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Developing a Strategy and Closure Criteria for Radioactive and Mixed Waste Sites in the ORNL Remedial Action Program: Regulatory Interface

J. R. Trabalka

Environmental Sciences Division
Publication No. 2799

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Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A05 Microfiche A01

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ORNL/TM-10228

ENVIRONMENTAL SCIENCES DIVISION

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ENVIRONMENTAL COMPLIANCE PROGRAM
(Activity No. KG 02 00 00 0; ONL-KG02)

Date of Issue -- September 1987

Prepared for the
Office of Basic Energy Research
Office of Health and Environmental Research

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
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U. S. DEPARTMENT OF ENERGY
Under Contract No. DE-AC05-84OR21400

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ABSTRACT

TRABALKA, J. R. 1987. Developing a strategy and closure criteria for radioactive and mixed waste sites in the ORNL Remedial Action Program: Regulatory interface. ORNL/TM-10228. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 80 pp.

Some options for stabilization and treatment of contaminated sites can theoretically provide a once-and-for-all solution (e.g., removal or destruction of contaminants). Most realizable options, however, leave contaminants in place (in situ), potentially isolated by physical or chemical, but more typically, by hydrologic measures. As a result of the dynamic nature of the interactions between contaminants, remedial measures, and the environment, in situ stabilization measures are likely to have limited life spans, and maintenance and monitoring of performance become an essential part of the scheme. The need for monitoring (and maintenance) should not be perceived as casting doubt on the effectiveness of the selected option, but, rather, as a reflection of current reality. Future advancements in technology will depend in large part on our ability to recognize the limitations of existing techniques to deal with contaminated sites.

Site closure actions 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 Oak Ridge National Laboratory (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 the 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. Unique features of the ORNL site and environs appear to be key ingredients in achieving the very long term institutional control necessary for successful financing and implementation of in situ stabilization. The key issue is whether the principal performance objective for site closure actions (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.

Thus, an inescapable summary conclusion is that some formal regulatory interface is necessary to ensure that (1) regulatory limitations and new guidance which can affect planning and implementation of the ORNL Remedial Action Program are communicated to ORNL staff and (2) potential technical and financial limitations which can affect

schedules or alternatives for achievement of long-term site stabilization and the capability to meet environmental regulations are provided to regulatory bodies as early as possible. Such an interface should allow decisions on closure criteria to be based primarily on technical merit and protection of human health and the environment. A plan for interfacing with federal and state regulatory authorities is described.

1. INTRODUCTION AND SCOPE

The Oak Ridge National Laboratory (ORNL) Remedial Action Program represents a comprehensive effort to meet new regulatory requirements and simultaneously ensure adequate protection of on-site workers, the public, and the environment by providing appropriate corrective measures at over 140 sites historically contaminated with radioactive, mixed,* or hazardous chemical wastes. Virtually all of these sites contain either radioactive or mixed wastes (Trabalka and Myrick 1987). A structured path of program planning, site characterization, alternatives assessment, technology development, engineering design, interim corrective action, and eventual site closure or decommissioning is required to meet these objectives. The site closure or decommissioning phase is designed to provide long-term containment of residual radioactive and/or hazardous materials. The specific objective of this phase is to bring each site to a "permanently"† stabilized state, requiring only periodic monitoring and minimal maintenance to ensure proper performance in protecting human health and environment (Berry et al. 1987).

Site closure or decommissioning requires that a series of steps be undertaken in preparation for custodial care to ensure that the site will remain stable without active maintenance. The first step is the development of appropriate performance objectives (Fig. 1, Rose et al. 1985; also see EG&G and DOE 1986). Performance criteria are numerical indices (i.e., radiation dose or hazardous waste concentration limits at specific points in space and time) used to judge or assess whether performance objectives will be or have been met by the stabilization concept of choice. Closure criteria are the performance objectives, performance criteria, and acceptable stabilization options for a given site or category of sites.

"Closure" may be defined as the site condition in which attainment of performance objectives has been demonstrated, and "stabilization," as the physical action(s) required to produce this condition (Fig. 1, Rose et al. 1985; also see EG&G and DOE 1986). It should be noted that the definitions of "closure" in the current U.S. Environmental Protection Agency (EPA) and U.S. Nuclear Regulatory Commission (NRC) regulations are conceptually equivalent to stabilization, and that a "postclosure" (i.e., poststabilization) interval of monitoring, maintenance, and performance evaluation is prescribed by most regulations (see Sect. 3.3). [I do not wish to be too dogmatic about the importance of such semantic differences between definitions, but it is arguable whether a site should be considered closed without suitable evidence that performance objectives are being met (see, for example, Rose et al. 1985; and EG&G and DOE 1986).]

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*Mixed wastes contain radioactive materials excluded from the jurisdiction of the Resource Conservation and Recovery Act and hazardous chemicals regulated under this Act.

†As permanent as human institutions, performance models, and technology permit.

Abbreviations Used in This Report

ACL	alternate concentration limit
AEA	Atomic Energy Act of 1954 (as amended)
ALARA	as low as reasonably achievable
CAA	Clean Air Act
CERCLA	Comprehensive, Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CWA	Clean Water Act
DOE	U. S. Department of Energy
EP	extraction procedure
EPA	U. S. Environmental Protection Agency
FR	Federal Register
FUSRAP	Formerly Utilized Sites Remedial Action Program
LLW	low-level waste
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
NEPA	National Environmental Policy Act
NERP	National Environmental Research Park
NPDES	National Pollutant Discharge Elimination System
NRC	U. S. Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
RCRA	Resource Conservation and Recovery Act
RfD	reference dose
RSD	risk-specific dose
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
SFMP	Surplus Facilities Management Program
SMCL	secondary maximum contaminant level
SWSA	solid waste storage area
TCA	Tennessee Code Annotated
TCLP	toxicity characteristic leaching procedure
TDHE	Tennessee Department of Health and Environment
TDS	total dissolved solids
TRU	transuranic (radioactive waste)
UIC	Underground Injection Control Program
UMTRCA	Uranium Mill Tailings Radiation Control Act of 1978
VOC	volatile synthetic organic chemical

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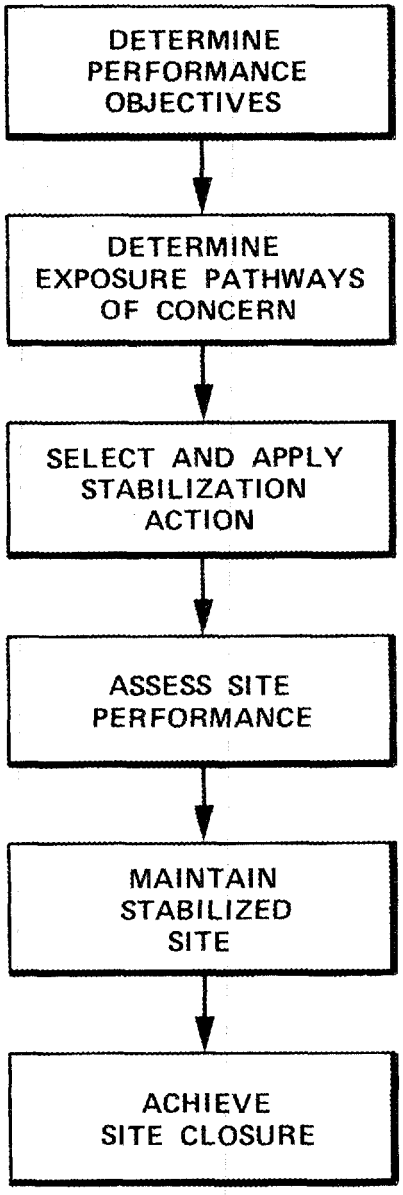

Fig. 1. Overall process of site stabilization and closure. Source: R. R. Rose, C. M. Morrow, L. J. Mezga, W. H. Pechin, and J. S. Baldwin. 1985. Minutes of the Site Stabilization and Closure Workshop, September 13, 1984, Denver, Colorado. 85/147. National Low-Level Radioactive Waste Management Program, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

It also should be recognized that currently operating, or active facilities (e.g., tank systems and land disposal units) are subject to more detailed specifications of technical standards and closure requirements under current regulations than are historically contaminated facilities (Sect. 3.3). The extent to which these detailed specifications may be applied or balanced [i.e., radioactive vs hazardous chemical waste regulations (Sect. 3.3.4)] by regulatory authorities to direct ultimate closure or decommissioning actions at historically contaminated sites in remedial action programs remains a major unresolved issue (Sects. 3.3.5, 3.3.6, and 3.3.7).

Experience with long-term performance of stabilization measures required for "permanent" site closure or decommissioning is very limited, particularly at the watershed scale currently envisioned for ORNL (Trabalka and Myrick 1987). The performance of remedial actions proposed for ORNL sites must be evaluated both individually and collectively; that is, their relative contributions to changes in the radioactive and/or hazardous waste content in groundwater and surface water must be assessed at specific discharge points in the White Oak Creek watershed and at the appropriate interface with connecting waters such as the Clinch River. Other pathways for human exposure (e.g., from air and food chains) may also be significant under certain circumstances and must be evaluated in such an assessment, that is, by performance modeling before, and both monitoring and modeling after, stabilization (Gilbert et al. 1985; EG&G 1986; EG&G and DOE 1986).

The complexity of the ORNL site and the magnitude of current projections of the overall resources needed for completion of remedial measures [estimated to be approximately one billion unescalated dollars (Berry et al. 1987)] dictate that closure criteria be established very early in the ORNL program to guide necessary actions and ensure the most efficient application of available resources. However, closure criteria and programmatic strategy are strongly interrelated. It is important, therefore, to recognize that alterations in the current strategy, which is based almost exclusively on the concepts of in situ stabilization and facility decontamination for reuse (Berry et al. 1987; Trabalka and Myrick 1987), would have a significant impact not only on the programmatic costs but also on the development of closure criteria.

Because these linkages exist, development of closure criteria and programmatic strategy must proceed in parallel, and it is necessary to address a number of important strategic questions very early. Are there technical, institutional, or regulatory limitations which make the currently proposed strategy infeasible and other alternatives more desirable? How effective must remedial measures be to satisfy regulatory requirements, and for how long a time must these measures remain effective? Are truly "permanent" solutions available at the current state of the art for application, in situ or otherwise, to ORNL-specific waste and environmental problems?

Providing answers to these questions requires that a review and analysis of a variety of technical, institutional, and regulatory issues associated with stabilization and closure be an integral

component in the development of a programmatic strategy. This also means that a framework for the acceptance of programmatic strategy and closure criteria by appropriate regulatory authorities must be developed. This report is designed to provide a survey and preliminary analysis of key issues, along with recommendations for (1) an overall Remedial Action Program strategy and basis for closure criteria and (2) a suggested framework for achieving the necessary interface between ORNL and the regulatory agencies.

2. CONCLUSIONS AND RECOMMENDATIONS

Some options for stabilization and treatment of contaminated sites can theoretically provide a once-and-for-all solution (e.g., by removing or destroying contaminants). Most realizable options, however, leave contaminants in place (in situ), potentially isolated by physical or chemical, but more typically, by hydrologic measures. As a result 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, and maintenance and monitoring of performance become an essential part of the scheme. The need for monitoring (and maintenance) should not be perceived as casting doubt on the effectiveness of the selected option, but rather as a reflection of current reality. Future technology advancements will depend in large part on our ability to recognize the limitations of existing techniques to deal with contaminated sites.

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. Unique features of the ORNL site and environs appear to be key ingredients in achieving the very long term institutional control necessary for successful financing and implementation of 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.

Current information on technical, institutional, and regulatory considerations leads to the following specific conclusions concerning the ORNL Remedial Action Program:

(1) Exhumation of the bulk of the contaminated materials (e.g., wastes, soils, sediments) from ORNL remedial action sites and greater-confinement disposal at an off-site location (or a new dedicated disposal facility on-site) is a very costly and highly unrealistic option.

(2) Long-term effectiveness of technologies for containing contaminants in situ cannot be ensured without some form of institutional oversight and evaluation.

(3) Long-term limitations on future uses of ORNL site lands and waters appear to be necessary, even desirable, for preservation of environmental quality and protection of human health and the environment.

(4) A carefully phased series of site stabilization steps (including research and development, initial implementation, monitoring, maintenance, performance reviews, and system modification, as appropriate) appears to be most compatible with current information and needs, such as

   (a) very low risks to off-site residents posed by current releases from ORNL radioactive and hazardous waste sites,
   (b) realities of the limitations on short-term availability of large sums of federal funds to finance remedial actions,
   (c) complex site characteristics and the limitations of remedial action technologies currently available,
   (d) need for long-term evaluation of existing technologies and development of innovative technologies, and
   (e) ORNL research mission and demonstrated capabilities, coupled with the designation of Oak Ridge Reservation as a National Environmental Research Park and Tennessee Wildlife Management Area.

(5) Most regulatory guidance is aimed at requirements for new facilities and thus provides information only indirectly applicable to, and therefore difficult to interpret for, remedial action sites.

(6) Considerable ambiguity remains about important aspects of EPA's radioactive and hazardous waste regulations, particularly with regard to requirements for remedial actions, including

   (a) no existing criteria for cleanup of land and facilities contaminated with radioactive materials (51 FR 22264*) or hazardous chemicals (51 FR 25457), or for application of the corrective action provisions of the 1984 Amendments to the Resource Conservation and Recovery Act (RCRA) (Garvey 1986a; 51 FR 7722-7723),
   (b) unclear definition of historical waste management unit boundaries [e.g., individual trench vs. entire solid waste storage area (SWSA) vs larger area consisting of SWSA, external contiguous contamination zone, and surrounding buffer zone on federally controlled site] for application of hazardous waste regulations to corrective actions at mixed-waste sites (e.g., 51 FR 1700-1701),

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*51 FR 22264 stands for Federal Register, vol. 51, p. 22264. The abbreviated form is used throughout this document for convenience.

(c) no current resolution of the impasse over regulation of mixed wastes (Garvey 1986c,d), new EPA standards on low-level waste (LLW) disposal expected in fiscal year (FY) 1987 (51 FR 38934), and negotiable radiation exposure limits in some regulations (40 CFR Part 61,* 40 CFR Part 191),

(d) new regulations on alternate concentration limits (ACLs), including the use of hydrogeologic barriers (not previously allowed) as part of an ACL demonstration, expected in FY 1987 (51 FR 38947), and

(e) new liner and leachate collection system design and construction guidance documents for RCRA-regulated units now in preparation (50 FR 28709).

(7) Remedial actions under the terms of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and RCRA regulations [as well as the National Environmental Policy Act (NEPA) and the as-low-as-reasonably-achievable (ALARA) principle for limiting radiation exposures under U. S. Department of Energy (DOE) Orders] require a case-by-case evaluation, hence implied flexibility but also much uncertainty about how the broad narrative standard to protect human health and the environment will be enforced [50 FR 28713, 50 FR 47920-47924, Superfund Amendments and Reauthorization Act (SARA) Sect. 121].

The fluid nature of the regulatory environment, literally changing while this document was being finalized, makes it difficult to determine the extent to which some of the conclusions reached can be applied to the ORNL Remedial Action Program. Thus, an inescapable summary conclusion is that some formal regulatory interface is necessary to ensure that regulatory limitations and new guidance which can affect program planning and/or implementation are communicated to ORNL staff as early as possible. It is also important that potential technical and financial limitations, which could affect schedules and/or design alternatives for achievement of long-term site stabilization and the capability to meet environmental regulations, are communicated to EPA and Tennessee Department of Health and Environment (TDHE) regulatory staff early on. Such an interface should allow decisions on closure criteria to be based primarily on technical merit and protection of human health and the environment.

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*40 CFR Part 61 stands for Title 40, Code of Federal Regulations, Part 61. The abbreviated form is used throughout this document.

Adoption of the basic RCRA closure performance standard (40 CFR Part 265.111 (a), (b); see p. 45 of this report) for all sites in the ORNL Remedial Action Program (through the addition of wording to include radioactive and mixed wastes), coupled with a program policy statement directed at (1) near-term control of the critical pathway represented by surface water releases and (2) compliance with the intent of the RCRA groundwater protection standard over the long term, by means of site corrective actions, may be a useful starting point. A plan for interfacing with regulatory staff from DOE, EPA, and the state of Tennessee (e.g., through regular meetings, and periodic exchanges of information, progress, and ideas) to involve them in the overall process, and vice versa, is described below.

The proposed target date for concurrence by regulatory authorities in the definition of a long-range strategy and closure criteria for the ORNL Remedial Action Program is the end of FY 1988, prior to initiation of alternatives assessments on major ORNL waste area groupings (Trabalka and Myrick 1987). The proposed framework for achieving this objective involves a series of steps as outlined in Table 1.

It is recommended that a Closure Criteria Committee, consisting of representatives from DOE, EPA, TDHE, and Martin Marietta Energy Systems, Inc. (hereafter called simply Energy Systems--staff from ORNL, the Oak Ridge Gaseous Diffusion Plant, the Y-12 Plant, and the Central Staff Organization) be formed no later than the fourth quarter (4Q) of FY 1987. A survey paper, highlighting key technical, institutional, and regulatory issues and containing initial recommendations on an overall strategy and basis for development of closure criteria, would be provided by the ORNL Remedial Action Program to initiate the committee's deliberations. It is proposed that the present document, including the strategy and closure criteria recommendations in Sect. 4, be considered the survey paper.

