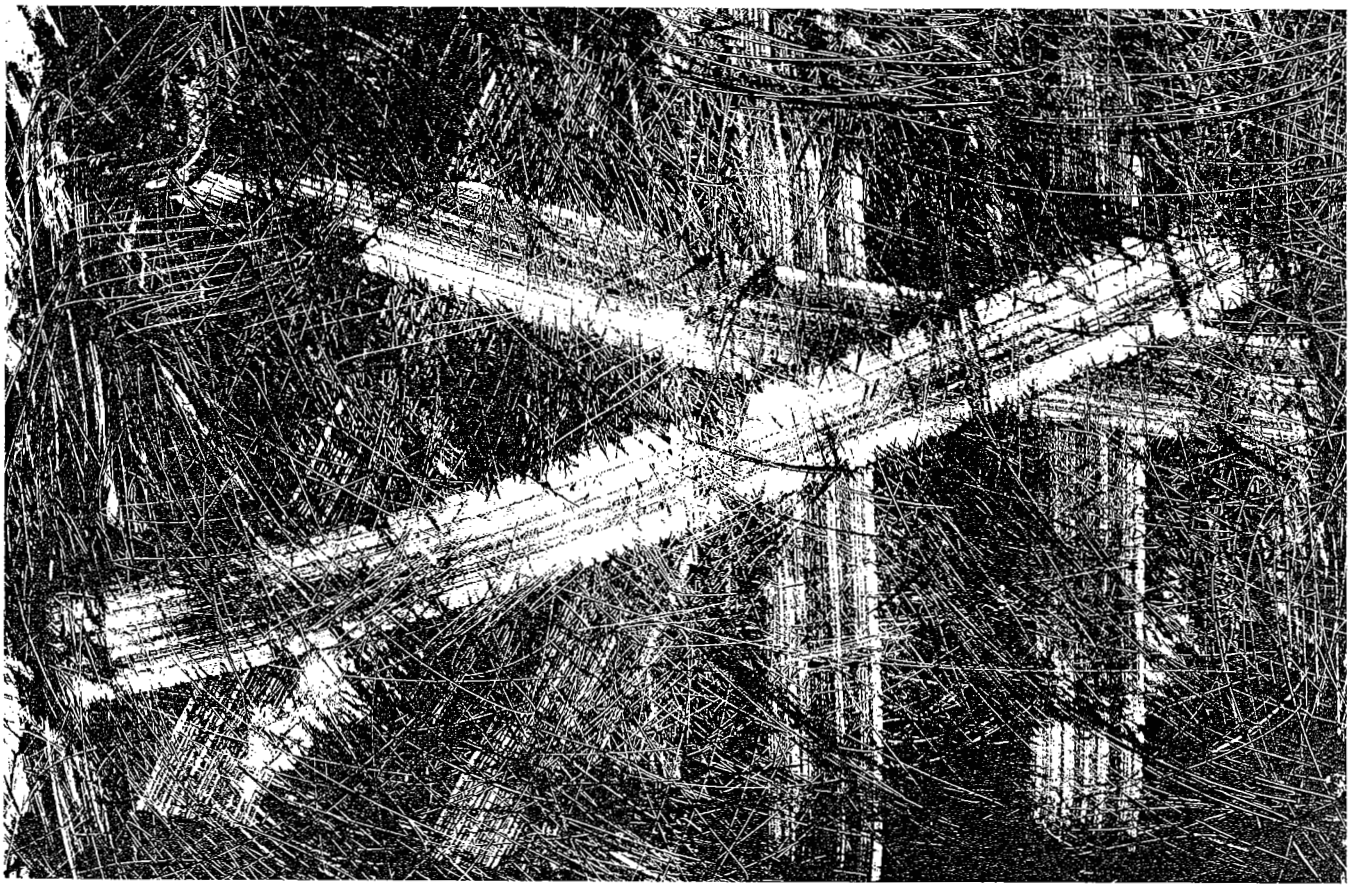
Safety of the High-Level Uranium Ore Residues at the Niagara Falls Storage Site, Lewiston, New York



