU-waste burial trenches are restricted to areas mapped as containing alpha-waste trenches [that is, if maps of the SWSAs indicating segregation of alpha-contaminated wastes from beta-contaminated and gamma-contaminated wastes are accurate (but see Sect. 3.2.2 of this report)].

4. SITE STABILIZATION STRATEGY

4.1 INSTITUTIONAL, REGULATORY, AND TECHNICAL CONSIDERATIONS

Although some options for stabilization and treatment of contaminated sites can theoretically provide a once-and-for-all solution (for example, by removing or destroying contaminants) most realizable options for ORNL sites leave contaminants in place (in situ), potentially isolated by physical or chemical, but more typically, by hydrologic measures. The very low risks to off-site residents posed by current releases from ORNL radioactive and hazardous chemical waste sites (Martin Marietta Energy Systems 1986; Oakes et al. 1987), the need to balance these risks against those to workers implementing remedial actions, and current estimates of the cost differential for stabilization options, all strongly favor in situ stabilization over removal and external disposal (Trabalka and Myrick in press).

Excavation, processing and certification, interim storage, and transport of contaminated materials can be technically difficult, hazardous to personnel, and very costly (NAS 1978; Oma et al. 1983). For example, costs for disposal at the ORNL site of excavated materials which could be classified as LLW are currently projected to be on the order of \$1200 to \$1800/m^3. In contrast, the estimated cost for implementing one of the most rigorous in-situ-stabilization technologies, vitrification, does not exceed \$300/m^3 (Buelt et al. 1987), and other options for ORNL sites are an order of magnitude less costly. Thus, preliminary cost estimates for exhumation options for most ORNL remedial action sites are over an order of magnitude greater than for in-situ-stabilization options. However, even these relatively high costs for exhumation options become significant underestimates when TRU-waste toxicity, bulk (as much as 2 x 106 m^3 of buried wastes and contaminated soils), and logistics, including ultimate disposal in a geologic repository, are incorporated into the analysis.

These considerations become particularly critical if LLW and TRU-waste burial locations cannot be clearly defined prior to exhumation, requiring that materials exhumed be treated as potential TRU wastes prior to assay. For example, Oma et al. 1983 estimated that costs for exhumation, assay, separation of LLW from TRU wastes, and processing and certification of the TRU-waste fractions would range from \$9,000 to 19,000/m^3, with the bulk of the cost (and its uncertainty) associated with the exhumation step (Oma et al. 1983; also see Bishoff and Hudson 1979). The high cost and uncertainty associated with the latter suggests that a significant potential for future cost reduction exists, arising from further technological development and/or field evaluations.

The midpoint of the range cited above was used as the base cost for implementation of the exhumation option at ORNL. It has been assumed that the costs for handling and interim storage of the LLW fraction exhumed will be similar to those for processing and certification of the TRU-waste fractions, and that a small fraction ($\leq$ 20 percent) of the total certifiable TRU wastes will require remote handling. It has also been assumed that the higher costs for processing and packaging of the fraction of ORNL buried-TRU wastes which would require remote handling (L. D. Bates, ORNL, personal communication, March 1987) are offset by the lower average

TRU content of ORNL buried wastes relative to other sites [Automated Sciences Group, Inc. (ASG) 1987; Joint Integration Office (JIO) 1987].

Thus, costs of \$14,000/m^3 (excluding shipping and repository disposal) could be required to deal with materials which post-exhumation assay would demonstrate to be LLW and certifiable TRU waste. Geologic disposal would increase the costs associated with the TRU-waste fraction by \$1000 to \$6000/m^3 for shipping to the repository (Detamore et al. 1985; Pierce et al. 1986; L. D. Bates, ORNL, personal communication, March 1987) and by \$1000 to \$10,000/m^3 for waste emplacement and repository operation (DOE 1980b; Oma et al. 1983; Detamore et al. 1985; ASG 1987); the ranges reflect both variations in cost recovery scenarios and cost differentials between contact-handled and remote-handled materials. As a result, exhumation of wastes and contaminated soils from TRU-contaminated sites could be two orders of magnitude more costly than in situ stabilization.

Because of the dynamic nature of the interactions between contaminants, remedial measures, and the environment, in situ stabilization is likely to have a limited life span, requiring that maintenance and monitoring of performance become essential parts of the scheme (as with all major civil engineering projects). This need should not be perceived as casting doubt on the effectiveness of the selected option, but rather as a reflection of current reality. Monitoring and periodic maintenance were responsible for the survival of a significant fraction of the Great Wall of China, portions of which date back to 2000 BP. Maintenance is also likely to be required whenever any "nonpermanent" treatment solution is chosen. Thus, funding of site closure actions should take into account the need for monitoring, maintenance, and a phased approach to such measures: initial implementation, monitoring, maintenance, performance reviews, and system modification as appropriate (Trabalka and Myrick, in press).