The recommended course of action is (1) presentation of the contents of the survey paper at the first formal meeting of the Closure Criteria Committee in 4Q-FY 1987 (following initial meetings of the DOE and Energy Systems representatives to review key issues and findings); (2) elicitation of responses from the EPA and TDHE representatives at a second formal meeting to be held in 1Q-FY 1988; (3) parallel in-house development of a strategy and an associated set of preferred closure criteria by the Energy Systems representatives, along with (4) preparation and implementation of a plan for negotiating potential options and preferred alternative(s) with regulatory authorities. The last of these steps will require periodic meetings (at least quarterly) with regulatory staff (EPA and TDHE) in FY 1988, following the strategy development phase, until related site closure criteria have been formulated and recommended by Energy Systems and DOE staff and negotiations with regulatory authorities have been completed.

The development of closure criteria will require a continuing review and evaluation of (1) the status of negotiations between ORNL and the EPA and state regulatory authorities, (2) relevant experience and unique requirements at other DOE contractor facilities, (3) potential options for site closure, and (4) new and evolving

Table 1. Proposed framework for development of a strategy and closure criteria for the ORNL Remedial Action Program

Steps	Objectives[a]
1	Formation of EPA/Energy Systems/ORNL/DOE-ORO/TDHE Closure Criteria Committee in 4Q-FY 1987
2	ORNL survey paper providing analysis of key institutional, regulatory, and technical issues, with initial recommendations on strategy and basis for closure criteria for Committee review and deliberations in 4Q-FY 1987
3	Quarterly committee meetings, supplemented by additional periodic exchanges of information, progress, new ideas from ORNL Remedial Action Program, including submittal of the Program's strategy document in 1Q-FY 1988
4	Establishment of an approved ORNL Remedial Action Program strategy and basis for development of closure criteria by 2Q-FY 1988
5	Draft set of closure criteria for review by all parties in 3Q-FY 1988
6	Establishment of approved closure criteria set for ORNL Remedial Action Program by 4Q-FY 1988

[a]4Q = fourth quarter; FY = fiscal year; EPA = U.S. Environmental Protection Agency; Energy Systems = Martin Marietta Energy Systems [Oak Ridge National Laboratory (ORNL), Oak Ridge Gaseous Diffusion Plant, Y-12 Plant, Central Staff Organization]; DOE-ORO = Oak Ridge Operations Office of the U.S. Department of Energy; TDHE = Tennessee Department of Health and Environment.

regulatory requirements (including feedback from Closure Criteria Committee deliberations). These criteria will be formulated in coordination with ORNL Remedial Action Program staff engaged in developing site performance models. Interaction will be necessary to ensure that the output of the models can be used to assess the effectiveness of remedial measures, both individually and in the context of overall site performance.

The survey paper (present report) was scheduled to be completed by early 4Q-FY 1987, prior to revision and update of the Remedial Action Program strategic planning document. It is recommended that submittal of the present report to the Closure Criteria Committee in 4Q-FY 1987 be followed by that of the Program's overall strategy document early in 1Q-FY 1988 (Table 1).

An attempt will be made to obtain regulatory concurrence on the Program strategy and basis for development of closure criteria by 2Q-FY 1988, to define a draft set of related closure criteria by 3Q-FY 1988, and to obtain EPA and TDHE concurrence on a set of closure criteria by the end of FY 1988 (Table 1).

3. DELINEATION OF KEY ISSUES

3.1 TECHNICAL CONSIDERATIONS AFFECTING THE CHOICE OF STABILIZATION CONCEPT

3.1.1 Background

There are strong environmental, economic, and social reasons for dealing with contamination without removing it from where it is found; hence, the initial focus in the ORNL Remedial Action Program has been on waste stabilization in situ and decontamination of facilities for reuse where practical (Bates et al. 1986; Berry et al. 1987). Although the most direct and obvious solution might appear to be removal of the offending contaminated materials for treatment or disposal elsewhere, this is often not practicable or desirable, nor does it necessarily represent a permanent solution in the broadest sense. Redeposition of excavated materials in an offsite location (e.g., commercial disposal facility) may simply move problems elsewhere (to be rediscovered by later generations).

Excavation, processing and certification, interim storage, and transport of contaminated materials can be technically difficult, hazardous to personnel, and very costly (Oma et al. 1983). For example, the costs for disposal at the ORNL site of excavated materials which could be classified as low-level radioactive waste (LLW) are currently expected 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 potential options for ORNL sites are an order of magnitude less costly. Thus, preliminary cost estimates for exhumation options for 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 might become significant underestimates if remedial-action-site waste toxicity (see Oma et al. 1983), bulk (as much as 2 million cubic meters of contaminated soils and sediments), and logistics, including ultimate closure of the disposal operation, were incorporated into a more detailed analysis.

Most of the currently available options for dealing with contaminated soils or sediments in situ rely on engineering solutions. It is therefore important to understand the following lessons drawn from civil and structural engineering before setting performance objectives for engineered options (Smith 1985):

(1) The properties of materials and components deteriorate with time, so any structure has a foreseeable and limited life.
(2) Consequently, it is necessary to monitor performance and to carry out maintenance to ensure continued performance to an acceptable standard.

(3) A need exists to design for both natural and man-made interventions of a catastrophic type (e.g., 100-year floods and intruder scenarios).

Monitoring and routine maintenance are normal activities for significant structures such as bridges, dams, and roads, and may be presented as an entirely appropriate way of managing the residual risks arising from current uncertainties in knowledge and practices for dealing with contaminated sites.

For obvious reasons, there is a desire to avoid treatment options which require a commitment to regular routine maintenance. Yet, a covering (capping) system that includes vegetation, for example, is by nature dynamic, and loss of vegetation and consequent erosion of the soil cover may lead to failure of the system as a whole. Still, it is important that such a system not be so dependent on regular maintenance that its omission could result in rapid overall failure.

Underlying the practical problems of reclamation of contaminated sites is the quest for "permanent" solutions and, indeed, whether they are possible at all. In defining expectations for long-term effectiveness, the questions of what can be achieved and what the aim should be needs to be explored carefully. Thus, the discussion of long-term effectiveness or performance must be both philosophical and technical: What do "effective" and "long-term" mean (see Sect. 3.3.5)? In the majority of cases, the stabilization measures employed have not been scientifically demonstrated to be effective. Instead, the measures chosen are usually based on professional judgments or predictions of behavior on the basis of very little practical experience and in the absence of field demonstration data.

Thus, the most important consideration in setting the performance objectives is the future use of the site and environs and whether this use can be guaranteed or controlled. Another is that all remedial measures that do not result in complete removal and destruction of contaminants are likely to need some attention to ensure continued effectiveness.

Next, a judgment must be made about how long a given stabilization measure will remain adequately effective. So limited is our knowledge that a seemingly desirable design life of 100 years (or more, as given in 10 CFR 192) may be frequently unrealistic. It may be more realistic to design with confidence for a comparatively short life (e.g., 30 years) than to make unrealistic claims for 100 years and beyond. This raises two important related issues: (1) the need to monitor the effectiveness of a given measure, and (2) the likelihood that future weaknesses or failures can be remedied.

Currently, the prospects for permanent closure of some waste sites containing long-lived actinides (e.g., uranium, plutonium) or toxic stable elements (e.g., mercury) seem rather dim, and existing stabilization and regulatory closure guidance is clearly inadequate. Once the lack of permanency is accepted, the main philosophical problem regarding the design of remedial measures will be overcome. One potential approach to such problems at ORNL is to design for control and decay in situ of shorter-lived fission waste products, such as

^{90}Sr. Passive measures designed to provide greater long-term confinement (e.g., in situ vitrification) could be exercised at sites (or portions of sites) contaminated with transuranic wastes or equivalent hazardous constituents. This approach would (1) provide a period sufficiently long for evaluation of the effectiveness of environmental processes and passive remedial measures in controlling the migration of the longer-lived but less-mobile actinides, (2) allow additional time needed for development of new technologies for more permanent site stabilization, and (3) reduce the need for immediate implementation of the more-expensive exhumation and disposal option. An objective of no migration seems inadvisable for uranium because of the long-term increase in hazards from the buildup of highly toxic decay products (Pa, Ra, Rn, and Th; see Kocher 1981 and Table 2 in Sect. 3.3.4).

3.1.2 Alternative Strategies

Stabilization measures may be classified for convenience into the following categories:

- Removal (exhumation or dredging) and redeposition, generally off-site; not considered in detail here for reasons outlined earlier, but not excluded from consideration (i.e., for specific circumstances, as discussed in Section 3.3.5). Also see Cristy and Jernigan 1981 and Fore et al. 1982 for supplemental reviews and reference sources.
- In situ measures (Stief 1985).

  (1) On-site processing of contaminated materials.
  (2) In situ treatment of contamination.
  (3) Covering and capping the contaminated materials.
  (4) In situ macroencapsulation (barrier systems).
  (5) Hydrologic (or hydraulic) measures.

3.1.2.1 On-site Processing

On-site processing encompasses methods for decontaminating the site or reducing environmental impact through the following series of steps: (1) exhumation, excavation, or dredging; (2) treatment to detoxify, neutralize, or solidify; and (3) redeposition of the treated materials (on-site). Because treatment directly at the excavation site may not always be practical, the contaminated materials may actually be treated elsewhere (increasing costs and transportation risks). A large number of processes (originating from operational experience in waste treatment and ore processing) are available for such treatment. Examples potentially applicable to ORNL sites might involve exhumation of certain burial trench (or auger hole) contents, followed by grinding and/or shredding, and either extracting radionuclides or hazardous wastes from nonhazardous materials or employing slagging pyrolysis to incorporate contaminants into a more stable waste form (e.g., Kibbey and Godbee 1980). Selection of on-site processing as a remedial action alternative requires consideration of several unique factors, including

(1) waste streams resulting from the treatment and their disposal, and (2) relatively high costs (for relatively large sites) when compared with other options, such as in situ treatment and macroencapsulation (Rulkens et al. 1985).

3.1.2.2 In Situ Treatment

In situ treatments are applied without excavation of the materials to be treated. Conceptual possibilities include grouting (e.g., Caron 1982; Spalding et al. 1985; Davis and Spalding 1986); solvent extraction (Sanning 1985); microbial degradation for certain organic wastes (e.g., Roop et al. 1983); chemical neutralization, solidification, or degradation (Sanning 1985); dynamic compaction (e.g., Spalding 1986); and electroosmosis (Sanning 1985). Most of these systems require injections of fluids into land-burial trenches, soils, or sediments in some manner (e.g., Spalding 1984; Spalding and Munro 1983; Spalding et al. 1985), although deep plowing or other methods of strata inversion are less complex examples of in situ treatment (Trabalka 1981; Sanning 1985).

Thermal fusion, or vitrification, methods (e.g., Oma et al. 1983; Buelt et al. 1987) also fall into this remedial measures category. Although in situ vitrification is currently being examined for use in stabilizing some ORNL remedial action sites (Bates et al. 1986), this technique has not been demonstrated beyond the pilot scale for radioactive wastes (or the bench scale for hazardous chemical wastes) containing volatile materials (such as ^{137}Cs). Thus, current efforts associated with this technology in the ORNL Remedial Action Program must be classified as research and development. This is but one example of the need for such activities in the program.

In situ treatments will usually be employed in concert with other containment options and are subject to many restrictive factors. None of the available on-site processing or other in situ techniques appear to be generally applicable, particularly to large areas contaminated with mixed wastes. The available methods are not novel, but their application to treatment of contaminated sites represents a major change in application (Sanning 1985).

3.1.2.3 Covering and Capping

The covering of offensive materials is an instinctive reaction that has been practiced throughout human history (Parry and Bell 1985). Covering systems for contaminated sites may be used alone or in combination with vertical and horizontal in-ground barriers to achieve greater isolation, or macroencapsulation, of a site. Thus, the isolation process, in its extreme form, may involve attempts to completely enclose the site and its contents within a barrier impermeable to the movement of water and pollutants from all directions. Because this process is extremely costly, a covering layer is often used as a cost-effective alternative. The term "covering

layer" is preferred over "capping" by some (e.g., Parry and Bell 1985); the latter has apparently been defined as requiring a totally impermeable layer--generally not a possible (or desirable) option.

Although it is possible to design a covering system to achieve a rigid set of physicochemical and structural criteria (e.g., EPA 1982), economic considerations often dictate the use of locally available materials to best advantage rather than the use of ideal materials (Parry and Bell 1985). The performance of covering materials is particularly time dependent: the condition of the covering materials and contaminant mobility will change with time, and environmental stress on the materials may increase (51 FR 10708; Davis and Spalding 1986; Spalding in press). The properties of all synthetic materials [also natural materials (Voorhees et al. 1983; Nelson et al. 1986)] are likely to deteriorate with time. The lack of historical evidence on performance, the changing properties of construction materials, and the long time scales involved in remedial measures make predictions of the long-term performance of covering systems quite difficult.

3.1.2.4 In Situ Macroencapsulation

The construction of bottom seals and vertical walls at contaminated sites may be done to (1) encapsulate the source of contaminants (e.g., wastes or soils) or (2) modify the local environment to create a diversion or separation of the contaminant plume in groundwater (Childs 1985a). However, currently available techniques, materials, and procedures cannot provide either total or permanent isolation of the contaminants. Encapsulation measures do not change the hazardous nature of materials, and in undertaking stabilization measures, one runs the risk of changing the local environment such that further opportunities for environmental movement of the contaminant may be provided. System failure due to reactions between the contaminants and the encapsulating materials may release the original target contaminants and/or toxic reaction products. Care must also be taken to ensure that contaminants are not released to the surrounding environment by construction activities.

The barriers may have significantly lower permeability than the materials they replace, but they are still permeable, and encapsulation acts merely to retard, not eliminate, movement of contaminants. Macroencapsulation measures usually require a significant initial investment and should be designed for the longest effective, predictable, or reasonable life expectancy. Monitoring of system performance should be considered essential (Childs 1985a).

3.1.2.5 Hydrologic Measures

Liquid-phase management of contaminants (e.g., in groundwater) using hydraulic and/or hydrologic manipulation is believed to have great potential, principally because the science of hydrogeology has been successfully applied to practical problems for many years. Measures such as extraction wells (Prudic and Randall 1979), drains

(Davis and Stansfield 1984; Melroy and Huff 1985; Bates et al. 1986), and bypass canals (Trabalka et al. 1979, 1980), might also be used in conjunction with barriers [e.g., vertical walls or dams (Duguid 1976; Trabalka 1981; Childs 1985a)] or permeable treatment beds (e.g., Childs 1985b; Buelt and Freeman 1986; Freeman et al. 1986). Such combinations can increase effectiveness and reduce the volumes of contaminated effluents which require separate treatment and disposal (e.g., from well pumping or leachate collection schemes).

The greatest concerns about the effectiveness of hydraulic or hydrologic systems involve external influences which frequently are remote from the site and not subject to effective control. Power sources and mechanical systems may fail, drains may clog, groundwater and surface-water conditions are subject to influence by climate fluctuations, remote well extraction, etc., and the rate of contaminant release may fluctuate. All of the elements in a hydrologic system change with time either naturally or by imposition of factors such as those described above. Such systems are dynamic, and continuous monitoring of performance, regular maintenance, and periodic reviews pursuant to system adjustments or modifications are imperative (Childs 1985a).

3.1.3 Preliminary Conclusions

Some options for stabilization and treatment of contaminated sites can theoretically provide a once-and-for-all solution (e.g., by removal or destruction of contaminants). Most realizable options for ORNL waste and environmental conditions, however, leave contaminants in place, isolated by physical or chemical, but more typically, by hydrologic measures. Such contaminant stabilization processes must be examined carefully to predict their long-term effectiveness. Because of the dynamic nature of contamination sources, remedial measures, and the environment in which they must operate, stabilization measures that do not result in complete elimination of contamination are likely to have limited life spans.

The monitoring of such measures should be part of the scheme. Such monitoring is an essential part of civil engineering projects and should not be perceived as casting doubt on the effectiveness of the selected option. 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 B.P. (Shirley 1981). Maintenance is likely to be required whenever a 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.

Predictions of performance are difficult because of the uniqueness of each individual case and the current lack of data on long-term effectiveness of specific options. Very few of the available technologies, other than hydrologic isolation systems, have been

sufficiently proven in short-term applications specific to treatment of contaminated sites even though they may have been tried for other purposes. The development of on-site and in situ processes for removing or destroying contaminants should be encouraged as providing more reliable, permanent solutions. It is important that long-term evaluation studies be established; properly planned and monitored demonstration projects appear to have a valuable role.

Future technological advancements will depend in large part on our ability to recognize the limitations of existing techniques to deal with contaminated sites. The commonly held belief that resources spent on research mean less for remedial actions is without merit. Reliance on a bootstrap approach in dealing with contaminated sites is contrary to the fundamental lessons learned from the success of high technology endeavors in the modern world (Sanning 1985).