NATIONAL RESEARCH COUNCIL

SAFETY OF THE HIGH-LEVEL URANIUM ORE RESIDUES AT THE NIAGARA FALLS STORAGE SITE, LEWISTON, NEW YORK

Committee on Remediation of Buried and Tank Wastes

Board on Radioactive Wastes Management

Commission on Geosciences, Environment, and Resources

National Research Council

WASHINGTON, DC 1995

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

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

Support for this study on Remediation of Buried and Tank Wastes was provided by the U.S. Department of Energy, under Grant No. DE-FC01-94EW54069. All opinions, findings, conclusions, and recommendations expressed herein are those of the authors and do not necessarily reflect the views of the Department of Energy.

Cover art by Mary M. Bernstein - *Ensnarement*

Additional copies of this report are available from:

Board on Radioactive Wastes Management
2001 Wisconsin Avenue, N.W.
HA456
Washington, D.C. 20007

Telephone: 202/334-3066

COMMITTEE ON REMEDIATION OF BURIED AND TANK WASTES

ROBERT J. BUDNITZ, *Chair*, Future Resources Associates, Berkeley, California
THOMAS A. BURKE, The Johns Hopkins University, Baltimore, Maryland
ROBERT J. CATLIN, University of Texas (ret.), Houston
JAMES H. CLARKE, Eckenfelder, Inc., Nashville, Tennessee
THOMAS A. COTTON, JK Research Associates, Inc, Vienna, Virginia
RODNEY C. EWING, University of New Mexico, Albuquerque
DONALD R. GIBSON, JR., TRW Environmental Safety Systems, Vienna, Virginia
JAMES H. JOHNSON, JR., Howard University, Washington, DC
THOMAS M. LESCHINE, University of Washington, Seattle
W. HUGH O'RIORDAN, Givens Pursley & Huntley, Boise, Idaho
GLENN PAULSON, Paulson and Cooper, Inc., Jackson Hole, Wyoming
BENJAMIN ROSS, Disposal Safety Incorporated, Washington, DC
PAUL A. WITHERSPOON, University of California, Berkeley
RAYMOND G. WYMER, Oak Ridge National Laboratory (ret.), Tennessee

Staff

ROBERT S. ANDREWS, Senior Staff Officer
DENNIS DuPREE, Senior Project Assistant
ANGELA TAYLOR, Project Assistant

BOARD ON RADIOACTIVE WASTE MANAGEMENT

MICHAEL C. KAVANAUGH, *Chair*, ENVIRON Corporation, Emeryville, California
B. JOHN GARRICK, *Vice-Chair*, PLG, Incorporated, Newport Beach, California
JOHN F. AHEARNE, Sigma Xi, The Scientific Research Society, Research Triangle Park, North Carolina
JEAN M. BAHR, University of Wisconsin, Madison
LYNDA L. BROTHERS, Davis Wright Tremaine, Seattle, Washington
SOL BURSTEIN, Wisconsin Electric Power (ret.), Milwaukee
MELVIN W. CARTER, Georgia Institute of Technology (emeritus), Atlanta
PAUL P. CRAIG, University of California, Davis (emeritus)
MARY R. ENGLISH, University of Tennessee, Knoxville
ROBERT D. HATCHER, JR., University of Tennessee/Oak Ridge National Laboratory, Knoxville
DARLEANE C. HOFFMAN, Lawrence Berkeley Laboratory, Berkeley, California
H. ROBERT MEYER, Keystone Scientific, Inc., Fort Collins, Colorado
PERRY L. McCARTY, Stanford University, California
CHARLES McCOMBIE, National Cooperative for the Disposal of Radioactive Wastes, Wettingen, Switzerland
PRISCILLA P. NELSON, University of Texas, Austin
D. KIRK NORDSTROM, U.S. Geological Survey, Boulder, Colorado
D. WARNER NORTH, Decision Focus, Incorporated, Mountain View, California
GLENN PAULSON, Paulson and Cooper, Inc., Jackson Hole, Wyoming
PAUL SLOVIC, Decision Research, Eugene, Oregon
BENJAMIN L. SMITH, Independent Consultant, Columbia, Tennessee