Currently, the prospects for "permanent" closure of some waste sites containing long-lived TRU wastes (e.g., plutonium) through in situ stabilization are uncertain. Once the lack of permanency is accepted, the main philosophical problem regarding design of remedial measures will be overcome. One potential approach to such problems at ORNL is to design for control and decay in situ (over a 100- to 300-year period of institutional control) of intermediate-lived fission waste products, such as ^{90}Sr and ^{137}Cs. This would provide a more-than-sufficient period for evaluation of the effectiveness of environmental processes and/or passive remedial measures in controlling the migration of the less-mobile transuranics, as well as for development of new long-term-stabilization technologies needed for more "permanent" stabilization of some buried-TRU sites. A no-migration waste management objective seems inadvisable for co-contaminants such as U because of the long-term increase in hazard from buildup of highly toxic decay products (Pa, Ra, Rn, and Th).

Predictions of site performance are difficult because of the uniqueness of each individual case and the current lack of data on long-term effectiveness of specific stabilization options. Very few of the available technologies, other than hydrologic isolation systems, have been sufficiently proven even in short-term applications specific to treatment of contaminated sites though they may have been tried for other purposes. Future technology advancements will depend in large part on the ability to recognize the limitations of existing techniques to deal with contaminated sites. Retrofitting or treating TRU-contaminated sites to meet the technological requirements in existing regulations (including RCRA requirements; 40 CFR Part 265.310) using the limited array of field-proven engineering approaches currently available is not cost-effective (Trabalka and Myrick, in press) and runs counter to the fundamental lessons learned from the success of high technology endeavors in the modern world (Sanning 1985). The further development of on-site processes for removing and separating contaminants and in situ techniques for long-term immobilization is ongoing at several DOE sites (JIO 1987) and should eventually lead to more cost-effective, reliable solutions.

Site closure measures must be affordable, and funding should take into account the need for a phased approach. A remedial action program of the magnitude currently envisioned for the ORNL site will probably require a structured federal financing effort, covering a period of decades for planning, technology development, implementation, and evaluation, and a potentially much longer period for necessary follow-up activities such as monitoring and maintenance. The length of formal institutional control over the site and related questions about future uses of the land and waters are thus of paramount importance. Features unique to the ORNL site and environs (National Environmental Research Park; Tennessee Wildlife Resources Agency Management Area; Oak Ridge Reservation buffer zone; and ORNL environmental research and waste-management-technology development capabilities under DOE auspices) appear to be key ingredients in achieving the very long term institutional control necessary for financing and implementing in situ stabilization. The key issue is whether the principal performance objective for site closure measures (and regulations) --long-term protection of human health and the environment--can be met using in situ approaches. Regulatory requirements and standards for stabilization and closure are currently incomplete, uncertain, and to some extent negotiable, making it difficult to judge their applicability to the unique and complex characteristics of ORNL site conditions (Trabalka and Myrick, in press).

4.2 SITE-SPECIFIC PRIORITIES AND STABILIZATION ALTERNATIVES

Estimated priorities for remedial actions at ORNL TRU-contaminated sites are presented in Table 4.1. These are based on radionuclide inventories and known releases, integrated with site and environmental characteristics (Trabalka and Myrick, in press). These priorities were based primarily on inventory and environmental data for tritium and the fission products because such materials appear to represent a more immediate concern than the transuranics. The principal contributors to the < 25 mrem/year dose commitment from ORNL site releases to the offsite population are ^{3}H, ^{60}Co, ^{90}Sr, and ^{137}Cs. Over 90 percent of the total dose commitment is attributable to ^{3}H and ^{90}Sr alone, with approximately equal contributions from each nuclide (Martin Marietta Energy Systems 1986; Oakes et al. 1987). The dominant source of ^{3}H is SWSA 5 in WAG 5, and the major sources of ^{90}Sr are WAG 1 (Main Plant Area), SWSA 4 in WAG 4, and SWSA 5. The Main Plant Area is also a significant source of ^{60}Co and ^{137}Cs (ORNL 1986a, 1986b, 1986c; Trabalka and Myrick in press).