3.2 INSTITUTIONAL CONSIDERATIONS RELATING TO SITE CLOSURE

3.2.1 General Philosophy

In light of the preceding discussion, the length of formal institutional control over the ORNL site and environs and related questions of future uses of the land and waters are of paramount importance. The selection of so-called intruder scenarios to be used in judging the potential performance of stabilization alternatives is also affected by these questions (see, for example, Gilbert et al. 1985; EG&G 1986). The nature of record keeping (e.g., locations, types, and quantities of contaminants, treatments carried out, etc.) and provisions for physical markers to define the geographic extent of contamination, as well as the scope of custodial care (and its financing), are similarly affected.

Stabilization measures must also be affordable. The priority attached to treatment of a given site, and to the specific hazards presented, will differ in the various levels of society: community, state, or federal. What may be of highest priority from a state's point of view may be of low priority from the federal government's perspective (see, for example, 51 FR 7723). The U.S. Congress recognized these potential conflicts and addressed them in legislation for the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (see Sects. 3.3.6 and 3.3.7).

When public funds have to be spent, it is important to achieve a realistic, long-term solution, and not to simply apply expensive, overengineered solutions or cosmetic treatments with questionable long-term utility. On the other hand, financial limitations may also lead to unrealistic claims and expectations about the long-term effectiveness of stabilization measures. It is better to be completely candid and objective about what is practical from both a technical and financial perspective.

Economic factors will affect the ORNL Remedial Action Program in two ways: (1) mode of financing and (2) selection of technical alternatives for remedial actions (see Sect. 3.3.6). A program of the magnitude currently envisioned, nearly 1 billion unescalated dollars, will require a structured federal financing effort over a period of decades to centuries, depending on the schedules proposed for implementation, evaluation, monitoring, and maintenance. However, limited availability of resources could limit the scope of remedial actions and dictate significant changes in the proposed schedules and strategy for the ORNL program. There are several ways in which this might occur.

Both regulatory bodies and federal agencies affected by regulations routinely perform analyses of the economic impacts of the regulations. Results of such analyses may be used to decide whether to seek congressional relief, interagency agreements, or changes in regulations (through the review and comment process) to lessen the economic impacts on federal facilities. The changes in the Final Rule implementing the CERCLA National Contingency Plan relative to compliance with state standards may well reflect the input from federal agency reviews (see 50 FR 47923ff.). Other limitations might result from congressionally imposed funding restrictions, that is, a pragmatic balancing of the costs and benefits of the ORNL Remedial Action Program against overall national needs for waste site cleanups and current economic realities, such as the burgeoning federal deficit. These possibilities dictate that a sound, defensible, long-term strategy be developed for the ORNL program, recognizing the potential for an adverse Congressional reaction to an unrealistic demand on the shrinking pool of federal resources. This becomes all the more important when one considers the very low risks to off-site residents currently posed by ORNL's radioactive and hazardous chemical waste releases (Sects. 3.3.4.1 and 3.3.6; Martin Marietta Energy Systems 1986; Oakes et al. 1987).

> "EPA agrees that it is rational as a matter of public policy to address the most seriously contaminated facilities first. Moreover, since the funding for corrective action is not unlimited, priorities would help maximize the use of available funds . . . EPA intends to develop rules that would allow federal agencies, subject to EPA approval after consultation with the states, to set priorities for correcting releases from solid waste management units that they own or operate" (51 FR 7723).

Taking all of this into consideration, federal financing for the ORNL Remedial Action Program at a relatively moderate rate of expenditure (i.e., over a longer time period) may be much more feasible than a large outlay of funds over a single decade, for example. The appropriation of funds at a moderate annual rate is not only more affordable than a short-term, lump-sum outlay of funds, but also fiscally more attractive when the lost revenues associated with a short-term, lump-sum investment are considered (e.g., lost interest accrual or investment return).

There also may be significant advantages to be gained from a technical and institutional viewpoint through a program strategy focused on a broader time horizon: Optimization of stabilization measures through improved performance assessment and technology development. The key issue is whether human health and the environment can be protected adequately using such an approach.

Given the current uncertainties associated with ensuring the long-term effectiveness (and financing) of stabilization measures, it is difficult to see how any option other than very long term institutional control, as permanent as human institutions can make it, could reasonably be considered viable for remedial action sites on large federally owned reservations. Long-term control by federal and/or state authorities also appears to be consistent with some desirable future land- and water-use options (e.g., outdoor recreation). Such control could, at the same time, obviate the need to consider complicated protection systems for low-probability intruder scenarios in developing performance criteria (see following section). A resultant benefit might be a more realistic, defensible assessment of potential human exposures to radioactive and hazardous chemical materials through pathways analyses.

3.2.2 Applicability to the ORNL Site

Five DOE sites throughout the United States have been designated as National Environmental Research Parks (NERPs) over the past decade. These sites are to be protected for use as outdoor laboratories in which to conduct a wide range of research and demonstration projects necessary to address systematically the environmental impacts of human activities, including radioactive and hazardous waste management (Preston and Kitchings 1984).

Over one-third of the DOE Oak Ridge Reservation has been designated as one such site, and the Oak Ridge Reservation has the added distinction of being classified as a Tennessee Wildlife Resources Agency Wildlife Management Area (TWRA-WMA). Successfully managed public hunts conducted during 1985 and 1986 yielded 926 deer, and an additional benefit was the verification of a screening technique for radioactive contamination used for the first time in connection with the hunts (Lundy 1986; Oakes et al. 1987). This activity has been conducted with no deleterious impact on ORNL operations and facilities, and only 2.3% of the deer have been confiscated because their levels of radioactivity did not meet the screening test (Keto 1986; Martin Marietta Energy Systems 1986; Oakes et al. 1987).

The potential contributions of the Energy Systems staff and facilities to research, development, and demonstration of innovative methods for waste treatment and disposal have been recognized by the Tennessee Department of Health and Environment (TDHE) in its review of the Draft Environmental Impact Statement for the proposed Central Waste Disposal Facility (Bruner 1984). The capabilities of ORNL scientists in modeling and assessing the migration of contaminants from waste

storage units has also been recognized on numerous occasions by the EPA [e.g., in the selection of ORNL to conduct a research program for development of the Toxicity Characteristic Leaching Procedure (51 FR 21648-21693; EPA 1986b; Francis and Maskarinec 1986) and of an ORNL groundwater contaminant transport model (Yeh 1981) for analyses in Case Study A in the draft ACL Guidance Manual (EPA 1985)].

It is also significant that TDHE recommended that "use of sites where groundwater contamination or potential contamination already exists as (a) a permanent solution, (b) an interim solution while research for other alternatives proceeds, and/or (c) as a study area for the preferred design" be evaluated in developing a new waste disposal facility on the Oak Ridge Reservation (Bruner 1984). This recommendation has even greater significance when considered in the context of the very low risks to off-site residents posed by current ORNL radioactive and hazardous chemical waste releases (Sects. 3.3.4.1 and 3.3.6; Martin Marietta Energy Systems 1986; Oakes et al. 1987).

Given the fact that the ORNL site also borders Melton Hill Reservoir, future use of the site (at least in part) as a wildlife reserve and outdoor recreation area does not appear to be inconsistent with research and evaluation of the long-term effectiveness of stabilization or closure actions. Intermittent consumption of surface water and site biota could then be the most severe intrusion scenario assumed in analyzing site performance. It appears probable that institutional controls--either passive (markers, barriers) or active (patrols, monitoring procedures)--and the temporary residence patterns of a typical human intruder (e.g., a few days in a recreational setting) would serve to greatly limit exposures to radioactive and/or hazardous materials (also see discussion on inadvertent human intrusion into geological repositories in 40 CFR Part 191, Appendix B).

Provision of long-term institutional control for the ORNL site should also greatly simplify procedures for ensuring that accurate records are maintained and updated appropriately as conditions change. Such considerations also improve the likelihood that passive controls, such as barriers and permanent markers, will remain effective and further limit human intrusion and exposures at remedial action sites. Maintenance and dedicated custodial care will significantly increase the prospects for success of passive controls, as demonstrated by long-term human experiences involving preservation of sacred religious relics, cemeteries, and buildings (churches, cathedrals, and abbeys).

3.2.3 Preliminary Conclusions

It appears that very long term institutional control of the ORNL site may be a very necessary and highly desirable ingredient in financing and implementing successful closure of ORNL remedial action sites. The unique features of the ORNL site and environs (NERP, TWRA-WMA, Melton Hill Reservoir, and ORNL's environmental and waste management research mission) appear to be highly compatible with this concept. Long-term institutional control and oversight should also

obviate the need to consider highly speculative and low-probability human intrusion scenarios in the development of closure criteria, and should provide the necessary framework of monitoring, maintenance, and surveillance to ensure the long-term effectiveness of stabilization measures.

3.3 REGULATORY CONSIDERATIONS DEALING WITH KEY CLOSURE ISSUES

3.3.1 Background

The Remedial Action Program is being implemented during a period of unprecedented change in national policy toward waste management. The ongoing attempt by the Congress and various federal and state agencies to delineate and implement that policy has resulted in an evolving regulatory picture within which major issues remain unresolved. The primary legislation that is potentially applicable to ORNL remedial actions includes the Atomic Energy Act (AEA; last amended in 1985), the Clean Air Act (CAA), the Clean Water Act (CWA; amended in 1987), the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA; amended in 1986), the National Environmental Policy Act (NEPA), the Resource Conservation and Recovery Act (RCRA; amended in 1984), the Safe Drinking Water Act (SDWA; also amended in 1986), and the Toxic Substances Control Act (TSCA). Although CERCLA, RCRA, and TSCA provide legal stimuli for undertaking corrective measures, it is the regulatory standards derived primarily from the AEA, CAA, CWA, and SDWA which determine the rigor of the environmental response required to protect human health and environment. For major federal environmental actions, NEPA defines the process by which decisions are made and implemented, but its applicability to RCRA and CERCLA remedial action programs is unclear, as is the specific applicability of RCRA and CERCLA to individual ORNL sites (Trabalka and Myrick 1987).

Regulatory requirements under the Atomic Energy Act (as amended, including U.S. Department of Energy Orders), CAA, CERCLA, CWA, RCRA, SDWA, and related legislation by the state of Tennessee must be considered in formulating closure criteria for the ORNL Remedial Action Program. Regulatory guidance on the subject of LLW-site closure, stabilization, and related performance objectives, although not directly applicable to all ORNL sites, is contained in a variety of sources (10 CFR Part 61, 40 CFR Part 61, 40 CFR Parts 190-192, and DOE 1987b). Appendix A (as amended, Lenhard 1986) to Order OR 5820.2 of DOE's Oak Ridge Operations Office (DOE 1985) provides all current DOE and NRC regulations which deal specifically with site closure. (The EPA's RCRA regulations tabulated in Appendix A have been superseded by revisions; see Sects. 3.3.2 and 3.3.3 for a review of current status.) The principal performance objective of all current regulations--protection of human health and the environment--is the same.

Several sets of expected regulations or clarifications of earlier guidance relevant to closure issues [e.g., DOE Order 5820.2

(Radioactive Waste Management, DOE 1984) and RCRA alternate concentration limits (EPA 1985)] are expected in FY 1987. Both CERCLA and the SDWA were reauthorized (and significantly amended) in 1986, followed by the CWA in early 1987, but the rapidly evolving corrective action requirements under RCRA Sections 3004(u,v) appear to have more immediate significance for ORNL (Trabalka and Myrick 1987). Important aspects of Tennessee's hazardous waste regulations also remain unresolved, including the state groundwater protection strategy (see Section 3.3.4.3). Other state regulations authorized by the CWA [under the Tennessee Water Quality Control Act of 1977, Tennessee Code Annotated (TCA) 69-3-101 et seq., and TDHE Rule 1200-4-4] have been addressed in the 1986 revision of the National Pollutant Discharge Elimination System (NPDES) permit for ORNL (EPA 1986a; Franzmathes 1986). Conditions in the NPDES permit could affect the selection of performance criteria for site closure.

Thus, in order to formulate programmatic strategy and develop closure criteria, it is necessary to interpret a wide variety of evolving federal and state regulations, as well as DOE Orders, and other written guidance designed to implement the individual laws. In some cases, NRC,s 10 CFR Part 61 regulations, for example, the requirements are not specifically enforceable for federal sites. It should be recognized, however, that

> "although DOE sites are exempt from the licensing requirements of 10 CFR Part 61, Executive Order 12088 (43 FR 47707; October 13, 1978) requires Federal facilities to comply with pollution control standards to the same substantive, procedural, and other requirements that would apply in the private sector. The basic requirement applicable to LLW sites would appear to be control of radiation exposure to the general public" (EG&G and DOE 1986).

Regulatory requirements and other guidance must be considered in evaluations of all technical and institutional issues associated with site closure:

(1) potential future uses of the land and waters of the ORNL site (and environs);
(2) the nature of institutional control (length of period, monitoring, maintenance, records, and markers);
(3) standards for control of human health and environmental effects;
(4) technical options for remedial measures; and
(5) cost-effectiveness of closure alternatives.

The discussion which follows surveys regulatory guidance that appears to be pertinent to each of the above issues.

3.3.2 Future Uses of ORNL Lands and Waters

Under Tennessee state law, White Oak Creek and its tributaries on the Oak Ridge Reservation are classified for the following uses: fish

and aquatic life, irrigation, livestock watering, and wildlife. Other natural surface waters near the ORNL site are additionally classified for recreation, and adjoining segments of the Clinch River are also classified for recreation, domestic water supply, industrial water supply, and navigation (TDHE Rule 1200-4-4).

Both groundwater and surface water on the ORNL site are defined as "waters of the State" whose physical, chemical, radiological, biological, or bacteriological properties may not be altered without a valid permit (e.g., NPDES permit) [TCA, Sects. 69-3-108 (b)(1) and 69-3-103(29)]. The significance of such alterations is evaluated in relation to the level of harm, potential harm, or detriment to the public health, safety, or welfare and to the health of animals, birds, fish, or aquatic life [TCA, Sect. 69-3-114(a)]. Thus, the terms of any alteration of site water quality and/or use classifications at any of the NPDES monitoring points in the White Oak Creek watershed must be negotiated with, and approved by, the TDHE. This would include the nature of any future use restrictions contemplated in the development of site closure criteria (also see Sect. 3.3.3).

Some restricted land uses at former DOE waste disposal sites are implied by the wording of Order 5820.2 [Chap. III, Sect. 3(f), Paragraphs (3), (5), and (6); DOE 1984]:

> "(3) a passive security system for the postclosure period; . . .
> (5) permanent identification markers for locating disposal excavations and monitoring wells when closure is complete; . . .
> (6) periodic surveillance and maintenance programs until closure is complete and modification of those programs, as necessary, to measure performance and assess the need for corrective measures following closure . . ."

The DOE requirements are directed primarily at historical and currently operating sites, and may be contrasted with those promulgated by the NRC for new commercial land disposal facilities for LLW (10 CFR Part 61). The distinction is that waste acceptance, packaging, and site location and design criteria are specified by the NRC such that these will be sufficient to " . . . ensure protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time after active institutional controls over the disposal site are removed" (10 CFR Part 61.42; also see NRC 1981, 1982).

It appears that developers of draft EPA standards for LLW disposal (51 FR 14558) may now be wrestling with similar issues (e.g., SAB 1985). In the interim, EPA recommends that "for . . . DOE waste management and storage operations, which are conducted on large facilities with many other potential sources of radionuclide emissions, . . . continued regulation under the broader scope of 40 CFR Part 61 is the most effective and practical approach" (50 FR 38066).

It would appear that NRC regulations are designed such that no restrictions on future land use at the disposal site would be needed once the postclosure institutional control period (100 years) had elapsed. A key point, however, is that even with all of the advantages

of initial design and acceptance criteria to assist in achieving long-term stability of the site and meeting performance objectives, a 100-year institutional control period is imposed. It is also apparently recognized that an element of significant uncertainty remains such that site operators are only required "to eliminate to the extent practicable the need for ongoing active maintenance of the disposal site following closure so that only surveillance, monitoring, or minor custodial care are required" (10 CFR Part 61.44; underlining added).

The dichotomy between expectations for new and historic sites is further highlighted in EPA standards for management and disposal of spent nuclear fuel, and high-level and transuranic (TRU) radioactive wastes (40 CFR Part 191). It is recognized that a combination of steps (site selection, design, and operational techniques, i.e., engineered barriers) is required to meet these standards, and that selection of disposal sites, designs, and operational techniques are no longer options for some wastes historically disposed of. Thus, these new EPA standards apply only to disposal operations occurring after the effective date of the regulations (November 18, 1985).

Another key provision in 40 CFR Part 191 relevant to the present discussion is that land- and water-use restrictions at the sites are explicitly applied to a controlled area, up to 100 km^2 in surface area, dedicated to keeping these dangerous materials away from future generations for a period of 10,000 years after disposal. These restrictions apply to the lithosphere and the groundwater within it below the controlled area. The controlled area can extend up to 5 km in any direction from the original emplacement of the wastes.