Staff

CARL A. ANDERSON, Staff Director
KEVIN D. CROWLEY, Associate Director
ROBERT S. ANDREWS, Senior Staff Officer
KARYANIL T. THOMAS, Senior Staff Officer
THOMAS KIESS, Staff Officer
SUSAN B. MOCKLER, Research Associate
LISA J. CLENDENING, Administrative Assistant
REBECCA BURKA, Senior Project Assistant
ROBIN L. ALLEN, Senior Project Assistant
DENNIS L. DuPREE, Senior Project Assistant
PATRICIA A. JONES, Project Assistant
ANGELA TAYLOR, Project Assistant
ERIKA WILLIAMS, Project Assistant

COMMISSION ON GEOSCIENCES, ENVIRONMENT, AND RESOURCES

M. GORDON WOLMAN, *Chairman*, The Johns Hopkins University, Baltimore, Maryland
PATRICK R. ATKINS, Aluminum Company of America, Pittsburgh, Pennsylvania
JAMES P. BRUCE, Canadian Climate Program Board, Ottawa, Ontario
WILLIAM L. FISHER, University of Texas, Austin
GEORGE M. HORNBERGER, University of Virginia, Charlottesville
DEBRA KNOPMAN, Progressive Foundation, Washington, D.C.
PERRY L. McCARTY, Stanford University, California
JUDITH E. McDOWELL, Woods Hole Oceanographic Institution, Massachusetts
S. GEORGE PHILANDER, Princeton University, New Jersey
RAYMOND A. PRICE, Queen's University at Kingston, Ontario
THOMAS C. SCHELLING, University of Maryland, College Park
ELLEN SILBERGELD, University of Maryland Medical School, Baltimore
STEVEN M. STANLEY, The Johns Hopkins University, Baltimore, Maryland
VICTORIA J. TSCHINKEL, Landers and Parsons, Tallahassee, Florida

Staff

STEPHEN RATTIEN, Executive Director
STEPHEN D. PARKER, Associate Executive Director
MORGAN GOPNIK, Assistant Executive Director
GREGORY SYMMES, Reports Officer
JAMES MALLORY, Administrative Officer
SANDI FITZPATRICK, Administrative Associate
SUSAN SHERWIN, Project Assistant

The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce Alberts is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Harold Liebowitz is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth Shine is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Bruce Alberts and Dr. Harold Liebowitz are chairman and vice chairman, respectively, of the National Research Council.

PREFACE

The study reported herein, requested by the Office of Environmental Restoration, U.S. Department of Energy (DOE), provided the Committee on Remediation of Buried and Tank Wastes an opportunity to focus on a specific example of buried radioactive waste, the Niagara Falls Storage Site (NFSS). Much of the background information was gathered and analyzed by a subcommittee, which also prepared initial drafts of this report. We acknowledge the efforts of the Committee members that served on that subcommittee, Tom Burke, Bob Catlin (Chair), Jim Johnson, and Ray Wymer.