The greater concern over potential releases of intermediate-lived radionuclides and the relatively small releases of transuranics observed at the White Oak Dam monitoring station (Martin Marietta Energy Systems

Table 4.1. Estimated priorities and costs for in situ stabilization of ORNL TRU-contaminated sites[a]

Site category Waste Area Grouping Site	Stabilization Priority	Reference alternative	Cost ($000,000)
I. LOW-LEVEL WASTE (LLW) LINES AND LEAK SITES			
1: Main Plant Area			
Contamination in inactive lines and in soil at 20 leak sites	High: Moderate inventory; soil and groundwater contaminated; rapid transfer to surface water	In situ grouting or vitrification; capping; hydrologic isolation	10-100
4: SWSA 4 5: SWSA 5 7: LLW Pits and Trenches Area 8: Melton Valley Area			
Melton Valley Area lines & 8 leak sites	Moderate: Moderate inventory; soil contaminated	Same as above	10-100
II. LLW STORAGE TANKS			
1: Main Plant Area			
W-5, W-6, W-7, W-8, W-9, W-10	Moderate: Large inventory; some Gunite-wall deterioration; no known releases	Partial sludge removal; in situ grouting or vitrification[b]	1-10 (All)
W-2, W-11, WC-15	Moderate: Small inventory; leaks and soil contamination	Same as above for Tanks W-5 to W-10c	≤1 (Each)
W-3, W-4	Low: Small inventory; accumulate groundwater	Same as above[c]	≤1 (Each)
W-15, W1-A, TH-2	Moderate: Large inventory; stainless steel; no known releases	Same as above[c]	≤1 (Each)

Table 4.1. (Continued)

Site category Waste Area Grouping Site	Stabilization Priority	 Reference alternative	 Cost ($000,000)
II. LLW STORAGE TANKS (Continued)			
5: SWSA 5			
New Hydrofracture tanks (W-24, W-25, W-26, W-27, W-28, W-29, W-30, W-31)	Very low: Large inventory; stainless steel with secondary containment	Sludge removal;[b] entombment or reuse	≤1 (All)
9: Homogeneous Reactor Experiment (HRE) Area			
HRE storage tanks (7560, 7562)	Moderate: Moderate inventory; leaks and soil contamination	Partial sludge removal; in situ grouting or vitrification[c]	≤1 (All)
III. LLW SEEPAGE PITS AND TRENCHES			
7: LLW Pits and Trenches Area			
Pit 1d Trench 6[d]	Low: Small inventory; relatively high leakage	In situ vitrification and/or improved cap; hydrologic isolation	≤1 (Each)
Pits 2, 3, and 4[d]	Moderate: Large inventory; releases via groundwater seeps	Same as above for Pit 1 and Trench 6	10–100
Trench 5[d]	Low: Large inventory; no observed groundwater seeps	Same as above	1–10
Trench 7[d]	Moderate: High inventory; releases via groundwater seeps	Same as above	1–10

Table 4.1. (Continued)

Site category Waste Area Grouping Site	Stabilization: Priority	Stabilization: Reference alternative	Stabilization: Cost ($000,000)
IV. NEW HYDROFRACTURE FACILITY			
10: Hydrofracture Injection Wells and Grout Sheets			
Subsurface grout sheets	Moderate: Large inventory; wells near periphery of grout sheets (300-m depth) are seriously contaminated with ^{90}Sr	Plugging of injection well; remedial investigation to determine extent of migration and scope of problem	10–15
V. SOLID WASTE STORAGE AREAS (SWSAs)			
1: Main Plant Area			
SWSA 1	High: Moderate inventory; in drainage pathway; known releases	Capping; hydrologic isolation; limited in situ grouting or vitrification	1–10
SWSA 2	Very low: No known residual contamination	Status confirmation via characterization	≤1
3: SWSA 3			
SWSA 3	High: Large inventory; rapid groundwater transport to surface waters	Capping; hydrologic isolation; limited in situ grouting or vitrification	10–100

Table 4.1. (Continued)

Site category Waste Area Grouping Site	Stabilization Priority	Reference alternative	Cost ($000,000)
V. SOLID WASTE STORAGE AREAS (SWSAs) (Continued)			
4: SWSA 4			
SWSA 4	High: Large inventory; trenches often parallel to elevation gradients, some in water table; major releases via seeps and surface runoff	Capping; hydrologic isolation; limited in situ grouting or vitrification	10-100
5: SWSA 5			
SWSA 5	High: Large inventory; trenches often parallel to elevation gradients; major releases via groundwater, seeps, and surface runoff	Same as above for SWSA 4	10-100

[a]Source: Trabalka and Myrick, in press; TRU = transuranium radionuclides with half-lives >20 years, present at concentrations ≥100 nCi/g; NA = not available.