The issue of future land-use restrictions was addressed further by EPA in implementing health and environmental standards to govern stabilization and control of mill tailings (40 CFR Part 192) at commercial uranium and thorium processing sites under the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA). Section 202 of the UMTRCA requires the federal government or the states to acquire and retain control of tailings disposal sites under licenses. The licensor is then authorized to require performance of any maintenance, monitoring, and emergency measures needed to protect public health and safety. The EPA believes

> "that these institutional provisions are essential to support any project whose objective is as long-term as are these disposal operations, and for which we have as little experience. This does not mean we believe that primary reliance should be placed on institutional controls; rather that institutional oversight is an essential backup to passive control. . . . [E]ven with the disposal actions required by these standards it would not be safe to build habitable structures on the disposal sites. Federal or State ownership of the sites is presumed to preclude such inappropriate uses" (50 FR 45936; underlining added).

Land-use restrictions at ORNL sites that would be closed under the terms of RCRA regulations for interim facilities are imposed by 40 CFR Part 265.117(c):

"Post-closure use of the property on or in which hazardous wastes remain after partial or final closure must never be allowed to disturb the integrity of the final cover, liner(s), or any other components of the containment system, or the function of the facility's monitoring systems, unless the Regional Administrator finds that the disturbance:

(1) Is necessary to the proposed use of the property and will not increase the potential hazard to human health or the environment; or
(2) is necessary to reduce a threat to human health or the environment."

The concept of using land-use restrictions to produce a controlled area, or buffer zone, around hazardous waste sites has been incorporated into EPA's proposed approaches for evaluating alternate concentration limits (EPA 1986c) and alternative closure options (52 FR 8712-8722) at RCRA sites, and is implicit in criteria for the risk-based variance to the secondary containment provisions in the RCRA hazardous waste storage tank regulations (51 FR 25452-24453).

A buffer zone "of adequate dimensions to carry out environmental monitoring activities . . . and take mitigative measures if needed" is also required by NRC's LLW regulations (10 CFR Part 61.52). The buffer zone concept espoused by EPA and NRC would appear to have important ramifications for developing closure criteria for many critical ORNL sites [e.g., the SWSAs and the LLW Pits and Trenches (Bates et al. 1986)]. Surprisingly, however, the seemingly desirable concept of using a buffer zone to limit the impact of radioactive or hazardous chemical constituents at older LLW sites was disavowed in a proposed amendment to DOE Order 5820.2 [Chap. III, Sect. (f), Disposal Site Closure/Post Closure]:

"Field organizations shall develop a site-specific comprehensive closure plan prior to initiation of operations at new or closure of existing LLW disposal sites. The plan shall be based on a documented performance assessment and ALARA analysis of closure alternatives which evaluate short- and long-term impacts and costs, <u>and reduced reliance on buffer zones to meet performance objectives</u>" (April 4, 1986; underlining added).

While such criteria may represent appropriate design objectives for developing new LLW-disposal sites, it could be very expensive to disregard the benefit of a buffer zone for many existing sites at which natural and engineered features are not currently state of the art. Thus, ORNL recommended that no particular closure concept be rejected because it relies in part on institutional control. This includes not only the use of buffer zones, but also monitoring and remedial backup. (The buffer zone concept was reinstated in the January 4, 1987 draft of the revised DOE Order.)

3.3.3 Nature of Institutional Control

Some issues and specific regulatory requirements have already been identified (e.g., the discussion of 40 CFR 192 in the previous section) because it is difficult to conceive of land-use restrictions without associated institutional controls. Limited, sometimes contradictory (e.g., use of the buffer zone concept), regulatory guidance on the topic of postclosure institutional control exists. This is also directed principally at closure of new waste management sites (i.e., those that were opened after 1980 and subjected to stricter technical standards during development than were historically contaminated sites). There are significant differences (e.g., in the lengths of the institutional control periods and performance objectives) in these regulations; thus, little in the way of generally applicable guidance is provided.

No specifications for the postclosure care interval are provided by DOE Orders or CERCLA regulations, but a 100-year postclosure period is prescribed by NRC regulations for commercial LLW land-disposal sites (see preceding section). A passive security system, "permanent" identification markers (presumably on-site), and surveillance and maintenance and performance assessment programs, along with later corrective actions if necessary, are mandated for closure of former DOE and new NRC LLW disposal sites (Sect. 3.3.2; also see 50 FR 38080, which delineates additional NRC guidance on security systems, markers, and records).

Major questions remain, however, about the long-term effectiveness of passive systems such as markers without some form of institutional oversight or maintenance. Thus, DOE has elected to require the use of both "administrative controls and physical barriers--active and passive controls" in its new guidelines for dealing with residual radioactivity at Formerly Utilized Sites Remedial Action Program (FUSRAP) sites and remote Surplus Facilities Management Program (SFMP) sites (DOE 1987b).

In addition to institutional land-use restrictions, an impressive set of technical specifications is imposed on UMTRCA sites by 40 CFR Part 192 regulations (liners and groundwater protection, sufficiently effective to control radiological hazards for 1000 years to the extent reasonably achievable, and, in any case, for at least 200 years; also see DOE 1987b). Thus, EPA also believes that institutional controls can play a major role "in assuring . . . that passive controls are adequate to achieve their design objectives" (50 FR 45936).

Along with the rather open-ended restrictions on future land use at sites closed under RCRA regulations, a period of postclosure care, including monitoring and maintenance, of indeterminate length is required [Part 265.117(a)]. Although the RCRA closure performance standard (Part 265.111) appears to represent a realistic statement of what is achievable at the current state of the art, it similarly implies a certain open-endedness to the institutional control period.

"The owner or operator must close his facility in a manner that

(a) minimizes the need for further maintenance, and
(b) controls, minimizes, or eliminates, to the extent necessary to protect human health and the environment, postclosure

escape of hazardous waste, hazardous constituents, leachate, contaminated runoff, or hazardous waste decomposition products to the ground or surface waters or to the atmosphere, and

(c) complies with the closure requirements of this Subpart including, but not limited to, the requirements of (Sections) 265.197, 265.228, 265.258, 265.280, 265.310, 265.351, 265.381, and 265.404."

This concept is reinforced in Part 265.117(a), which indicates that postclosure care must continue for 30 years after closure unless the EPA Regional Administrator determines that a "reduced period is sufficient to protect human health and the environment (e.g., leachate or groundwater monitoring results, characteristics of the hazardous wastes, application of advanced technology, or alternative disposal, treatment, or reuse techniques indicate that the hazardous waste management unit or facility is secure)." The wording of Part 265.117(a) further makes it clear that the Regional Administrator retains the right to extend the postclosure care period if he finds that this is necessary to protect human health and the environment.

The postclosure plan required by RCRA (40 CFR Part 265.118) must describe groundwater monitoring and maintenance activities as directed in Part 265.117. "[A] survey plat indicating the location and dimensions of landfill cells or other hazardous waste disposal units with respect to permanently surveyed benchmarks" (Part 265.116) and "a record of the type, location, and quantity of hazardous wastes disposed of within each cell or other disposal unit of the facility . . . to the best of (the operator's) knowledge and in accordance with any records . . . kept" must also be provided to the local zoning authority, or the authority with local jurisdiction over land use, and the Regional Administrator (Part 265.119). "The plat filed . . . must contain a note, prominently displayed, which states the owner's or operator's obligation to restrict disturbance of the hazardous waste management unit in accordance with the applicable Subpart G regulations" (Part 265.116). Part 265.119 also requires "a notation on the deed to the facility property--or on some other instrument which is normally examined during title search--that will <u>in perpetuity</u> notify any potential purchaser of the property that: (1) the land has been used to manage hazardous waste, and (2) its use is restricted under 40 CFR Subpart G regulations" (underlining added).

Landfills are subjected to a variety of detailed technical specifications for closure implementation, monitoring, and maintenance (Part 265.310), including requirements to "place a final cover over the landfill" and to "protect and maintain (permanently) surveyed benchmarks" used in developing the survey plat under Part 265.116. The requirements of Part 265.310 may also be applied to other RCRA-regulated facilities (e.g., impoundments or tank systems) depending on the degree of environmental decontamination at closure (compare, for example, 40 CFR Parts 265.197, 265.228, 265.258, and 265.280 with Part 265.310).

3.3.4 Standards for Control of Human Health and Environmental Effects

3.3.4.1 Background

Regulatory guidance for dealing with radiation exposure and radioactive wastes, as one category, and with hazardous chemical wastes, as another, is generally addressed in separate sets of regulations. Thus, the review and discussion which follows is similarly subdivided. (Regulations promulgated by EPA under the SDWA and UMTRCA are exceptions to this rule; see later discussion.)

Although regulatory guidance on so-called mixed wastes (mixtures of radioactive and hazardous chemical constituents) is not completely clear, it is reasonable to assume that the most of ORNL's wastes are potentially subject to both hazardous chemical and radioactive waste regulations (52 FR 15937; EPA 1987). Potential conflicts between such regulations have been recognized (Jacobs and Lynch 1985; Rose et al. 1985; Garvey 1986c,d; EG&G and DOE 1986), and even though RCRA [Sect. 1006(a)] prohibits development of regulations inconsistent with the Atomic Energy Act (AEA), resolution of some conflicts may be problematic (Garvey 1986c,d).

Some resolution could have been provided by the penultimate (May 9, 1987) draft of the DOE Final Rule (10 CFR Part 962) clarifying the term "by-product material" for application of RCRA to DOE wastes. This rule was designed to "ensure, to the greatest extent possible within the existing regulatory framework, that wastes in which the hazard is primarily chemical in nature will be regulated under RCRA, and that wastes in which the hazard is primarily radiological in nature (and thus where application of RCRA's . . . standards might be technologically unsound) will continue to be regulated exclusively under the AEA." Thus, the definition of "by-product material" in Sect. 11e(1) of the AEA was interpreted to mean that the words "yielded in or made radioactive by the exposure to the radiation incident to the process of producing or utilizing special nuclear (fissile) material," refer only to wastes "that are either <u>directly yielded in the process</u>" of producing or utilizing such material, or "whose radioactivity is a <u>direct and necessary consequence of that process</u> . . . virtually all direct process wastes are substances, such as high-level radioactive and transuranic wastes, in which protection from the radiation hazard provides protection from the chemical hazard, and to which the application of RCRA's standards might be environmentally unsound" (underlining added).

Since these concepts were not retained in the Final Rule for 10 CFR Part 962 (52 FR 15937-15941), it may be necessary "for EPA and the state(s) . . . to modify hazardous waste requirements" under RCRA Sect. 1006(a) in order to regulate mixed wastes in which the radiological hazard predominates (Garvey 1986d; 51 FR 38941). Regardless of which regulatory option is ultimately selected, a system for comparing the relative hazards of hazardous chemicals and radionuclides on an equivalent basis must be developed.

3.3.4.2 Radiation and Radioactivity

Radiation exposure

The as-low-as-reasonably-achievable (ALARA) guidance document (Kathren and Selby 1980) for DOE Order 5480.1A (Environmental Protection, Safety, and Health Protection Program for DOE Operations; DOE 1981), as well as the draft guidance document for Order 5820.2 (EG&G 1985) and revised 10 CFR Part 20 regulations (51 FR 1092ff.), indicate that an appropriate ALARA target for control of population exposures is 25 mrem/year (whole-body dose or effective dose equivalent); 10 CFR Part 61, 40 CFR Part 61, and 40 CFR Parts 190, 191, and 192 also cite the 25-mrem annual dose equivalent as a regulatory limit. It is important to note that the estimated dose to the maximally exposed off-site resident was <25 mrem in 1985 and 1986 (see Sect. 3.3.6; Martin Marietta Energy Systems 1986; Oakes et al. 1987).

Newer EPA regulations (40 CFR Parts 61 and 191) indicate more flexibility in setting population dose limits, as follows: "less stringent alternative standards [are] available if it can be shown that no member of the public will receive a continuous (whole body) exposure of more than 100 mrem/year or an infrequent exposure of more than 500 mrem/year from all sources (excluding natural radiation background and medical exposures)." These dose limits have been incorporated into both DOE Order 5480.1A and the guidelines for dealing with residual radioactivity at DOE's Formerly Utilized Sites Remedial Action Program (FUSRAP) sites and remote Surplus Facilities Management Program (SFMP) sites (DOE 1987a, 1987b; Miller 1986).

The lifetime calculated risk to any individual member of the public is unlikely to exceed 10^{-5} per year when exposed continuously to a effective-dose-equivalent rate of 100 mrem/year over a lifetime (51 FR 1113). The 100-mrem reference level, in conjunction with the constraints of other EPA, NRC, and DOE regulations, including ALARA programs, is believed to be adequate to ensure that the annual average risk to any individual member of the general public is within, or below, the range of 10^{-6} to 10^{-5} judged acceptable by the International Commission on Radiological Protection (51 FR 1103; ICRP 1977). This range represents "a subjective judgment of risk normally accepted in everyday life as producing no undue concern" (51 FR 1102).

Current DOE Orders and NRC and EPA regulations are mute on dose limits for so-called intruders, although it is clear that neither the 25- or 100-mrem annual dose limits nor the more stringent groundwater protection standards in EPA regulations (e.g., 10 CFR Part 191) are meant to apply to intruders. Further, the environmental impact statements (NRC 1981, 1982) underlying the NRC's 10 CFR Part 61 rule, as well as its adopted waste classification limits, support a 500-mrem/year dose limit for intruders. Thus, the alternative dose limits in 40 CFR Parts 61 and 191 and in the current DOE standards (described above) appear to represent the most appropriate guidelines for dealing with intruder scenarios.

Radiation standards have not been promulgated for the protection of the environment, but rather for control of human health risks (e.g., ICRP 1977). However, protection of human health will serve to provide adequate safeguards for protection of the environment in all but a few extreme cases. Deleterious effects from chronic irradiation of natural populations of aquatic or terrestrial organisms have not been observed at dose rates $\leq$1 rad/day (roughly equivalent to 1000 mrem/day, for purposes of comparison to human exposure standards) (e.g., Blaylock and Trabalka 1978).

Conservative calculations of potential radiation exposures to aquatic organisms in the White Oak Creek drainage near ORNL have suggested that maximally exposed organisms might receive doses on the order of 1 rad/day (Boyle et al. 1982). However, measurements of in situ doses and of radionuclides in biota indicate that doses are actually <<1 rad/day (Trabalka and Allen 1977).

Radioactivity in water

Concentration limits for radionuclides in water (or air) corresponding to the 100-mrem/year population exposure limit are contained in Attachment 1 of DOE Order 5480.xx (Radiation Protection of the Public and the Environment; DOE 1987a), which updates and supercedes portions of DOE Order 5480.1A (DOE 1981), and these may be converted to correspond to other limits by applying a simple proportion. Values corresponding to a 100-mrem/year population dose rate may also be derived from proposed EPA drinking water standards and ancillary information (51 FR 34836-34862) by use of simple proportions. Revised 10 CFR Part 20 regulations (51 FR 1144-1199, Table 2, Appendix B) also provide ambient concentrations conforming to a 100-mrem/year reference level for population exposure. Potential drinking water concentration limits for the principal radionuclides at ORNL remedial action sites, derived from these three different sources (DOE, EPA, and NRC) based on a 100-mrem/year reference level, are shown in Table 2.

The differences in the Table 2 values for a given radionuclide are quite significant in some cases (e.g., ^{232}Th and ^{237}Np), and reflect the uncertainties in critical elements (i.e., absorption factors, internal distributions, and organ- and tissue-specific risk estimates) of the dosimetric models used to derive effective-dose-equivalent concentrations. In addition, the NRC has attempted to adjust for differences between population age groups by reducing radionuclide concentrations (which would otherwise correspond to an adult reference level of 100 mrem/year) by a factor of 2. Thus, the expected dose rate to adults from concentrations listed in the NRC column in Table 2 is only 50 mrem/year, and these concentrations are typically about one-half of the values in the DOE and EPA columns of the table.