The Committee offers thanks to the representatives from DOE and its contractors at the NFSS and the Fernald Environmental Management Project site who gave generously of their time and efforts in providing briefings and documents and responding in a timely manner to all questions. We also extend thanks to those representatives from federal and state agencies and other organizations, as well as to other interested members of the public, who offered comments.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

This report examines the existing and proposed modification of a waste containment structure at the DOE Niagara Falls Storage Site (NFSS) in Lewiston, NY, used since 1949 to store highly radioactive residues separated during the processing of very rich uranium ores from the former Belgian Congo (now Zaire). The high-level residues remaining after the removal of uranium have been stored at the former Lake Ontario Ordnance Works (LOOW) since 1949 (prior to 1949, the residues were returned to the African Metals Corporation of Belgium). The present area of the LOOW, reduced in size, is now known as the NFSS. The high-level residues, along with other, less radioactive residues and wastes, are presently stored at NFSS, buried under an interim cap to prevent influx of moisture from precipitation and outflux of radon gas.

At the request of the Office of Environmental Restoration of the U.S. Department of Energy (DOE), the National Research Council (NRC) agreed to identify issues or concerns with (a) the existing waste containment structure that requires consideration of immediate, short-term action, and (b) long-term risks posed by the structure to the surrounding population and environment. The NRC passed this request to the Committee on Remediation of Buried and Tank Wastes to accomplish this study.

This report provides background information on the past, present, and planned future handling and storage of the NFSS high-level residues based on presentations from DOE and its contractors, a review of documents pertaining to the study, and a visit to the site, during which time the residents of the area and others had the opportunity to express their views and concerns. The Committee's conclusions and recommendations are listed below; more detailed discussion and explanation can be found in the text of the report.

Conclusions

1) Available site sampling and monitoring information indicates that there is no immediate hazard to the off-site public from the residues in their present configuration.

2) The high-level residues pose a potential long-term risk to the public, given the existing environmental conditions and future unpredictability, if they are left permanently at the NFSS.

3) The proposed actions of replacing the interim cap with a "permanent" cap and of long-term site maintenance and monitoring do not address the potential risks to the public for the long periods of time commensurate with the duration of that potential risk.

4) An important alternative, that of solidifying the high-level residues on site and shipping the solidified residues to an off-site location, has not been considered, even though this alternative was chosen for managing essentially identical residues of common origin currently stored in silos at the Fernald Environmental Management Project (FEMP) site in Ohio. If this alternative is considered, the occupational as well as public health and safety aspects are important. Inputs from waste treatment technology projects, such as the project for handling similar residues now being implemented at the FEMP site, will provide important information for making such assessments.

5) The present and potential future interactions between the NFSS and disposal sites adjacent to the NFSS, where non-radioactive toxic chemical and landfill wastes are currently disposed, have not been addressed adequately, either in the NFSS final environmental impact statement (FEIS) or in subsequent studies and documentation.

6) The potential future health hazards posed by non-radiological, toxic materials such as lead and barium that are constituents of the buried high-level residues at NFSS have not been adequately assessed.

7) There are substantial uncertainties in the estimates of costs and associated risks for managing the residues at NFSS that have not been fully addressed.

8) Current site monitoring activities are inadequate for the determination of long-term site integrity and potential future risks to the public and the environment from the movement off-site of radioactive and non-radioactive wastes in the NFSS containment structure, as well as the possible influx of waste materials from the disposal sites adjacent to the NFSS.

Recommendations

The Committee makes the following recommendations for future actions by DOE to manage the NFSS high-level residues in a way that provides protection to the health and safety of the public and the environment, both in the short and long terms.

1) Following completion of related or similar treatment technology studies such as the FEMP vitrification demonstration and related cost-risk-benefit studies, a program should be developed by DOE for removal, treatment, and disposal off-site of the NFSS high-level residues. Because there is no immediate hazard to the off-site public from the residues in their present configuration, such studies will help ensure proper handling of the residues when they are removed for disposal, as well as to provide an example for future remediation of other sites containing radioactive residues.

2) After removal of the high-level residues, remaining wastes should be buried under a suitable protective cap.

3) The adequacy of site monitoring and maintenance activities necessary to ensure the safety of the public and the integrity of the NFSS should be assured. An alternative NFSS monitoring strategy should be developed to measure and track transport of radiological and chemical contaminants from the NFSS waste containment structure, as well as those reaching NFSS from contiguous waste disposal areas off site, both prior to and following removal of the residues.