[b]Sludge solidification and disposal costs not included; these are covered under the Remote-Handled (RH) TRU-Waste Management Program.

[c]Sludge solidification and disposal costs not included; however, these are not currently covered under the RH-TRU Program.

[d]All sites are asphalt capped, and groundwater diversion measures have been employed at Trench 7.

1986; ORNL 1986a, 1986b, 1986c; Oakes et al. 1987) have resulted in limited information on TRU (and uranium) nuclide releases from specific sites. As noted in Sect. 2.2.2, historical surface-water monitoring data do not permit any conclusions to be drawn about long-term trends for TRU waste migration from individual sites. However, integrated surface-water releases of TRU materials from all ORNL sites, monitored at White Oak Dam near the junction of White Oak Creek with the Clinch River, (1) have remained relatively constant for the past decade and (2) have not made significant contributions to off-site population exposures (Martin Marietta Energy Systems 1986; Oakes et al. 1987).

A reference site-stabilization alternative and associated implementation-cost estimate obtained from preliminary planning activities are provided in Table 4.1 for each ORNL site, wherever possible. The definitive process of alternatives evaluation (and costing) must await completion of the RI/FS sequence (Sect. 5). Thus, the reference alternatives identified in Table 4.1 are not yet preferred alternatives generated by a detailed assessment exercise, but rather are preliminary alternatives: Yardsticks for comparison purposes. In addition, cost estimates for these preliminary site-stabilization alternatives are relatively crude, currently based on order-of-magnitude ranges. It may be quite some time before better estimates become available (for example, until it is known to what degree buried TRU wastes and LLW in the SWSAs can actually be isolated from one other and whether in situ grouting is an acceptable alternative to in situ vitrification).

A variety of technology demonstrations, including field evaluations, are ongoing: (1) geophysical trench mapping (to assist in isolating potential TRU-waste trenches from LLW trenches), (2) polyacrylamide grouting of buried TRU-waste trenches and particulate grouting of LLW trenches in solid waste disposal areas, and (3) grout-curtain hydrologic barriers at LLW Trench 7. Field tests are also planned for capping and hydrologic isolation of typical shallow-land burial trenches in one SWSA and for in situ vitrification of TRU wastes at WAG 7, LLW Pits and Trenches Area, sites. Many other technological alternatives will ultimately be evaluated and costed during the execution of ORNL's RI/FS (Trabalka and Myrick, in press). These will undoubtedly include field evaluations of in-situ-TRU-assay technology in ORNL SWSAs once initial field trials, scheduled during FY 1987 at an Idaho National Engineering Laboratory site (J. Caldwell, Los Alamos National Laboratory, personal communication, April 9, 1987), have been carried out.

5. REMEDIAL ACTION PROGRAM IMPLEMENTATION

The influences on RAP strategy described in the preceding Sections have resulted in the establishment of a phased RAP, as briefly outlined in Sect. 2.1. The first step in the implementation process involves the establishment of a regulatory-approved inventory of sites that will have to be evaluated in preparation for future remedial actions and the development of a perimeter groundwater-monitoring capability for the major WAGs. Continued control over these sites will be provided through maintenance, surveillance, and interim corrective actions to ensure adequate protection of human health and the environment until final site disposition has been achieved. For each of the sites in the RAP inventory, a detailed characterization and assessment of site conditions and the potential for environmental and health impacts will then be performed. This study will include an evaluation of alternatives for accomplishing any corrective actions needed. These alternatives (for decommissioning or closure) will be screened for their applicability to ORNL environmental conditions, and field-scale technology demonstrations will be performed, where necessary, at specific sites prior to full-scale implementation. Finally, site decommissioning or closure implementation will be carried out, according to priorities approved by regulatory authorities, to provide long-term management of residual contaminants.

The RAP work-breakdown structure (WBS) developed to guide this effort is presented in Table 5.1, along with an estimate of the cost of work to be included in each program phase. It is not possible to identify the exact fraction of the budget associated exclusively with TRU-contaminated sites. However, this represents a significant fraction of the effort in each phase over the period indicated because these sites contain approximately 70 percent of the LLW and >99 percent of the TRU-waste inventories, respectively, disposed and/or spilled in the external environment at ORNL (Trabalka and Myrick, in press). A representative figure for the pre-remedial-action costs associated with TRU-contaminated sites (that is, costs for actions required prior to decommissioning or closure) may be approximated by taking 50% of the costs for WBS phases I through IV in Table 5.1. This amounts to about 32 million dollars through FY 1991.