Since the objective of a 100 mrem/year reference level is to ensure that a given risk level (e.g., 10^{-5} per year) is not exceeded, it becomes necessary to reduce concentrations of individual

Table 2. Principal radionuclides and reference-level concentrations in drinking water

Principal radionuclide	Physical half-life[a] (years)	Reference-level concentrations (pCi/mL per 100 mrem/year)		
		DOE[b]	EPA[c]	NRC[d]
^{3}H	12.28	2000.	2000.	1000.
^{10}Be	1.6×10^{6}	30.		10.
^{14}C	5.73×10^{3}	70.	70.	30.
^{22}Na	2.602	10.	10.	6.
^{55}Fe	2.7	200.	200.	100.
^{60}Co	5.271	5.	5.	3.
^{90}Sr	28.6	1.	1.	0.4
^{93}Zr	1.53×10^{6}	90.	200.	40.
^{99}Tc	2.13×10^{5}	100.	100.	60.
^{106}Ru	1.008	6.	7.	3.
^{125}Sb	2.77	50.	100.	30.
^{129}I	1.57×10^{7}	0.5	2.	0.3
^{134}Cs	2.062	2.	2.	0.9
^{137}Cs	30.17	3.	2.	1.
^{147}Pm	2.6234	100.		60.
^{151}Sm	90.	400.	700.	200.
^{152}Eu	13.6	20.	50.	10.
^{154}Eu	8.8	20.	20.	7.
^{155}Eu	4.96	100.	200.	50.
^{226}Ra	1.600×10^{3}	0.1	0.1	0.07
^{228}Ra	5.75	0.1	0.3	0.04
^{228}Th	1.9132	0.4		0.2
^{229}Th	7.34×10^{3}	0.04		0.02
^{230}Th	7.7×10^{4}	0.3	0.4	0.1
^{232}Th	1.405×10^{10}	0.05	0.5	0.03
^{231}Pa	3.276×10^{4}	0.01		0.007
^{232}U	72.	0.1		0.04
^{233}U	1.592×10^{5}	0.5		0.3
^{234}U	2.445×10^{5}	0.5	1.	0.3
^{235}U	7.038×10^{8}	0.6		0.3
^{236}U	2.3415×10^{7}	0.5		0.3
^{238}U	4.468×10^{9}	0.6	1.	0.3
^{237}Np	2.14×10^{6}	0.03		0.002
^{238}Pu	87.75	0.04		0.2
^{239}Pu	2.4131×10^{4}	0.03	1.	0.1
^{240}Pu	6.569×10^{3}	0.03		0.1
^{241}Pu	14.4	2.		7.
^{241}Am	4.322×10^{2}	0.03	0.1	0.03
^{244}Cm	18.11	0.06		0.07

Table 2. (Continued)

Principal radionuclides	Reference level concentrations (pCi/mL per 100 mrem/year) NRC[d]
Undifferentiated mixtures:	
(1) Not containing ^{231}Pa or ^{237}Np	0.01
(2) Not containing, in addition, ^{226}Ra, ^{228}Ra, ^{229}Th, ^{232}Th, ^{232}U, ^{241}Am, or ^{244}Cm	0.1
(3) Not containing, in addition, ^{90}Sr, ^{129}I, ^{134}Cs, ^{228}Th, ^{230}Th, ^{233}U, ^{234}U, ^{235}U, ^{238}U, ^{238}Pu, ^{239}Pu, or ^{240}Pu	1.

[a]Values from Kocher 1981.

[b]Values from DOE Order 5480.xx (Radiation Protection of the Public and the Environment; March 31, 1987 draft), Table 1, Column 2.

[c]Values derived from EPA Advance Notice of Proposed Rulemaking, National Primary Drinking Water Regulations, Appendices C and D (51 FR 34859-34860). The Appendix C values were multiplied by 0.025 to convert from pCi/L per 4 mrem/year to pCi/mL per 100 mrem/year and the inverse of the Appendix D values was multiplied by 0.1 to convert from mrem/year per pCi/L to pCi/mL per 100 mrem/year. Converted values were recorded with two significant figures, and then rounded down to one significant figure (i.e., 75 becomes 70 rather than 80).

[d]Values from 10 CFR Part 20, Appendix B, Table 2, Column 2. The NRC has reduced these concentrations by a factor of 2 to adjust for differences between population age groups; thus, the corresponding annual effective dose equivalents and risk estimates for adults are 50 mrem and 1×10^{-5}, respectively.

radionuclides in mixtures (51 FR 1200) when the sum of the fractional dose contributions would result in a dose rate of >100 mrem/year. Thus, this so-called mixture rule requires that the sum of the ratios of concentrations of individual radionuclides to their respective reference-level concentrations be ≤ 1. [This seemingly important concept has not been used in developing drinking water standards for hazardous chemicals (see Sect. 3.3.4.3).]

The limits for public exposure from spent fuel, and high-level and TRU waste disposal sites (40 CFR Part 191) through "special source" groundwater supplies are derived from Safe Drinking Water Act (SDWA) standards (40 CFR Part 141), and are much more stringent than implied by the 25- or 100-mrem annual dose limits. They include a 4-mrem/year dose-equivalent limit for exposures from beta- and gamma-emitting radionuclides and a 15-pCi/L limit for alpha-emitters (excluding radon). Such "special sources" are located on-site or within a 5-km distance from controlled areas, are major water supplies (for thousands of persons), and are irreplaceable.

While it seems likely that such guidelines may be applied to LLW disposal sites, it also (currently) appears unlikely that their application would have an immediate impact on the ORNL Remedial Action Program because (1) no sources of public groundwater are located on-site, and (2) the contaminant level in the nearest public drinking water intake should (on the average) be subject to a greater than 100-fold dilution, by the Clinch River, below the contaminant level at the site boundary (Boyle et al. 1982; Martin Marietta Energy Systems 1986; Oakes et al. 1987). Thus, attainment of either 25- or 100-mrem/year targets at the site boundary should be sufficient to meet the more stringent standards for the nearest public drinking water supply. Based on 1985 and 1986 environmental monitoring data and calculations of radiation dose to off-site residents, it appears highly likely that the 4-mrem limit could be met even if a hypothetical water intake were constructed at the mouth of White Oak Creek (see Martin Marietta Energy Systems 1986 and Oakes et al. 1987).

However, these conclusions might not apply to other ORNL sources of groundwater and surface water without the buffer zone and attenuation of releases provided by federal control of the Oak Ridge Reservation. Without such control, the more stringent 40 CFR Part 141 standards could be applied to some potential on-site water sources, particularly groundwater, under the terms of EPA and state regulatory authority (see Sects. 3.3.2 and 3.3.4.3).

Radioactivity in sediments and soils

Remedial action guides for residual uranium (and thorium) soil and sediment contamination have been developed by Bernhardt et al. (1985) from existing federal standards and guides and independent environmental radiological pathway analyses. These guides, which have been approved by the TDHE for conducting remedial actions at the Aerojet Heavy Metals Company of Jonesboro, Tennessee, are 35, 100, and 2000 pCi/g of depleted uranium for unrestricted access, deeply buried, and doubly lined land-disposal conditions, respectively. Appropriate

guides for slightly enriched uranium should be quite similar by analogy with NRC guidance (46 FR 52061). (Some ambiguity remains because of the classification of uranium as a "hazardous constituent" in EPA regulations for uranium and thorium mill tailings; see the following section).

3.3.4.3 Hazardous Chemicals

Water quality

The legislative mandate behind the nation's drinking water standards is the Safe Drinking Water Act (SDWA). Under the SDWA, the EPA is charged with promulgating maximum contaminant levels (MCLs) that (with the exception of turbidity) are "the maximum permissible level of a contaminant in water which is delivered to the free-flowing outlet of the ultimate user of a public water system"; for turbidity, control is "at the point of entry to the distribution system." As defined under SDWA regulations, the MCLs are not ambient (i.e., surface water or groundwater) standards, but are standards applicable to the water that is delivered to the consumer, which may be, but is not necessarily, treated or finished. A water system that provides piped water to the public for human consumption is defined as a "public water system" if it "has at least fifteen service connections or regularly serves an average of at least twenty-five individuals daily at least 60 days out of the year." Regulations under the SDWA are, in some cases, a function of the population served by the system and whether that population is served year-round or not. Pursuant to the provisions of the SDWA, primary enforcement authority over public water systems rests with the state (as authorized by the EPA Regional Administrator).

The EPA has also established secondary maximum contaminant levels (SMCLs) for twelve variables (40 CFR Part 143) to protect the aesthetic quality of drinking water delivered to users of public water systems. The SMCLs, which were promulgated in 1979 (44 FR 42195), "are not federally enforceable but are intended as guidelines for the states." The factors used in setting these SMCLs included taste, odor, appearance, staining, corrosivity, and laxative effect. The secondary regulations are mentioned here because several of the secondary variables (copper, corrosivity, sulfate, and zinc) are being considered for elevation to primary variables (according to 48 FR 45511). Other provisions of the SDWA pertain to underground injection of wastes (Sect. 1424) and the protection of sole-source drinking water aquifers from impacts due to federal funded projects (Sect. 1424e).

In contrast, the Clean Water Act (CWA), as administered by EPA and the states, provides the regulatory means for protecting the quality of natural surface waters and some groundwater. Under the CWA, the EPA has issued criteria that define levels of water quality variables to protect human health and aquatic life. Section 304(a)(1) of the CWA requires EPA to periodically update these criteria "to reflect the latest scientific knowledge on the identifiable effects of pollutants on public health and welfare, aquatic life, and recreation" (51 FR 8361). The 65 individual water quality criteria documents

issued by EPA in 1980 (64) and 1984 (1) completed the coverage of priority pollutants listed in Sect. 307(a)(1) of the CWA (45 FR 79318 and 49 FR 5831). Fourteen new ambient water quality documents covering protection of aquatic life (50 FR 30784, 51 FR 8361 and 19269), including revisions of 9 of the 1980 documents, have been issued in 1985 (9) and 1986 (5), respectively.

The 1980 and 1984 human health criteria, which apply to many constituents, take into account ingestion of both contaminated water and contaminated aquatic organisms, but do not consider feasibility factors such as treatment technology or costs; thus, these criteria are more similar in concept to SDWA MCL goals (MCLGs) than to MCLs. [The MCLGs are nonenforceable criteria designed to prevent any adverse health effects (set equal to zero for carcinogens); MCLs are enforceable standards set as close to MCLGs as possible, accounting for technology, treatment, and costs.] For cadmium, hexavalent chromium, lead, selenium, and silver, the criteria are identical to the current MCLs. For arsenic, lindane, toxaphene, and halomethanes, the recommended (as a goal) ambient water concentration under the CWA is zero because of carcinogenicity, whereas the current SDWA MCLs for these contaminants are 0.05, 0.004, 0.005,and 0.10 mg/L, respectively. For mercury, the CWA criterion (for ingestion through water and contaminated aquatic organisms) is 0.000144 mg/L, about one-fourteenth the current SDWA MCL of 0.002 mg/L.

These CWA criteria "have no regulatory significance under the SDWA" (45 FR 79320). However, the EPA and the states that have been granted permitting authority by the EPA are expected to use the CWA criteria, along with designated uses for the water bodies in question (i.e., Sect. 3.3.1), in deriving ambient water quality standards that are, in turn, used in setting allowable limits for point-source discharges to surface waters under the National Pollutant Discharge Elimination System (NPDES) (45 FR 79319). The CWA criteria may also be used as cleanup standards for CERCLA actions under certain circumstances (see following subsection "Water Contamination").

The EPA has been revising its regulations, as authorized under the SDWA, based on (1) experience since application of the interim regulations, (2) occurrence frequency and human exposure potential, (3) human health concerns and basic toxicology, (4) water treatment technologies and costs, (5) analytical chemistry and monitoring methods, and (6) implementation options to protect public health while minimizing unnecessary costs (48 FR 45502). The SDWA regulations were to be revised in four phases:

I. Volatile synthetic organic chemicals
II. Synthetic organic chemicals, inorganic chemicals, and microbiological contaminants
III. Radionuclides
IV. Disinfectant by-products including trihalomethanes

Proposed rules for Phase I, volatile synthetic organic chemicals (VOCs), including MCLGs and MCLs for nine VOCs, were issued in 1984 (49 FR 24330) and 1985 (50 FR 46902; also see 51 FR 4618), respectively. A set of MCLGs for the second phase was issued in 1986

(50 FR 46936; 51 FR 4618), along with final regulations for fluoride, a Phase II constituent (51 FR 11396). Proposed MCLGs for the third phase were expected in 1986 (51 FR 14559), but no action was expected on the fourth phase prior to December 1987 (51 FR 14559). On June 18, 1986, new amendments to the SDWA were signed into law, finalizing existing drinking water standards and requiring the EPA to promulgate regulations for the remaining 82 priority contaminants within 3 years of enactment (Goldfarb 1986). However, the amendments do not require the EPA to set standards for the trihalomethanes.

Water contamination

Several EPA regulations cite the primary drinking water standards as the MCLs allowed in groundwater affected by an active, permitted waste-management facility. The hazardous waste management rules (40 CFR Parts 260-270) promulgated under Subtitle C of RCRA state that the concentrations of 14 primary-drinking-water-standard substances in groundwater at the boundary of a RCRA-permitted facility for treatment, storage, or disposal of hazardous waste must not exceed the standard if the background concentration is less than the standard [Part 264.94(a)(2)]. For hazardous constituents that do not have primary drinking water standards, the concentration limit is equal to the background concentration. Concentration limits are to be specified in Part B of each facility's RCRA permit, and there are provisions for setting alternate concentration limits (ACLs) in circumstances in which the regulatory agency finds that an ACL would "not pose a substantial present or potential hazard to human health or the environment" [Part 264.94(b)]. Significant revisions in the EPA regulations dealing with ACLs and other groundwater monitoring and standards issues are expected in 1987 (51 FR 38947; also see the following subsection "Sediment and soil contamination").

The EPA health and environmental protection standards for uranium and thorium mill tailings (40 CFR Part 192, promulgated under UMTRCA) incorporate, with a few minor modifications, the groundwater protection standard of RCRA (40 CFR Part 264) for active tailings management facilities [40 CFR Part 192.32(a)]. The mill tailings rule adds uranium and molybdenum to the list of hazardous constituents that, lacking a primary drinking water standard, must not exceed background concentrations. Alternate concentration limits are permissible if they are found to be "as low as reasonably achievable" after considering "practicable corrective actions," and if the Part 264.94(a) concentration limits are satisfied at "all points [more] than 500 m from the edge of the disposal area and/or outside the site boundary" [Part 192.32(a)(2)(iv)]. This standard does not apply directly to the DOE Uranium Mill Tailings Remedial Action Program (UMTRAP), but DOE would very likely be expected to meet this standard at any off-site location used for long-term management of wastes from an UMTRAP site. The potential impact of these regulations on operating facilities has recently been reviewed by Gillen et al. (1985).

Prior to the enactment of the Superfund Amendments and Reauthorization Act (SARA) in 1986, there were no explicit standards in

CERCLA. Remedial alternatives were required to attain or exceed the legally "applicable or relevant and appropriate" standards of federal laws (40 CFR Part 300.68). This requirement was extended to include state laws by SARA Sect. 121(d). Pertinent federal laws are now specified to include (but are not limited to) the CAA, CWA, RCRA, SDWA, and TSCA. In addition, "remedial action shall require a level or standard of control which at least attains Maximum Contaminant Level Goals established under the Safe Drinking Water Act and water quality criteria established under section 304 or 303 of the Clean Water Act, where such goals or criteria are relevant and appropriate under the circumstances of the release or threatened release."

The critical concern is that these SDWA goals and CWA criteria are set equal to zero for carcinogens (see previous subsection "Water quality"). This requirement would apply not only to a significant subset of hazardous chemicals but also potentially to all radionuclides, including those which occur naturally (51 FR 34847). Thus, the way in which the words "relevant and appropriate" are interpreted will have a tremendous impact on the selection of standards to be applied under the amended CERCLA. Development of ACLs based on an assumed point of human exposure beyond a facility's boundary are also effectively eliminated by the restrictions in SARA Sect. 121(d). Although the legislative history of SARA indicates that drinking water standards need not be applied for water resources that are not used for drinking, for example, there may still be instances in which the statutory language is used to enforce very stringent cleanup measures. Significant concepts and statutory language from SARA may also be applied in revising RCRA cleanup standards during reauthorization of RCRA in 1988.

The Underground Injection Control Program (UIC) regulations (40 CFR Parts 144-147) established by the EPA under the authority of the Safe Drinking Water Act (SDWA) also utilize the primary drinking water standards as a groundwater protection standard for permitted facilities. The requirement in Part 144.12(a) is that no injection activity shall be conducted "in a manner that allows the movement of fluid containing any contaminant into underground sources of drinking water, if the presence of that contaminant may cause a violation of any primary drinking water regulation under 40 CFR Part 142 or may otherwise adversely affect the health of persons." This regulation applies only to "underground sources of drinking water" as defined in Part 146.3; that is, it does not apply to aquifers that are not used as sources of drinking water, and that either yield too little water or have too high a total dissolved solids content (TDS >10,000 mg/L) to be used as sources of public water supply. There is also a provision (Part 146.4) to permit the EPA to exempt underground sources of drinking water that are not currently used as drinking water sources and will not be sources of drinking water for reasons of poor water quality, depth, location, or other factors. [The state of Tennessee has recently adopted regulations for underground injections of waste as authorized by TCA, Sect. 69-3-105 (TDHE Rule 1200-4-6); however, primacy has not yet been granted by EPA.]

A draft groundwater management strategy for the state of Tennessee has been prepared by a task force from the TDHE Division of Ground-Water Protection (TDHE 1985). This is the first in a series of steps designed

to culminate in the submittal of a final draft strategy to EPA for approval in FY 1987.

Sediment and soil contamination

Since the primary objective of EPA hazardous waste regulations is protection of water supplies, groundwater in particular, standards for maximum contaminant levels in soils and sediments are not incorporated.* Under RCRA regulations, for example, the determination of hazardous waste characteristics is related to demonstrated or measurable ignitability, corrosivity, reactivity, and toxicity, including extraction-procedure (EP) toxicity (40 CFR Parts 261.11 and 261.20). The last of these characteristics, EP toxicity, was intended to identify wastes which pose a hazard by releasing significant concentrations of toxic materials into groundwater through leaching, and the results of the EP-toxicity leaching procedure can potentially determine the RCRA regulatory status of some historically contaminated sites, such as surface impoundments.