INTRODUCTION

The National Academy of Sciences/National Research Council (NAS/NRC) Committee on Remediation of Buried and Tank Wastes (hereafter, "Committee") was established in 1992 to study the remediation of buried and tank-contained radioactive wastes from the perspective of safety issues, risk to the public, workers, and the environment, technology required, and cost. At the request of the U.S. Department of Energy (DOE) (letter of March 17. 1994, from R.P. Whitfield, DOE Deputy Assistant Secretary for Environmental Restoration, to R.J. Budnitz, Committee Chairman), the Committee agreed to review documentation pertaining to the present and proposed waste containment structure for radioactive residues buried at the Niagara Falls Storage Site (NFSS), Lewiston, NY, and to review evaluations of these structures, the waste configurations, and environs as they pertain to provision of adequate and appropriate protection to the surrounding population and environment (letter of March 24, 1994, from R.S. Andrews, Committee Staff Officer, to R.P. Whitfield, DOE). The Committee agreed to determine whether any immediate short-term action might be needed pending completion of further assessments. If the proposed waste containment structure and configuration were not considered to be adequate to provide an appropriate degree of long-term protection, the Committee would review alternative approaches and their risk as detailed in the 1986 NFSS Final Environmental Impact Statement (hereafter, 1986 FEIS, or U.S. Department of Energy, 1986).

A four-person subcommittee of the Committee, Thomas A. Burke, Robert J. Catlin (Chair), James H. Johnson, Jr., and Raymond G. Wymer, reviewed documents provided to it by DOE and received presentations from DOE and its NFSS contractors at three meetings in 1994: February 23-24, at the National Academy of Sciences Beckman Center, Irvine, CA; May 2-4, at the Holiday Inn, Grand Island, NY, and the NFSS, Lewiston, NY; and June 29-30, at Bechtel National, Inc., Oak Ridge, TN. During the May meeting, representatives of the U.S. Environmental Protection Agency, the State of New York Departments of Health and Environmental Protection, and members of the public were invited to address the subcommittee and DOE representatives and contractors, both after the presentations and during the site visit. On September 29, 1994, the subcommittee visited and received presentations at the Fernald Environmental Management Project (FEMP) site at Fernald, OH, concerning the management and future plans for disposal of the high-level residues presently stored there in silos. Various questions posed by the subcommittee that were not answered at meetings were addressed in subsequent reports and correspondence with DOE. The background information presented in this report was summarized from the many documents provided by DOE and its contractors (see Bibliography in Appendix A).

BACKGROUND

HISTORY OF THE NFSS RESIDUES

In about 1942, the Mallinckrodt Chemical Works in St. Louis, MO, began extracting uranium from very rich Belgian Congo ores received from the African Metals Corporation of Belgium (AMCB) for use in the Manhattan Engineering District Project. The residues remaining after uranium extraction (classified as K-65 residues; see Table 1) contain many of the uranium decay products that had been in secular equilibrium with the ^{238}U and ^{235}U isotopes. The ^{234}U was recovered with the uranium product, thus removing an important member of the decay chain. In addition, the extraction process resulted in separation (i.e., removal) of some ^{230}Th from the residues. The residues were returned to the AMCB until April 1949, after which time they were sent to the Lake Ontario Ordnance Works (LOOW) in Lewiston Township, upstate New York, for storage in a large silo. The residues were classified, as shown in Table 1, based on U_3O_8 content of the ores from which they were recovered. The present area of the LOOW, much reduced in size, is now known as the Niagara Falls Storage Site (NFSS); the storage silo was located in the northeast panhandle of the site (Figure 1).