5.1 RI/FS IMPLEMENTATION AND COSTS

This activity, required by RCRA for all sites exhibiting continuing releases of hazardous constituents, is anticipated to take approximately 5 years to complete. Initial estimates indicate an expenditure of approximately $25 million over the lifetime of the entire effort, including both ORNL and subcontractor involvement (Table 5.1), with approximately half of the outlay targeted for TRU-contaminated sites. The subcontractor selection and award process is expected to be completed in June 1987. The large number of, and considerable diversity in, the remedial action sites to be investigated at ORNL, coupled with the hydrogeologic complexity of the ORNL environs (Trabalka and Myrick, in press), presents a unique challenge. In response, an intensive 5-year program has been outlined to provide the DOE equivalent of the EPA's RI/FS sequence for all sites which are anticipated to require a detailed

Table 5.1. Remedial Action Program budget--work-breakdown structure

Work-breakdown structure	Projected funding requirements ($000)				
	FY 1987	FY 1988	FY 1989	FY 1990	FY 1991
I. Preliminary Assessment and Site Investigation	$ 4,560	$ 2,925	$ 2,965	$ 2,365	$ 230
II. Maintenance, Surveillance, and Corrective Actions	2,350	3,835	4,710	4,750	4,800
III. Remedial Investigations and Feasibility Study	3,708	6,850	7,700	3,400	2,400
IV. Technology Demonstrations	1,635	2,125	1,350	1,025	500
V. Program Strategy Development	1,537	905	745	685	355
VI. Site Decommissioning and Closure	1,890	1,845	5,495	9,315	12,500
VII. Program Support	525	600	700	700	700
Totals	$16,205	$19,085	$23,665	$22,240	$21,485

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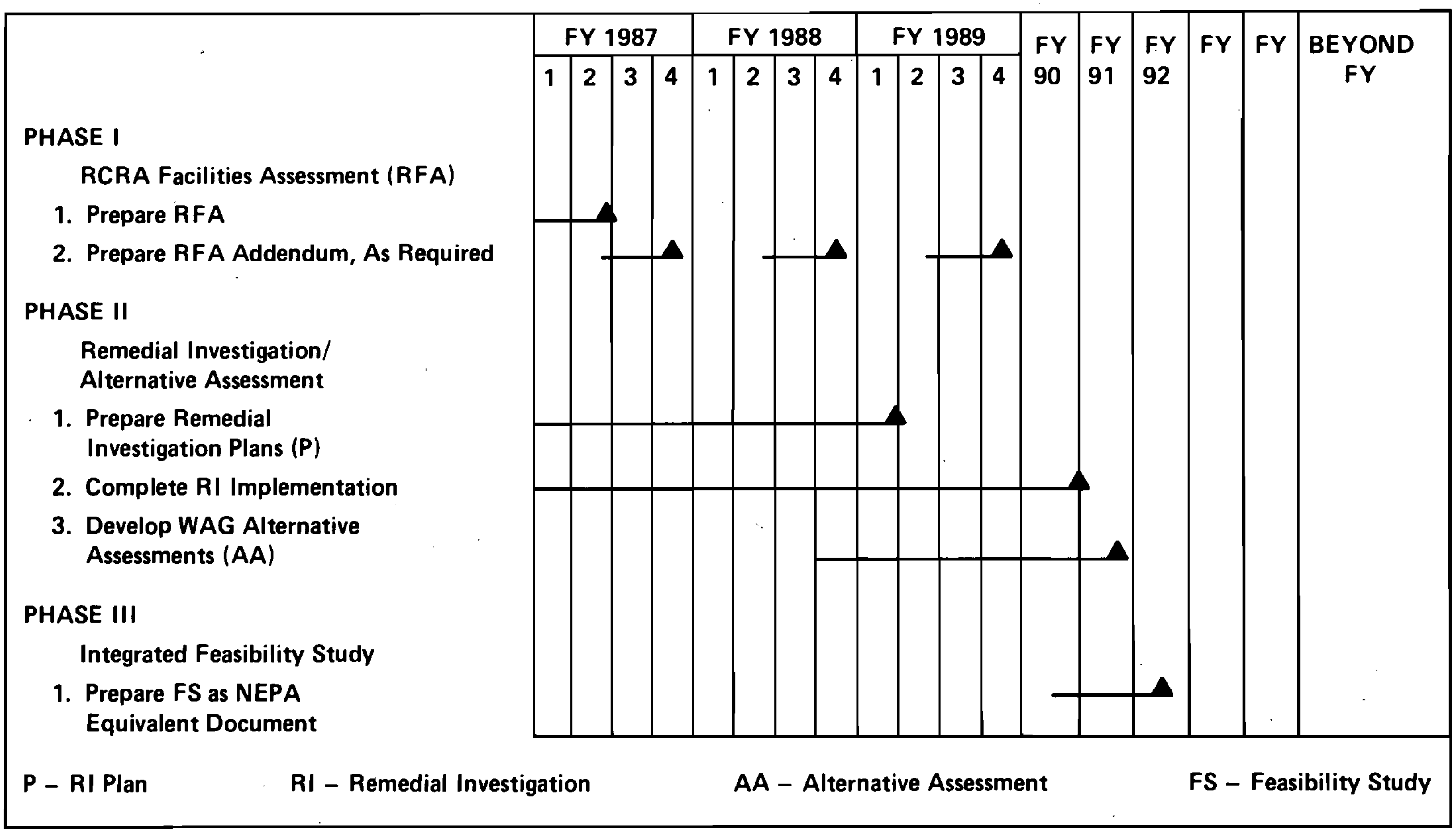