The EP-toxicity characteristic is determined currently by first leaching the solid material with an acetic acid solution (pH $\leq$5.0) for 24 h (40 CFR Part 261, Appendix II), and then testing the leachate to see whether hazardous chemical contaminants are present at concentrations $\geq$100 times the corresponding SDWA MCLs (40 CFR Part 261.24, Table 1). If so, then that waste or waste-containing material would be deemed to exhibit the characteristic of EP toxicity.

The EPA reached the conclusion that a dilution factor of 100 would typically occur in the process of migration from a hazardous waste unit to a drinking water supply--hence, the factor of 100 and the determination in RCRA standards that the requirements of Part 264.94 (described above) are meant to apply at the boundary of a waste management area (e.g., vertical plane of infinite depth no more than 10 ft from the edge of a disposal trench), but not within the confines of that area. [The TDHE guidelines for "clean closure conditions" at CERCLA sites (Gregory 1985) are generally equal to MCLs (or other water quality criteria when MCLs are not available) and MCLs x 100 for soil. The derivation for soil contamination does not have a scientific or statutory basis. It is questionable (with reference to the EP-toxicity test) because it incorporates the very conservative assumption of total leaching of contaminants (into a fluid volume equal to 5% of that used in the EP-toxicity leaching procedure). Application of this set of

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*Soil cleanup standards for polychlorinated biphenyls (PCBs) exist for sites contaminated after May 4, 1987 (TSCA PCB Spill Cleanup Policy; 52 FR 10709). PCB residuals in soils from areas with restricted and unrestricted access must be $\leq$25 and $\leq$10 parts per million by weight (ppm), respectively. In addition, the soil in areas with unrestricted access must be excavated to a depth $\geq$10 in and replaced with soil containing <1 ppm PCBs. However, "spills which occurred before the effective date of this policy are to be decontaminated to requirements established at the discretion of EPA, usually through its regional offices" (52 FR 10689).

TDHE guidelines would also imply decontamination of soils to a concentration much lower (by factors in excess of 1000 for some hazardous constituents at ORNL sites) than required to protect human health and the environment. Compare, for example, the TDHE soil guideline for PCBs (7.9×10^{-5} ppm; Gregory 1985) with the cleanup standards in the new TSCA PCB Spill Cleanup Policy (<1 to 10 ppm in uncontrolled areas; see footnote on pp. 62-63 of this report)].

The EPA has proposed expanding the EP-toxicity characteristic to include nickel, thallium, and 38 additional organics (51 FR 21648-21693), and to introduce a new toxicity characteristic leaching procedure (TCLP) to replace the current EP-toxicity leaching procedure (51 FR 1750; also see EPA 1986b and Francis and Maskarinec 1986). The EPA has proposed a two-leaching-fluid system for the new TCLP, with the fluids selected according to the alkalinity of the waste materials (51 FR 21656). In addition, the new approach uses "apportioned chronic toxicity reference levels," or reference levels for drinking water (Table 3; described below), combined with a compound-specific dilution and attenuation factor for the organics (obtained from application of a groundwater transport model), to calculate "regulatory level concentrations," [i.e., maximum allowable leachate concentrations for individual toxicants (Table 3; 51 FR 21650)]. The EPA "is studying the use of the MINTEQ speciation model" in order to derive appropriate dilution and attenuation factors for toxic elements, but "has not been able to complete these studies yet, and therefore will continue to employ a standard attenuation factor of 100. Once development . . . is completed, element specific factors will be proposed" (51 FR 21671).

In its proposal, the EPA has proposed expansion of the list of materials covered by the EP-toxicity characteristic not only beyond the list of eight elements and six pesticides used as the original basis, but also beyond the exclusive use of MCLs from primary drinking water standards as the new basis (Table 3). Thus, in addition to the inclusion of proposed MCLs for volatile organics in this expanded list, chronic toxicity reference levels for other organics, based on reference doses (RfDs) for noncarcinogens and risk-specific doses (RSDs) for carcinogens, respectively, are incorporated (also see Sect. 3.3.5 and 52 FR 8714).

The RfD is an estimate of a daily dose of a substance which will result in no adverse effect even after a lifetime of exposure, and the RSD is the estimated lifetime daily dose of a carcinogen which will result in a cancer incidence equal to a specific risk level (10^{-5} for both Class A and B carcinogens and 10^{-4} for Class C carcinogens). In order to account for toxicant exposure from sources other than water, RfDs are reduced to a fraction (10 to 40%) of the chronic toxicity reference levels, [i.e., the apportioned chronic toxicity reference levels or reference levels in drinking water (Table 3)], before applying dilution and attenuation factors to derive regulatory levels; this apportionment is also done in developing MCLs.

Table 3. Proposed RCRA toxicity characteristic contaminants and regulatory concentration limits (51 FR 21648-21693)

Contaminant	Reference level in drinking water: Concentration (µg/mL)	Reference level in drinking water: Basis[a] (µg/mL)	Maximum leachate concentration[b] (µg/mL)
Acrylonitrile	0.002	RSD	5.0
Arsenic	0.05	MCL	5.0
Barium	1.0	MCL	100.
Benzene	0.005	MCL[c]	0.07
Bis(2-chloroethyl)ether	0.0003	RSD	0.05
Cadmium	0.01	MCL	1.0
Carbon disulfide	1.0	RfD	14.4
Carbon tetrachloride	0.005	MCL[c]	0.07
Chlordane	0.002	MCL	0.03
Chlorobenzene	0.1	RfD	1.4
Chloroform	0.005	RSD	0.07
Chromium	0.05	MCL	5.0
o-Cresol	0.7	RfD	10.
m-Cresol	0.7	RfD	10.
p-Cresol	0.7	RfD	10.
2,4-D	0.1	MCL	1.4
1,2-Dichlorobenzene	0.3	RfD	4.3
1,4-Dichlorobenzene	0.75	MCL[c]	10.8
1,2-Dichloroethane	0.005	MCL[c]	0.40
1,1-Dichloroethylene	0.007	MCL[c]	0.1
2,4-Dinitrotoluene	0.001	RSD	0.13
Endrin	0.0002	MCL	0.003
Heptachlor	0.0001	RSD	0.001
Hexachlorobenzene	0.0002	RSD	0.13
Hexachlorobutadiene	0.05	RSD	0.72
Hexachloroethane	0.3	RSD	4.3
Isobutanol	2.5	RfD	36.
Lead	0.05	MCL	5.0
Lindane	0.004	MCL	0.06
Mercury	0.002	MCL	0.2
Methoxychlor	0.10	MCL	1.4
Methylene chloride	0.6	RSD	8.6
Methyl ethyl ketone	0.5	RfD	7.2
Nickel	0.15	RfD[d]	15.
Nitrobenzene	0.004	RfD	0.13
Pentachlorophenol	0.25	RfD	3.6
Phenol	1.0	RfD	14.4
Pyridine	0.03	RfD	5.0
Selenium	0.01	MCL	1.0
Silver	0.05	MCL	5.0
1,1,1,2-Tetrachloroethane	0.7	RSD	10.
1,1,2,2-Tetrachloroethane	0.02	RSD	1.3

Table 3. (Continued)

Contaminant	Reference level in drinking water		Maximum leachate concentration[b] (μg/mL)
	Concentration (μg/mL)	Basis[a] (μg/mL)	
Tetrachloroethylene	0.007	RSD	0.1
2,3,4,6-Tetrachlorophenol	0.1	RfD	1.5
Thallium	0.002	RfD[d]	0.2
Toluene	1.0	RfD	14.4
Toxaphene	0.005	MCL	0.07
1,1,1-Trichloroethane	0.2	MCL[c]	30.
1,1,2-Trichloroethane	0.06	RSD	1.2
Trichloroethylene	0.005	MCL[c]	0.07
2,4,5-Trichlorophenol	0.4	RfD	5.8
2,4,6-Trichlorophenol	0.02	RSD	0.30
2,4,5-TP (Silvex)	0.01	MCL	0.14
Vinyl chloride	0.001	MCL[c]	0.05

[a]RSD = risk-specific dose (carcinogens); MCL = Maximum Contaminant Level from National Interim Primary Drinking Water Standards; RfD = reference dose (noncarcinogens), fractionated according to estimated contribution from sources other than drinking water (see text).

[b]Concentration obtained using the toxicity characteristic leaching procedure.

[c]Proposed MCLs (50 FR 46880).

[d]Based on projected RfDs (51 FR 21665-21671).

The MCLs for noncarcinogens are generally based on 20% of the relevant RfDs (to account for exposure from other sources such as food and air), whereas MCLs for carcinogens are based on lifetime risk levels ranging from 2×10^{-2} to 2×10^{-6} (3×10^{-4} to 3×10^{-8} per year; 50 FR 46880-47025, 51 FR 21665-21668). However, since no mixture rule applies to reduce the contribution from individual constituents (see Sect. 3.3.4.2), the total risk from some drinking water sources can potentially be $>3 \times 10^{-4}$ per year. As an illustration of this point, if each of the 13 hazardous chemicals for which the EPA has evaluated carcinogenic risk in setting MCLs is present in a drinking water source at concentrations equal to only 3% of their corresponding MCLs, then the total risk to a consumer (assuming simple summation of effects) would be 1×10^{-5} per year. This would increase to 4×10^{-4} per year if each chemical were present in the mixture at its MCL, and would be higher still if the other 13 potential carcinogens in Table 3 were similarly added to the mixture.

Thus, unlike the standards for radioactivity (Sect. 3.3.4.2), no defined mechanism appears to exist within the regulatory framework of CERCLA, RCRA, and SDWA to control the total risks from exposure to hazardous chemical mixtures in drinking water. However, the EPA's reported goal for RCRA groundwater cleanups involving toxic mixtures is a lifetime (70-year) risk $\leq 1 \times 10^{-4}$ (Garvey 1987), and the risks associated with hazardous chemicals (including mixtures) in drinking water may be overstated because of EPA's conservative approach to carcinogen risk assessment (Lave 1987; Wilson and Crouch 1987). Current practice is not to use the best estimate (maximum likelihood or central tendency) of risk, but rather the upper bound in a 95% confidence interval constructed about that estimate (Lave 1987). As a result, EPA's risk estimates are often an order of magnitude (or more) greater than those obtained by others (see, for example, differences between the EPA and the National Academy of Sciences estimates in 50 FR 46880-47025; also Wilson and Crouch 1987).

3.3.5 Technical Options for Remedial Actions

Little in the way of specific design information is provided in existing DOE, EPA, NRC, or TDHE regulations that either applies directly to, or represents general guidance on, technological requirements for achieving site closure for the ORNL Remedial Action Program. The language in the extant version of DOE Order 5820.2 (DOE 1984), for example, simply mentions options such as capping and filling for former LLW landfill disposal sites, and although other potential measures are tabulated in other DOE guidance (EG&G 1985; EG&G and DOE 1986), these include only the obvious possibilities and not the more innovative ones (e.g., in situ vitrification and permeable treatment beds). NRC regulations (10 CFR Part 61.28; also see TDHE Rule 1200-2-11-.12) ask that (1) geologic, hydrologic, or other site data, tests, or experimental results and (2) any revisions to plans for decontamination and/or dismantlement of surface facilities, backfilling,

or site stabilization for postclosure care pertinent to long-term containment be provided in the application for closure. (Similarly comprehensive language has been incorporated into the January 4, 1987 draft of the revised DOE Order.)

As described earlier in Sect. 3.3.2, the NRC standards were based on the concept that combined site, design, waste, and operational characteristics, along with appropriate closure methodology and postclosure controls, would ensure attainment of performance objectives at new land disposal facilities (10 CFR Part 61, Subparts C and D). Some information relevant to site stabilization and performance criteria for ORNL remedial actions is thus provided, albeit indirectly, in Subpart D, Technical Requirements for Land Disposal Facilities, in the NRC regulations (also see TDHE Rule 1200-2-11-.17). The concept is that site stabilization actions undertaken at closure could provide some remedies for specific deficiencies in the technical requirements identified in Subpart D, for example, by

- removing contaminated sediments from floodplains;
- altering upslope drainage areas to decrease runoff;
- increasing the depth to the water table to eliminate groundwater intrusion and outcrops (seeps) within the disposal site;
- reducing surface erosion and water infiltration, using covers and directed surface drainage;
- characterizing waste contents as accurately as possible;
- increasing waste stability and integrity;
- reducing voids in disposal trenches;
- locating and mapping boundaries of disposal trenches;
- providing an appropriate buffer zone at the site boundary;
- increasing cover thickness or installing intruder barriers for higher-activity (Class C) wastes, to be effective for at least 500 years; and
- either developing more suitable waste forms (e.g., through on-site or in situ treatment in a remedial action context) for wastes representing greater hazards (i.e., $\geq$0.10 uCi/g for TRU, $\geq$4600 uCi/cm^3 for ^{137}Cs, and $\geq$7000 uCi/cm^3 for ^{90}Sr) or exhuming such materials for disposal by greater-confinement methods.

Viewed in this manner, the information provided by the NRC in Subpart D regulations appears to be very useful guidance, much of which is already being applied to the ORNL Program (Bates et al. 1986; Trabalka and Myrick 1987).

Although an extensive list of potential methods for "remedying releases" is provided in 40 CFR 300.70 of the CERCLA National Contingency Plan, no criteria (or references) for design and implementation are included. Presumably, "existing design standards" in "EPA guidance documents" (e.g., EPA 1982, 1984) were meant to be used, just as these, along with recently proposed regulatory standards (51 FR 10708-10712, 52 FR 8704-8709), "provide the basis for interpreting the new minimum technological requirements" imposed by the 1984 Hazardous and Solid Wastes Amendments to RCRA (50 FR 28709).

These new RCRA requirements are that new or interim status landfills and surface impoundments that receive wastes beginning May 8, 1985, must have two or more liners and leachate collection and groundwater monitoring systems in order to qualify for permits. Under the congressional directives provided by the 1984 amendments, EPA plans to issue new guidance documents on the installation of liners and leachate collection systems and on record keeping (50 FR 28710). The "upcoming liner guidance will also discuss a construction quality assurance . . . plan which would document the liner design, materials, and installation procedures" (50 FR 28710).

The EPA has proposed interim liner design standards which remain effective until final regulations or guidance documents are issued: upper liner of flexible membrane (or functional equivalent) "designed, operated, and constructed to prevent the migration of any hazardous constituent into such liner during the active life and postclosure care period"; lower liner "constructed of at least a 3-foot thick layer of compacted clay or other compacted soil material with a hydraulic conductivity of no more than 1×10^{-7} cm/sec"; and both liners "of materials that have appropriate chemical properties and sufficient strength and thickness to prevent failure" (51 FR 10720-10721). The proposed design standards for leachate collection systems require that they

> "be designed, constructed, maintained, and operated to detect, collect, and remove liquids . . . during the active life and the postclosure care period. The leachate collection system must be:
> (i) Constructed of materials that are chemically resistant to the waste materials managed . . . and the leachate expected to be generated and of sufficient strength and thickness to prevent collapse under the pressure exerted by overlying wastes, waste cover materials . . . and
> (ii) Designed and operated to function without clogging during the active life and postclosure care period" (51 FR 10721).

Proposed standards for landills are further designed to "ensure that the leachate depth over the top liner does not exceed 30 cm" (51 FR 10721).

The EPA has also proposed that alternative technical requirements be applied to closures of landfills, surface impoundments, and waste piles in "situations where residual contaminants are present in low concentrations, are of low toxicity, and have low mobilities, where migration of the waste residuals to any medium is unlikely, and where long-term monitoring is guaranteed" (40 CFR Parts 264.310(c) and 265.310(c); 52 FR 8712-8722). The factors to be considered in establishing alternative closure requirements are similar in many ways to those evaluated in an ACL demonstration. The main difference is that in the proposed closure demonstration attenuation in the unsaturated zone may be taken into account (and may require a different type of monitoring). In addition, ACLs address only groundwater contamination, but the proposed closure analysis would also address surface water releases and the potential exposure pathways of direct contact and atmospheric release (52 FR 8714). Permissible exposure

limits include water quality standards and criteria and health-based limits derived from RfDs and carcinogenic potency factors developed by EPA or from site-specific EPA-reviewed public health evaluations issued by the Agency for Toxic Substance and Disease Registry of the Center for Disease Control, U. S. Department of Human Services (52 FR 8714).

As with CERCLA regulations, the principal test of RCRA liner/leachate collection design criteria is whether or not they are sufficient to "protect human health and environment" (51 FR 10721). Thus, the liner and leachate collection requirements may be waived by the Regional Administrator "if the owner or operator demonstrates . . . that alternative design and operating practices, together with location characteristics, will prevent the migration of any hazardous constituent into the groundwater or surface water at least as effectively" [e.g., 40 CFR Parts 265.221(c) and 265.301(c)]. Further, any landfill or surface impoundment that received waste and was operational before November 8, 1984, is exempt from the statutory minimum technological requirements. However, it must have been in compliance with, or exempt from, RCRA single-liner regulations, that were in effect before the 1984 amendments, in order to have been considered operational by November 8, 1984 (EPA's interpretation; see 50 FR 28707). Exemptions were provided for those units for which retrofitting with liners would have been impracticable, burdensome, or dangerous (47 FR 32290, 32315; 50 FR 28707).