When the storage silo at NFSS was full, the remaining K-65 residues were sent to the Feed Materials Production Center, now designated as the Fernald Environmental Management Project (FEMP), at Fernald, OH, where they were stored along with K-65 residues shipped directly from Mallinckrodt and with K-65 and other residues produced by uranium recovery operations performed at the FEMP site. Although a different uranium separation process was used at the FEMP site than was used at the Mallinckrodt Chemical Works, the K-65 residues at the two sites are essentially the same in chemical and radiological properties.

At the NFSS, approximately 3,510 metric tons of residues were stored in a silo, a volume of about 11,000 m^3. The residues contain approximately 520,000 pCi/g of ^{226}Ra and 54,000 pCi/g of ^{230}Th. The concentrations of these isotopes in the K-65 residues stored at the FEMP site are somewhat lower, and have a somewhat lower ratio of radium to thorium because of the different separation process used. The residues also contain a low concentration of unseparated uranium, as well as other elements such as barium (which was added during processing by Mallinckrodt), lead, and molybdenum, and minor amounts of rare earth elements and noble metals.

In addition to the K-65 residues, there are large amounts of other radioactive contaminated materials from uranium ore processing stored at NFSS (Table 1). At NFSS, a distinction is made between "residues" and contaminated materials with high ^{226}Ra concentrations, whereas the term "wastes" is used for all other contaminated materials at the site. The residues other than those classified as K-65, together with the wastes, have much lower concentrations and total

TABLE 1. Inventory of Radium-226 and Thorium-230 in NFSS Residues and Wastes (after Bechtel National, Inc., 1994a, Table 3-1, p. 3-15)

Classification[a]	Volume,(m^3)	^{226}Ra Inventory,(Ci)	^{230}Th Inventory, (Ci)
Residues			
K-65	3,000	1,881	195
L-30	6,000	87	87
F-32	500	0.2	0.2
L-50	1,500	6	6
Contaminated Wastes			
R-10 residues and soil	45,000	5	5
Remaining Contaminated soils	134,500	3	3
Totals	190,500	1,982	296

K-65 residues -- from processing ore containing 35-60% U_3O_8
L-30 residues -- from processing ore containing ~ 10% U_3O_8
F-32 residues -- from processing ore containing unknown precentage of U_3O_8
L-50 residues -- from processing ore containing ~ 7% U_3O_8
R-10 residues -- from processing ore containing ~ 3.5% U_3O_8