Fig. 5.1. Proposed schedules for Remedial Investigation/Feasibility Study activities.

assessment (Fig. 5.1). As the first step in this program, a RCRA Facilities Assessment (RFA), that is, an expanded version of the CERCLA Phase I exercise carried out in FY 1986, has been conducted for all Waste Area Groupings to document the site characteristics and determine the need for follow-up efforts (ORNL 1987).

Preliminary schedules for completion of the RI/FS phase are provided in Table 5.2 by WAG. Under the plan outlined in Fig. 5.1 and in Table 5.2, detailed Alternatives Assessments (AAs) would be prepared for each WAG following completion of the RI activities. These AAs would be tiered to a single Feasibility Study for ORNL, thus providing a comprehensive assessment of the need, priority, timing for, and extent of future remedial actions. This FS would have to be the functional equivalent of an EIS in order to comply with the requirements of both RCRA and NEPA. Although it appears that the FS might be able to serve as an EIS-equivalent document, significant unresolved questions exist about the practicability of NEPA compliance through the RCRA RI/FS process.

Is the need for a response to the ORNL situation great enough to justify bypassing the full application of NEPA requirements? This probably would have entailed early public scrutiny and a programmatic EIS before significant (irretrievable?) commitment of resources by the RAP to the RI/FS process. Would a detailed comparison of NEPA procedures with those of RCRA, from initial phases through judicial review, justify a conclusion that they are functionally equivalent? A negative response to this question might mean that the ORNL FS might only be a precursor to a NEPA environmental impact analysis. Although the RI/FS process might exempt the EPA from complying with NEPA requirements, would such an exemption apply equally to DOE? These concerns involve legal questions and DOE policy issues that must be resolved before the RAP can develop a satisfactory NEPA compliance strategy. Specific guidance on NEPA compliance requirements has been formally requested from DOE by the RAP.

Shared responsibilities for DOE programmatic support of RAP activities will be required because sites or facilities with different programmatic affiliations are located in areas that cannot be hydrologically isolated from one another and thus require assessment as part of a WAG rather than as isolated sites. Individual programmatic responsibilities for RAP support during the RI/FS will be defined during FY 1987. Currently, support is being provided by the following DOE programs: Environmental Compliance, Interim Waste Operations, Civilian and Defense Surplus Facilities Management, and TRU-Waste Management.

An attempt will be made to refine further the scope of the RI/FS activity and the schedules in Table 5.2 during the follow-up to the RFA in FY 1987. However, the scope of the ORNL RAP Program and planned activities such as the RI/FS are also subject to change based on overall DOE or federal priority setting under EPA's own developing rulemaking under Sect. 3004(u) of RCRA! Thus, it should be recognized that a parallel federal effort in priority setting may be based on alternative criteria or information and, conceivably, might reach the conclusion that the ORNL RI/FS is not as important as other DOE or federal compliance actions. This points to the need to keep abreast of the developing federal effort in this area and, whenever possible, to provide direct input to this alternative priority-setting process.