Testing of innovative and experimental technologies and treatment methods is allowed and encouraged by both CERCLA (50 FR 47928) and its 1986 reauthorizing legislation (SARA Sect. 209) and by the 1984 amendments to RCRA (50 FR 28728). As outlined in its CERCLA guidance, the EPA intends to "encourage the development and consideration of innovative approaches to remedying site problems" (50 FR 47928) and also "supports the practice of on-site testing (of treatment alternatives) where appropriate and practicable" (50 FR 47929). Although EPA believes that permanent solutions (e.g., "destruction, neutralization, or immobilization of waste") should be preferred over others "only to the extent that they are more cost-effective than other alternatives over the <u>anticipated life of the response</u>" (50 FR 47929; underlining added), SARA requires EPA to utilize permanent solutions and alternative treatment or resource recovery technologies to the maximum extent practicable [Sect. 121(b)]. Furthermore, if any hazardous substances are left at a site, EPA must review the effectiveness of the remedial measures every five years to assure that human health and the environment are being protected [SARA Sect. 121(c)].

The definition of the "anticipated life of the response" appears to be related to the EPA's concept of "long-term effectiveness" in setting technical standards (e.g., the proposed design standards for liners and leachate collection systems described above). The design objective for such systems appears to be maximal effectiveness for a period of about 40 years [i.e., the estimated period of operation and postclosure care for landfills or surface impoundments (51 FR 10709)].

> "<u>EPA's position . . . is that absolute prevention of migration forever, or for the long term, is beyond the current technical</u>

state of the art. Thus, at some time, some migration through the liner will probably occur" (51 FR 10708; underlining added).
"Based on presently available information, the Agency does not view liner systems as the primary means of controlling the migration of hazardous constituents in the long term . . . Since the function of the liner systems, then, is relatively short-term in nature, as opposed to providing protection for many decades or even hundreds of years, the effectiveness of liners is overshadowed by other factors in the analysis of long-term risk reduction. These other factors include: (1) the location of the unit with respect to climate, hydrogeology, and population, (2) the nature of the waste in the unit, and (3) the long-term performance of the final cover that is placed over the unit at closure" (51 FR 10711; underlining added).
"The Agency is developing regulatory programs in each of these three areas. At the time that we promulgate rules in these three additional areas, we may reexamine the need for liner designs that are more stringent than the interim statutory double-liner design . . . The Agency is interested in comments on the interrelationship of engineering-, location-, and waste-related factors in determining the risk presented by hazardous waste landfills and surface impoundments. Should the Agency be considering tradeoffs in facility design based on site specific factors? . . . To what extent can such `tailoring' of requirements be achieved on the national and local levels?" (51 FR 10711; underlining added).

It is apparent from these queries and others on liner structure and composition (51 FR 10711-10712) that EPA is far from clear on the optimal design and operation of liners and leachate collection systems for operating sites and much less so for previously closed sites. Thus, it is difficult to project what the standards for a final cover are likely to be!

The EPA's position may be compared with that of the NRC (10 CFR Part 61, Subpart D; also see TDHE Rule 1200-2-11-.17) in which

(1) "the primary emphasis in disposal site suitability is given to isolation of wastes, a matter having long-term impacts, and to disposal site features that ensure that the long-term objectives . . . are met, as opposed to short-term convenience or benefits,"
(2) "site design features must be directed toward long-term isolation and avoidance of the need for continuing active maintenance after site closure," and
(3) "wastes designated as Class C . . . must be disposed of so that the top of the waste is a minimum of 5 meters below the top surface of the cover or must be disposed of with intruder barriers that are designed to protect against an inadvertent intrusion for at least 500 years" (underlining added).

Although there may appear to be significant differences in philosophy underlying the technical standards proposed by the EPA and NRC, this is not the case. The two agencies appear to be in agreement that the principal emphasis for ensuring long-term containment needs to be focused on site location (hydrogeology, population) and waste characteristics, not on site design features (e.g., covers or liners). The NRC makes this clear in 10 CFR Part 61.51 regulations:

> "The disposal site must be designed to complement and improve, where appropriate, the ability of the disposal site's natural characteristics to ensure that the performance objectives . . . will be met" (underlining added).

The differences are that the EPA is (1) only now in the process of initiating rulemaking dealing with site location and waste characteristics requirements under RCRA and (2) likely to be skeptical about the role of engineered covers or liners in assuring long-term containment of land-disposed wastes (also see Sect. 3.3.2).

3.3.6 Cost-Effectiveness of Closure Alternatives

Analyses of cost vs benefit or risk vs cost are either implicit in or required by some regulations and DOE Orders dealing with the design or selection of stabilization options for remedial actions. Such analyses may be performed on either a generic or a site-by-site basis, depending on the specific application (e.g., technology evaluation) and/or regulatory need.

3.3.6.1 ALARA

The ALARA principle (Sect. 3.3.4.2) guides both normal operations and remedial actions carried out under DOE Orders, NRC regulations, and some EPA regulations (e.g., 40 CFR Part 192). This principle implies a cost-vs-risk comparison and a consideration of all relevant risks, including a balancing of the radiation exposure risks to remedial action personnel and the public, as part of the alternatives evaluation process. An expenditure of $1000 per person-rem avoided may represent a crude index for decision making (Auxier and Dickson 1983; Kathren and Selby 1980). However, since decisions must be evaluated on a case-by-case basis and the relationships between technology and economics are constantly shifting, the application of the ALARA principle has been fraught with controversy (e.g., Auxier and Dickson 1983).

The revised 10 CFR 20 regulations provide one potentially feasible option to detailed ALARA analyses: Compliance with the more stringent (i.e., 25 mrem/year) standards in 40 CFR 190 for radiation exposures of the general public from nuclear fuel cycle operations (51 FR 1130). However, in a remedial action setting, one must not lose sight of the fact that the avoidance of excessive radiation exposures of the personnel involved in stabilization or closure actions is a goal as important as reducing the future dose commitments to the public. Thus,

implementation of the "simpler" alternative seemingly offered by the 10 CFR 20 regulations, in lieu of ALARA analyses for remedial actions, can also be nontrivial (Gilbert et al. 1985).

For example, the estimated effective dose equivalent from all ORNL releases to the maximally exposed member of the general public was <25 mrem in 1985 and 1986 (Martin Marietta Energy Systems 1986; Oakes et al. 1987). The total estimated dose to downstream populations (including Chattanooga) from aquatic pathways has averaged <10 person-rem/year over the past decade (compare the results of Little and Cotter 1980 and Boyle et al. 1982 with those in Martin Marietta Energy Systems 1986 and Oakes et al. 1987). These population doses are extremely small when you consider the estimated $1 billion cost of the ORNL Remedial Action Program. Assuming (optimistically, but unrealistically) that these doses can be reduced to zero by implementing this program, the resulting $100 million cost per person-rem avoided can hardly be justified when you consider the costs involved when using any established ALARA criterion.

Therefore, ALARA analyses for the ORNL program have to be focused on assessment of the potential for significant increases in future exposures of members of the public should the Remedial Action Program not be undertaken and the recommended policy of long-term institutional control not be adopted. These increased population doses could accrue in the off-site populations from contaminants migrating from the ORNL site as a whole, or perhaps be the result of direct exposures at specific areas of the site, for example, under conditions resulting from lapse of institutional control.

3.3.6.2 CERCLA, NEPA, and RCRA

The role of economic factors in NEPA and CERCLA decision making (i.e., selection of remedial action alternatives) appears to have some basic similarities. For example, although a monetary cost vs benefit analysis is not explicitly required by NEPA and should not be performed when there are important qualitative considerations [e.g., unquantified environmental impacts, values, and amenities (40 CFR Part 1502.23)], this does not mean that economics should not be considered in a NEPA review. Rather, it means that other factors (e.g., environmental quality) may take precedence.

Likewise, in selecting remedies for implementing CERCLA requirements, although an analysis of relative cost-effectiveness is to be used in making a choice [40 CFR Part 300.68; SARA Sect. 121(b)], the selection must be made from a set of alternatives that attain or exceed any "legally applicable or relevant and appropriate" federal or state "standard, requirement, criteria, or limitation" [SARA Sect. 121(d)]. Economic considerations may not be used to justify an alternative that does not satisfy this requirement. "Selection of any remedy must both protect public health and welfare and the environment, as well as achieve cost-effectiveness" (50 FR 47926). Exceptions are permitted if (1) the selected alternative is not the final remedy planned, (2) compliance would result in greater risks to human health and the environment than from other alternatives, (3) no technically practical

alternative exists, (4) the level of performance "is equivalent to that required under the otherwise applicable standard, requirement, criteria, or limitation, through use of another method or approach", (5) a state has not consistently applied its standard, requirement, criteria, or limitation in similar circumstances at other sites, and (6) the need for action at other Superfund sites limits the amount of money available [SARA Sect. 121(d)(4)].

Although no regulations governing the cost-effectiveness of the corrective actions required by the 1984 amendments to RCRA have been promulgated, it is the EPA and TDHE position that "RCRA is not requiring the selection of unreasonable alternatives. After defining those alternatives which accomplish the desired goals, it is appropriate to determine which alternative does so at least overall cost" (Leming 1986; underlining added). The definition of "desired goals" is thus the critical uncertainty and the highest priority.

3.3.7 Preliminary Conclusions

Although a relatively small proportion of the sites in the ORNL Remedial Action Program appear to be regulated under RCRA regulations for new or interim status facilities (Trabalka and Myrick 1987), some of the RCRA performance standards [e.g., closure; 40 CFR Part 265.111(a), (b)] appear to be very appropriate for ORNL sites, including those sites which are contaminated solely with radionuclides. Meeting the spirit of RCRA, if not the exact letter of all technical specifications that apply to new or interim status operating facilities, will undoubtedly be one of the major program objectives.

In addition, specific RCRA requirements for such facilities may well be deemed "applicable or relevant and appropriate" or "desired goals" by EPA and TDHE for ORNL sites subject to regulation under either CERCLA (SARA Sect. 121) or the corrective action provisions of the 1984 amendments to RCRA [Sect. 3004(u); 50 FR 28711-28714]. Such determinations can only be made on a site-by-site basis and are therefore not absolutely predictable (also see limitations on RCRA corrective actions; 50 FR 28713). The distinctions between CERCLA and RCRA remedial action standards from ORNL's perspective may be slight in actual practice because (1) RCRA corrective actions and CERCLA remedial actions are both mandated only where necessary to protect human health and the environment, (2) the RCRA corrective action provisions must be integrated with those of other statutes administered by EPA (e.g., CERCLA), (3) SARA may specifically require application of some RCRA standards at CERCLA sites (Garvey 1986b; SARA Sect. 121), and (4) the uncertainties associated with the presence of hazardous chemicals at ORNL radioactive and mixed waste sites makes dual regulation under CERCLA and RCRA Sect. 3004(u), either concurrently or sequentially, a distinct possibility (McSlarrow 1987; Miller 1987; Trabalka and Myrick 1987).

> "RCRA provides more flexibility since evaluations are made by the permittee who has control over the selection of alternatives to be

> evaluated. CERCLA requires specific categories of alternatives including an evaluation which exceeds all regulatory standards and health/environmental concerns. RCRA does not have such specific requirements. Under RCRA, it is intended that alternatives be designed to achieve the goals established and within a reasonable time frame" (Leming 1986; underlining added).

These observations become even more important when you consider the limited potential for using ALARA analyses in making decisions about remedial action alternatives (see the previous section).

Limits were originally imposed on the authority of states to set standards for CERCLA sites that were more stringent than those set forth in applicable or relevant and appropriate federal environmental and public health laws (40 CFR Part 300; 50 FR 47912). The EPA's position with reference to state cleanup standards was that

> "it would be unwise to oblige CERCLA cleanups to conform to 50 different and possibly conflicting sets of State standards; further, some States have not based standards on protection of health or the environment. The fact that EPA may have approved some of these standards is irrelevant, because under some statutes, such as RCRA, EPA is obliged to approve State standards that are more stringent than those of EPA. This approval does not signify an EPA determination that attaining the [State] standards is necessary to protect public health and welfare and the environment" (50 FR 47924).

[State water quality standards adopted under the CWA were not included in the EPA's position on state standards. These standards are federally enforceable and are to be applied where applicable or relevant and appropriate" (50 FR 47924)].

The Congress evidently did not agree with the EPA's position; SARA now requires formal consideration of not only the more stringent state standards, but also SDWA MCLGs and CWA criteria (which are set at zero for hazardous chemical carcinogens and radionuclides) where such standards are "relevant and appropriate" to CERCLA remedial actions. In addition, states also play a more direct role in the selection of remedial alternatives at CERCLA sites, particularly at federal sites not on the National Priority List [Garvey 1986b; SARA Sects. 120(a), 120(f), 121(b), and 121(f)]. Rule making by EPA is also to "assure a state's full participation in establishing . . . priorities for cleaning up hazardous releases at federal facilities under [RCRA] section 3004(u)" (51 FR 7723).

It is significant that prior to enactment of SARA, the TDHE position was that should "proposed CERCLA legislation . . . impact the State's authority to regulate Federal Facilities under the 3004(u) provision . . . TDHE would consider application of regulation under other applicable laws" (Leming 1986). Although this specific concern appears to have been eliminated by provisions in SARA Sects. 120 and 121, the TDHE has thus effectively served notice that it will play a major role in determining what standards, requirements, criteria, or

limitations are relevant or appropriate to ORNL remedial actions, not solely limited to its statutory authority under CERCLA and RCRA.

The circumstances under which (1) SDWA MCLGs and CWA criteria could be judged relevant and appropriate and (2) TDHE would propose standards that are more stringent than existing federal standards are critical unresolved issues for the ORNL Remedial Action Program. These serve to highlight the currently incomplete, uncertain, and, to some extent, negotiable aspects of regulatory requirements for remedial actions and thus to focus attention on the critical need for a regulatory interface in closure criteria development.

4. PROGRAM STRATEGY AND CLOSURE CRITERIA DEVELOPMENT

4.1 STRATEGY DEVELOPMENT

A program strategy directed at meeting the intent and spirit of the CERCLA, RCRA, and NRC's LLW regulations by focusing closure actions on remedies for site deficiencies which would have been addressed in the technical requirements for new facilities seems most in keeping with existing regulatory guidance. For example, retrofitting most ORNL remedial action sites with double liners and leachate collection systems appears impracticable, both from a technical and an economic perspective. Such systems do not represent the long-term solutions needed to deal with ORNL site and waste problems (Sects. 3.1.1 and 3.3.5), and ORNL releases do not currently pose a threat to human health and environment off-site (Sect. 3.3.6). It therefore appears feasible to apply a variety of in situ techniques, but primarily hydrologic measures in conjunction with institutional control, to provide long-term controls on releases from ORNL sites. Several options can be adopted, where necessary to protect human health and the environment, to implement such a strategy and assure simultaneous protection of both groundwater and surface waters: (1) eliminating potentially usable, but contaminated, sources of groundwater by dewatering contaminated areas, thus reducing contaminant transport out of these areas; or (2) providing on-site or in situ treatment methods, e.g., covering systems, vertical barriers, leachate collection systems, grouting and/or vitrification, to isolate or fix contaminants in place, thus controlling contaminant transport across the site boundaries.

These measures would have to remain effective for a period sufficiently long to allow decay of fission products to acceptable levels and to provide an adequate assessment of the long-term effectiveness of environmental processes and passive remedial techniques in controlling (but not totally eliminating) the future migration of hazardous chemicals and very long lived radionuclides (see Sects. 3.1.1, 3.1.3, 3.2.3, and 3.3.4.2). The nature of institutional control thus becomes a critical "closure criterion" for either of the two basic options and must be agreed upon prior to initiating development of other closure criteria.

Selection of the second option described above also implies a regulatory and programmatic commitment to focus on research and development of innovative and untested technologies in implementing the ORNL program. The current limitations of passive systems could require either limited excavation and removal of wastes or demonstrations and further development of innovative technologies for some ORNL sites (Sects. 3.1.3 and 3.3.5), for example, auger holes and trenches containing TRU wastes and higher concentrations of LLW and hazardous materials in solid waste storage areas (Boegly et al. 1986). This choice seems most in keeping with ORNL's unique mission and research capabilities, the nature of the wastes generated, and the buffer zone represented by the site and environs.

A strategy of the type suggested above appears to be highly consistent with EPA's proposed approach for evaluating both ACLs (EPA 1986c) and alternative closure options (52 FR 8712-8722) at RCRA sites, and is implicit in criteria for both the risk-based variance to the secondary containment provisions in the RCRA hazardous waste storage tank regulations (51 FR 25452-24453) and the cost-effectiveness of CERCLA remedial actions (see previous section). One of the objectives of a regulatory interface would be to determine whether the basic strategy and proposed options for implementation are truly viable on the basis of regulatory requirements.

4.2 CLOSURE CRITERIA DEVELOPMENT

4.2.1 Water Contamination

The reference level concentrations for hazardous chemical and radioactive constituents in drinking water (Tables 2 and 3, respectively) appear to represent an initial basis for the formulation of closure criteria for ORNL surface waters (i.e., White Oak Creek and tributaries). Given the current state of the art, including uncertainties in both reference levels (Table 2) and risk estimates (e.g., Barnthouse et al. 1986, 51 FR 21665-21668), these two independent sets of values may well be grounded in comparable levels of health risk in complex effluents, despite the concerns expressed in Sect. 3.3.4.3. Although the basis for this assessment (and other alternatives) should be carefully examined, it seems doubtful that suitably comprehensive alternatives are currently available (and acceptable) to regulatory bodies (but see Barnthouse et al. 1986 and 52 FR 8714).