Table 5.2. Proposed schedules for ORNL Remedial Investigations/Feasibility Study[a]

Waste Area Grouping	Completion schedules by phases[b,c] (month/year)				
	I	IIA	IIB	III	
	RFA	(RI or	RFI)	AA	FS
1: Main Plant Area	4/87	12/87	9/90	6/91	3/92
3: Solid Waste Storage Area 3	4/87	3/88	9/89	3/90	3/92
4: Solid Waste Storage Area 4	4/87	12/87	3/89	9/89	3/92
5: Solid Waste Storage Area 5	4/87	3/88	9/89	3/90	3/92
7: LLW Pits and Trenches Area	4/87	9/88	3/90	9/90	3/92
8: Melton Valley Area	4/87	6/88	12/89	6/90	3/92
9: Homogeneous Reactor Experiment Area	4/87	3/88	9/89	3/90	3/92
10: Hydrofracture Injection Wells and Grout Sheets	4/87	2/87	9/90	6/91	3/92

[a]Key to abbreviations:

AA	Alternatives Assessment
CERCLA	Comprehensive Environmental Restoration, Compensation, and Liability Act
FS	Feasibility Study
LLW	low-level waste
RCRA	Resource Conservation and Recovery Act
RFA	RCRA Facility Assessment
RFI	RCRA Facility Investigation
RI	Remedial Investigation

[b]Comparison of phases in DOE Order 5480.14, CERCLA, and RCRA Sect. 3004(u):

Phase I is comparable to the EPA's RCRA Facility Assessment or the CERCLA Preliminary Assessment/Site Investigation. RFA covering all units was provided to EPA in April 1987 (ORNL 1987).
Phase IIA is comparable to the EPA's CERCLA Remedial Investigation Plan or the RCRA Facility Investigation Plan.
Phase IIB is comparable to the EPA's CERCLA Remedial Investigation or the RCRA Facility Investigation.

Table 5.2. (Continued)

Phase III is comparable to the EPA's CERCLA Feasibility Study and the RCRA Corrective Measures Study. A single, comprehensive FS has been proposed to cover all of the Waste Area Groupings. Individual Alternatives Assessments will be prepared for each grouping prior to issuance of the final FS.

[c]All schedules following completion of Phase IIA (RI or RFI Plans) are tentative and subject to change based on (1) acquisition of new information from site characterization activities and (2) programmatic reviews by, and negotiations between, DOE and the regulatory agencies. All RCRA units within a grouping that are subject to new or interim-status permit requirements will also adhere to the applicable permit requirements.

5.2 DECOMMISSIONING/CLOSURE PHASE

Upon completion of the RI/FS sequence, major closure or decommissioning actions will be implemented according to priorities and schedules negotiated with the EPA and Tennessee State regulatory authorities. The magnitude of the efforts for long-term management of ORNL sites can only be roughly approximated because site-characterization information is currently preliminary in nature. Programmatic support responsibilities for the major undertaking represented by the Site Decommissioning and Closure phase of the RAP have not been formalized at this time. Initial projections indicated that long-term solutions for dealing with the entire inventory of RAP sites would require a period of 15 to 20 years and the expenditure of approximately $1 billion (unescalated) (Bates et al. 1986; Berry et al. in press).

This initial cost estimate was based on the assumption that capping, hydrologic isolation, and limited in situ grouting, rather than in situ vitrification, would be used to stabilize TRU-contaminated areas (for example, the TRU-waste burial trenches in the SWSAs). Plans were to examine in situ vitrification for potential application to the LLW Pits and Trenches, but the implemental costs were not factored into initial estimates. It may be necessary, however, to apply this technology at the LLW Pits and Trenches and at a variety of other ORNL sites (or portions of sites such as the SWSAs), thereby increasing the potential range in cost estimates for in situ stabilization. Thus, a significant fraction of the initial $1-billion estimate for the entire RAP may be required to deal just with the TRU-contaminated sites (Table 4.1). The resource requirement for in situ stabilization of TRU-contaminated sites at ORNL (limited to well plugging and abandonment for the New Hydrofracture Facility) is estimated to range from $100 to $700 million (unescalated). This is based on the values in Table 4.1 plus an additional $25 to $50 million for environmental monitoring, remedial backup, and performance evaluation.

Meeting the objectives (and the schedule) will require that resources be made available when needed and that the concept of in situ stabilization be accepted. It must be stressed that the resource estimates are based principally on implementation of in situ measures to stabilize wastes at most ORNL sites, in accordance with the strategy outlined earlier (Table 4.1; Trabalka and Myrick, in press). Significant alterations in that strategy (for example, resulting in adoption of exhumation and external disposal as the preferred option), could result in major increases in the resources required for program implementation (Sect. 4.1). (It does not appear reasonable to even consider exhumation as a hypothetical option for dealing with waste migration from the Hydrofracture injection site.)

The total cost of the exhumation option for ORNL is heavily dependent on the degree to which TRU wastes and LLW (and corresponding contaminated soil fractions) can be segregated, mainly in the SWSAs (Sect. 3.2.2). Since the information needed will be developed during the RI/FS phase of the RAP, the outcome, and thus the associated cost, is difficult to project. In order to provide an estimate, a number of assumptions must be made--not the least of which is that in-situ-TRU-assay technology will be expeditiously (and successfully) developed to isolate TRU-contaminated materials at ORNL sites. For purposes of estimation, it is assumed that

(1) by using such technology buried TRU wastes and contaminated soils can be localized within a waste and soil volume that is no greater than twice the sum of extant volume estimates (Table 3.2; Hydrofracture grout sheets excluded) and (2) volumes of poorly characterized materials associated with the LLW system and leak sites will prove to be very small by comparison. This case would thus require that a volume of 38,000 to 134,000 m^3 be exhumed, assayed, processed, and certified into equal portions (19,000 to 67,000 m^3) of TRU waste and LLW, respectively. Based on such assumptions and the volumetric cost estimates developed in Sect. 4.1 (\$14,000/m^3), expenditures for implementing the exhumation option at ORNL could range from \$0.5 to \$2 billion (unescalated). These cost estimates do not include ultimate waste disposal (for example, transportation and geological repository costs for TRU wastes; see Sect. 4.1).

Much greater cost estimates, potentially $\geq$\$7 billion, result if it is assumed that TRU-waste trenches cannot be isolated from alpha-waste or other LLW trenches before exhumation. In such cases, much larger volumes of wastes and contaminated soils ($\geq$500,000 m^3; Table 3.2) would have to be exhumed, assayed, and processed in order to separate TRU-contaminated materials from LLW. However, the extremely large cost differentials involved indicate that intensive development of in situ TRU assay is an obvious necessity--and an extremely cost-effective undertaking--to prevent such cases from becoming reality. This is another illustration of the critical relationship between technology advancements and potential cost-effectiveness of remedial actions, as suggested in Sect. 4.1.

In any of these exhumation scenarios, the potential volume of certifiable TRU waste and contaminated soil involved (>60,000 m^3) is large enough that it could require development of a new geological repository for ultimate disposal of these materials (along with materials from some other DOE sites; ASG 1987). When coupled with the time delays imposed (1) by needed technology development (for example, for in situ TRU assay, exhumation, and onsite processing) and (2) by the logistics associated with exhumation, processing, certification, and shipping of relatively large volumes of TRU-contaminated materials, it appears unlikely that exhumation and offsite disposal could be accomplished in the 15- to 20-year time frame projected for implementation of the in-situ-stabilization alternative.

The current regulatory climate does not appear to permit serious consideration of a continuation of past waste management practices, along with an expanded monitoring effort (that is, a "leave-in-place" option) as an alternative to the RI/FS and, ultimately, site decommissioning and closure to meet new requirements. However, for the sake of comparison, a leave-in-place cost estimate for TRU-contaminated sites in the ORNL RAP has been developed based on 100-year projections of unescalated costs for (1) environmental monitoring under new regulatory requirements and (2) conducting maintenance, surveillance, and limited corrective actions (Berry et al. in press). As with the other cases considered, uncertainties in these estimates are quite large, but, assuming no inflation, it is estimated that monitoring would entail \$50 to \$100 million and maintenance, surveillance, and interim corrective actions, \$50 to \$200 million, for a total of \$100 to \$300 million. For this particular case, projected RAP expenditures for collection and treatment of contaminated groundwater play a major part in determining overall costs of the maintenance, surveillance, and interim-corrective-action component. These expenditures could be greatly reduced (or perhaps eliminated) by the use of capping and hydrologic isolation (estimated cost: $100 million) as an interim corrective action (or limited closure step; for example, see ASG 1987) at most sites. The total costs for the leave-in-place option thus fall within the lower end of the range of costs projected for implementation of in situ stabilization.

Schedules for carrying out decommissioning or closure actions (equivalent to Phases IV and V under DOE Order 5480.14) will be developed during the latter phases of the RI/FS and submitted for DOE, EPA, and State approval. Because of the need to ensure functional equivalence of the RI/FS process with NEPA requirements, it is expected that most major actions will be carried out after completion of the entire RI/FS sequence. However, interim decommissioning or closure actions may also be necessary, and such actions will be identified on a case-by-case basis during execution of the sequence.

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