It should be possible to develop reference level concentrations for additional hazardous chemical constituents as the first step in formulating ACLs by using the methodology adopted by the EPA in expanding the list of hazardous chemicals covered by the EP-toxicity characteristic (51 FR 21648-21693; also see 52 FR 8714) (or, alternatively, the methodology described by Barnthouse et al. 1986). Many of the reference levels for drinking water in Table 3 can be increased significantly, up to an order of magnitude (see Sect. 3.3.4.3), if it can be demonstrated that pathways other than consumption of drinking water contribute negligibly to human health risks and that environmental effects (e.g., on the White Oak Creek biota) will not be significant). By the same token, it may be necessary to reduce the levels in both Tables 2 and 3 to accommodate exposures through other pathways (e.g., from soil radioactivity; see Sect. 4.2.2). Thus, pathways screening appears to be a high-priority exercise for initial performance modeling (e.g., Gilbert et al. 1985).

It is also significant that EPA has requested comment on whether "as an alternative to using the [drinking water standards; MCLs], the Agency should consider using the RfD or RSD values as the starting

point (for modeling in its revised EP-Toxicity Characteristic rule), <u>even when [MCLs] are available</u>" (51 FR 21650; underlining added). If such an alternative is adopted by the EPA, this could have significant implications for RCRA groundwater standards, that is, implying ultimate changes to reflect the use of risk-based assessments (now used only in ACL demonstrations) rather than comparisons with MCLs or background levels in determining water quality degradation (also see 52 FR 8714). Adoption of a risk-based approach to closure criteria development would be highly desirable from a human health perspective.

Risk estimates associated with current MCLs differ by 4 orders of magnitude while reference level concentrations for radionuclides (Table 2) are based on a common risk estimate. The result is that potential risks from hazardous chemicals could be greater or lower (depending on the chemical present) than the risks from radionuclides when these materials occur in drinking water in concentrations equal to current standards (Sect. 3.3.4.3). Thus, in order to assure that a total risk of 10^{-6} to 10^{-5} per year (Sects. 3.3.4.2 and 3.3.4.3) from exposure to ORNL effluents containing radionuclides and hazardous chemicals is not exceeded, it may be necessary to reduce the concentrations of some hazardous chemicals to levels lower than their MCLs and to reduce the reference level for radionuclides in water to <100 mrem/year (because of the added risks from hazardous chemicals).

Proper utilization of a risk-based approach requires the development of a system for comparing the relative risks of hazardous chemicals and radionuclides on an equivalent basis--no mean feat! It also should be recognized that adoption of a risk-based approach would have to be embraced not only by EPA, but also by TDHE, in order to have a practical impact under RCRA. Hence, the ultimate selection of a groundwater protection strategy by the state of Tennessee (Sect. 3.3.4.3) becomes an even more critical factor in determining groundwater protection standards.

In the face of this uncertainty, it is proposed that the reference levels for drinking water in Table 3 (or their equivalent) and in column 1 of Table 2 (or an appropriate fraction if estimates of combined risks from radionuclides and hazardous chemicals exceed 10^{-6} to 10^{-5} per year and/or dose contributions from soil radioactivity are significant) be used as initial targets for closure (performance) criteria for ORNL groundwaters at the termination of formal institutional control, nominally projected to occur $\geq$200 years following the completion of closure and decommissioning. [The maximum leachate concentrations in Table 3 may be useful in judging whether inventories of hazardous chemical constituents at some sites (e.g., SWSA trenches, surface impoundments) are likely to pose significant problems.] If performance modeling indicates that such criteria are not likely to be met at the end of a nominal 200-year control period, using the initially preferred site stabilization option, one solution could be to extend the institutional control period. Alternatively, other closure and decommissioning options could be considered. The latter could involve either the development of detailed ACL

demonstrations and derived ALARA limits for the offending hazardous constituents and radionuclides, respectively, or the implementation of alternative stabilization options at critical ORNL sites.

4.2.2 Sediment and Soil Contamination

Guidelines for disposal of ORNL sediments and soils as "uncontaminated radioactive waste" are potentially applicable as closure criteria [e.g., for so-called clean-closure conditions or residual surface radioactivity at remedial action sites (see below)]. Development of comparable guidelines for sediments and soils containing hazardous chemical wastes has been deferred pending: (1) a determination that data obtained in addition to the results from the EP-toxicity characteristic leaching procedure have a significant regulatory basis; (2) completion of EPA's own analysis of the suitability of existing transport models (e.g., Sect. 3.3.4.3) and soil criteria (51 FR 25457); and (3) demonstration that these wastes contribute significantly to human health and environmental risks at ORNL sites.

The proposed guidelines for ORNL, given in Table 4, were derived on the basis of pathways analysis, as described in the table, using the assumption of unrestricted public access to ORNL waste sites, including the potential for continuous occupancy (see Gilbert et al. 1985 for a description of the methodology employed; and EG&G and DOE 1986, DOE 1987b, and Sect. 3.3.4.2 for the regulatory basis).

The guidelines were designed to be consistent with revised DOE and NRC regulations governing control of population exposures (Sect. 3.3.4.2) as well as the guidelines established for residual radioactivity at Formerly Utilized Sites Remedial Action Program (FUSRAP) and remote Surplus Facilities Management Program sites (DOE 1987b). These require that (1) lifetime average dose rates do not exceed 100 mrem/year, (2) no individual receives >500 mrem in any one year or >100 mrem/year for more than a few years, and (3) soil concentration guidelines are to be derived from these dose limits by means of an environmental pathways analysis.

As described in Sect. 3.3.4.2, existing regulatory guidance indicates that an annual committed effective dose equivalent of 25 mrem is an appropriate ALARA target for population exposures from any single waste-generating source (e.g., proposed revisions to 10 CFR Part 20 regulations--51 FR 1092ff, as well as 10 CFR Part 61, 40 CFR Parts 61 and 191, and Kathren and Selby 1980). Such a limit would also appear to be appropriate for ORNL sites once the period of formal federal control has elapsed and such sites are opened (at least hypothetically) to unrestricted public access. It also should be recognized that exposures from food and drinking water represent additional contributions that must be taken into account (Sect. 4.2.1). The guidelines in Table 4 thus represent a compromise solution, as outlined below.

The establishment of soil contamination limits for beta- and gamma-emitters and alpha-emitters based on different annual dose

Table 4. Proposed guidelines for residual radioactivity in surface soils (0- to 1-m depth)

Measurements above background	
Soil contamination limits	Contaminant
Concentration (pCi/g)	
40	Beta- and gamma-emitters[a]
15	Alpha-emitters[b,c]
External dose rate at 1 cm through a 7-mg/cm^2 absorber (μrad/h)	
15	Beta- and gamma-emitters[d]

[a]Fifty-year annual committed effective-dose-equivalent for pathways analysis = 75 mrem (Gilbert et al. 1985) in the context of guidance in DOE 1987b; limiting pathway and radionuclide: external exposure from ^{137}Cs (or ^{60}Co). DOE control of ORNL sites assumed to last at least 200 years. Much higher limits (1 x 10^6 pCi/g) would be appropriate if ^{3}H was the sole contaminant (Gilbert et al. 1985). Concentration guideline listed above is twice the value of the Gnome nuclear test site cleanup guideline and 4 times the limit used for Amchitka, Gasbuggy, Rio Blanco, and Tatum Dome nuclear test site cleanups (Church 1981). An analysis of organ-dose commitments from global radioactive fallout (UNSCEAR 1972) yielded a limit of 20 pCi/g for an assumed 50%-50% mixture of ^{90}Sr and ^{137}Cs.

[b]Annual dose equivalent through pathways analysis = 25 mrem (Gilbert et al. 1985); limiting pathway and radionuclide: inhalation of ^{232}Th. Also see pathways analyses for Th, U, Pu, and Am isotopes in Bondietti et al. (1979); EPA limits for population exposures to transuranium elements (EPA 1977); and Formerly Utilized Sites Remedial Action Program guidelines for ^{232}Th (DOE 1987b). Concentration limit is also equal to the detection limit (5-min count) for the ZnS scintillation technique for remedial action field surveys developed by Los Alamos National Laboratory (Ahlquist et al. 1978; Umbarger 1981).

[c]Higher limits of 30-35 pCi/g would be justifiable if soil contamination was restricted solely to uranium (isotopes other than ^{232}U) (Bernhardt et al. 1985).

[d]Essentially equal to twice the average natural background rate in the ORNL area (Burson 1976). Designed to prevent the lifetime dose rate from ^{137}Cs from exceeding an average value of 75 mrem/year in the context of the soil concentration limit. Since radioactive decay reduces the effective concentration over 50 years, the initial dose rate at the time of soil disposal is higher by approximately 75% (130 mrem/y).

equivalents of 75 mrem and 25 mrem, respectively (see the table), is related to (1) differences in the physical half-lives of key constituents (e.g., tens of years or less for typical fission products such as ^{137}Cs or ^{60}Co vs $>1 \times 10^4$ years for actinides such as ^{239}Pu or ^{232}Th) and (2) the logical expectation that institutional control of ORNL sites by DOE will last for a period long enough (e.g., $\geq$200 years) to reduce annual doses from beta- and gamma-emitters to levels below regulatory concern (<1 mrem; see 51 FR 1092ff). It is also expected that institutional control will lower the effective occupancy factor for ORNL sites and thus limit total annual exposures to the general public until that time (Sect. 3.2.3). The guidelines for soil concentrations in Table 4 are thus meant to apply simultaneously without compromising a 100-mrem annual effective-dose-equivalent limit for exposures of the general public.

A decision to quantify individual alpha-emitters or beta- and gamma-emitters could yield less restrictive cleanup concentration guidelines and potentially lower decontamination costs than the alternative shown in Table 4 because significant differences in environmental mobility and radiotoxicity exist among the individual nuclides (e.g., see Table 2). Yet simplified guidelines (e.g., using gross-alpha measurements to represent concentrations of all actinides, have major advantages when clear and unambiguous operating procedures are desired (i.e., for purposes of effective administrative control). In addition, uncertainties about the long-term environmental behavior of the different actinide elements under local conditions often make it difficult to take advantage of more detailed information on individual radionuclides. When compared with simpler alternatives, resorting to more discriminatory guidelines or analytical methods also implies increased costs and, almost inevitably, delays in schedules.

The working standard corresponding to the soil concentration limit for alpha-emitters in Table 4 is 2.6 dis/min per 100 cm^2 using a highly sensitive ZnS scintillation technique developed for remedial action field surveys by Los Alamos National Laboratory (Ahlquist et al. 1978; Umbarger 1981). This working value also represents the detection limit achievable with this instrumentation using a 5-min counting time (it also requires a 30-min soil drying time). Thus, in order to apply these new soil guidelines, ORNL will have to obtain a new generation of instrumentation for conducting field surveys for alpha-emitters in environmental media. (New procedures and an analytical methodology for determining the presence and content of hazardous chemicals in soils will also be required.)

Other potentially usable criteria may be derived secondarily from the limits in Table 4. As one example, if ORNL were to opt for a system of very tight land-use restrictions and institutional controls for all disposal and remedial action sites in lieu of lower soil contamination limits, the Table 4 criteria could be increased quite significantly. Such a choice would also require that site usage restrictions and institutional controls be maintained for a period longer than 200 years. Significant increases in the soil concentration limit for alpha emitters could require implementation of additional

remedial measures (e.g., physical barriers to migration) that would have to be effective for as long as the wastes remain hazardous. Such options appear to be inadvisable based on current information. Among the reasons against higher concentration limits for surface soils are the following:

(1) the ALARA concept itself;
(2) the uncertainties about the long-term effectiveness of available remedial action technologies in limiting future radiation exposures from the actinide elements, in particular;
(3) the likelihood that future restrictions on both occupational and population exposures will occur;
(4) the potential loss of flexibility in futures uses of sites left contaminated at higher levels of radioactivity, particularly those located within the main ORNL complex; and
(5) the uncertainties inherent in dose calculations from pathways analyses, which indicate the need for prudence and conservatism in setting guidelines for remedial actions.

Derivation of appropriate guidelines for replacement of contaminated soils in excavations at sites where operating facilities are being upgraded and where remedial actions are being implemented is a more complex issue and one that is not readily resolvable with the limited information currently available. At the outset, it would appear that the guidelines for soil replacement would be highly site-specific [i.e, heavily dependent on the areal and volumetric distribution of radioactivity both within and adjacent to a given site, as well as on the projected (in situ) stabilization method for achieving ultimate closure of that site].

Thus, the criteria used to judge whether soil replacement was desirable could potentially range from the Table 4 values at clean closure locations, at which excavation and removal of all highly contaminated materials was deemed necessary, to very high multiples of those values at other sites, at which stabilization-in-place was the preferred option. Clear-cut choices for stabilization of most Remedial Action Program sites will not be developed for some time to come (Bates et al. 1986; Trabalka and Myrick 1987). Thus, the reasons given previously for not using soil contamination limits higher than those in Table 4 would seem to apply to the issue of soil replacement as well.

Yet it is also true that storage and disposal of radioactive wastes, including soils, at ORNL is becoming increasingly more difficult and expensive; the available capacity for such operations is currently at a premium. Thus, waste minimization has become a very desirable and necessary activity for all ORNL programs, including those engaged in remedial actions. The decision to return contaminated soils to excavations at remedial action sites could thus be viewed as a potentially sound and cost-effective procedure for waste minimization.

In order to make a determination of cost-effectiveness and to develop a suitably quantitative procedure for effective management of contaminated soils, assessment of the impact of the following factors, as well as their interrelationships, appears to be necessary:

(1) areal and volumetric distribution of contaminants within and around sites--requiring a presurvey and analysis of historical information on site conditions as part of the planning process, well before operations are scheduled to commence;

(2) estimated inventories of contaminated soils (and the various concentrations of contaminants) to be excavated at each site;

(3) projected impact of soil replacement on the effectiveness of the preferred stabilization method for ultimate closure of the site (e.g., increased environmental mobility of radionuclides or hazardous chemicals resulting from the replacement of soils with unacceptable physicochemical characteristics and/or contaminant loadings at some sites where in situ stabilization was the preferred option;

(4) effects of site location and projected future uses on development of closure criteria (e.g., estimated need for clean closure zones within the main ORNL complex, in particular);

(5) estimated availability and costs of other options for disposal or storage of wastes generated by facilities upgrading and remedial action activities [e.g., construction, including the costs (risks) of transporting the contaminated soil to a disposal site];

(6) relative costs for temporary storage (followed immediately by replacement) of excavated soils at remedial action sites and for other disposal or long-term storage options [e.g., accounting for both the short- and long-term costs of health and environmental protection measures needed for the replacement option and contrasting these with costs obtained in (5)];

(7) potential for minimization of the volume of soil to be disposed of as radioactive waste by avoiding highly contaminated areas identified in (1) whenever possible (e.g., by relocating construction and excavation sites);

(8) utilization of technological options for construction and excavations that reduce or eliminate personnel exposures or waste generation whenever practicable;

(9) methods for combining some facilities upgrading with appropriate remedial actions in order to reduce the overall costs and impacts of both actions (e.g., by grouting pipeline trenches or solution cavities in known problem areas along the LLW and process waste transfer systems during line repair or replacement); and

(10) potential for disposing of excavated contaminated soil at nearby remedial action sites which already contain much larger volumes of contaminated materials, including soils (e.g., as part of stabilization and closure plans for major ORNL sites slated for near-term corrective actions).

4.3 CONCLUDING OBSERVATIONS

One of the primary lessons to be learned from past experiences with the conduct of major remedial action programs at DOE sites other than ORNL is the critical importance of careful, even exhaustive, advance planning and coordination (Church 1981). This implies development of an extensive knowledge base on site conditions, remedial action alternatives and costs, and health, safety, and environmental protection needs and costs well before such programs (or their individual subcomponents) are to be implemented. Such a knowledge base is being prepared for the ORNL Facilities Upgrade and Remedial Action Programs (Bates et al. 1986; Trabalka and Myrick 1987), but since these efforts are only in the preliminary stages of development, the pool of information available is still rather limited (e.g., for the ten factors enumerated above).

Yet, based on this limited amount of current information, it seems apparent that tight coordination is needed among all ORNL programs which can affect one another by generating significant volumes of contaminated soils requiring either remedial action or new waste disposal activities. In addition, an upgraded field survey capability to provide the potential to meet lowered residual radioactivity concentration guidelines, particularly for alpha-emitters in soils (Table 4), needs to be developed. These are all necessary ingredients in the successful development of meaningful closure criteria and appropriate health, safety, and environmental protection both on-site and off-site.

ACKNOWLEDGMENTS

I would like to acknowledge D. C. Kocher, T. E. Myrick, R. M. Reed, and F. E. Sharples for their reviews of the draft manuscript and/or suggestions of reference materials for the report. I would also like to thank J. L. Seiber for early word-processing support.

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