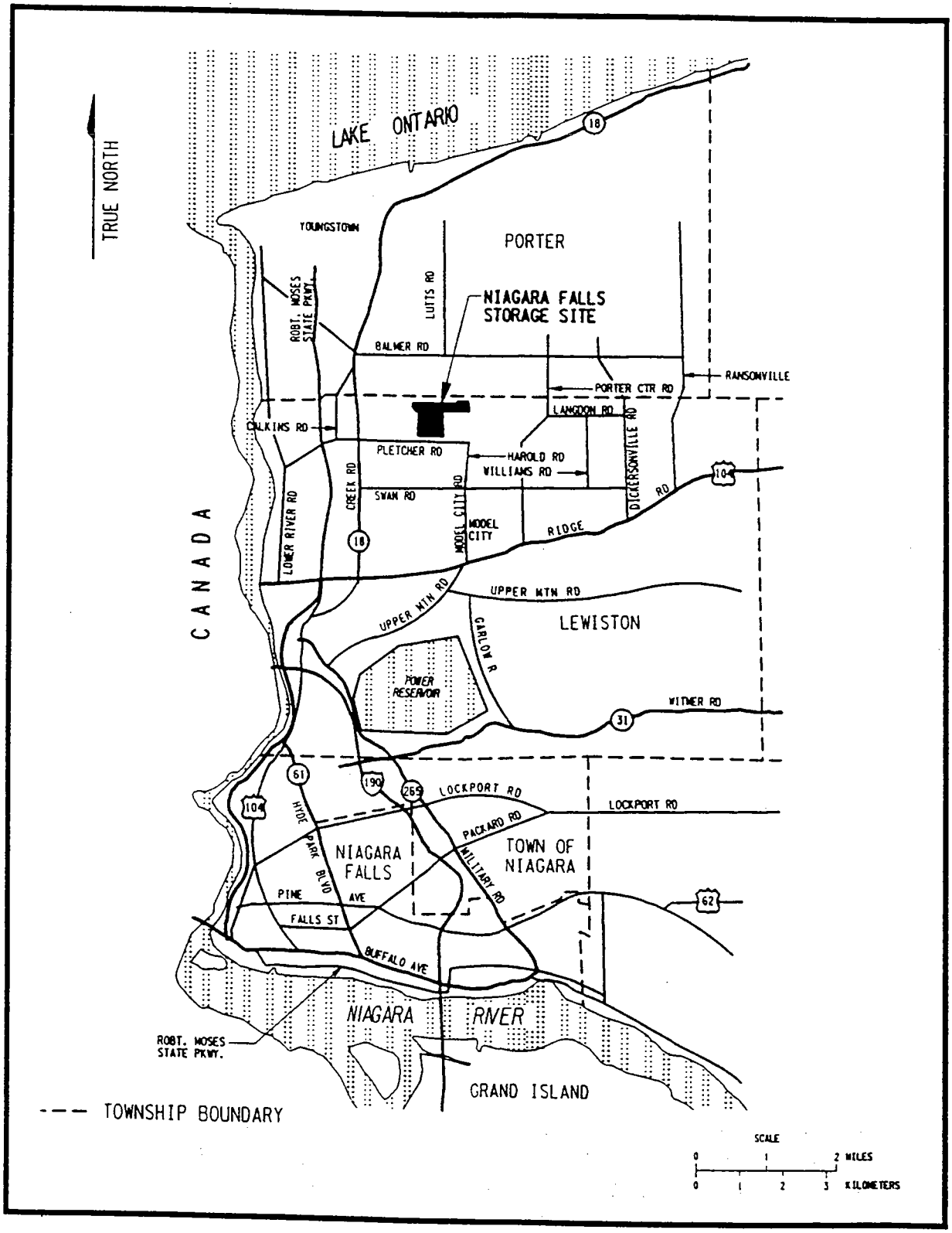


FIGURE 1. Location Map for Niagara Falls Storage Site (NFSS), NY (Bechtel National, Inc., 1994a)

amounts of ^{226}Ra and ^{230}Th than do the K-65 residues. An important feature of the K-65 residues is that the concentration of ^{226}Ra in them is much higher than the concentration of ^{226}Ra in what are classified as "uranium mill tailings" from processing of typical uranium ores from the United States. For example, the uranium concentration in the original Belgium Congo ores from which the K-65 residues were derived ranged from 35 to 60 percent U_3O_8, whereas the concentration of uranium ores in sandstone deposits such as are found on the Colorado Plateau is from 0.2 to 0.4 percent U_3O_8.

The other residues of concern stored originally at other locations at the NFSS were produced by processing of less concentrated ores at the Linde Ceramics Plant at Tonawanda, NY. These residues, called L-30, F-32, and L-50 residues, also have substantial concentrations of ^{226}Ra and ^{230}Th, exceeding those from common uranium mill tailings. The term "high-level" residues is used here to denote the K-65, L-30, F-32, and L-50 residues, or any combination thereof. The R-10 residues, produced at Linde by the processing of ore containing about 3.5 percent U_3O_8 were inadvertently intermixed with soil during ground surface storage at NFSS and subsequent mixing during site cleanup, and are now classed by DOE as a waste (U.S. Department of Energy, 1986, Table 3.5, p. 3-14).

In 1982 DOE initiated interim measures to consolidate and store all radioactive materials on the site and adjacent properties. From 1983-1985, the K-65 high-level residues were transferred by hydraulic mining from the storage silo to the reinforced concrete cellar of a previously existing building (numbered 411 in Figure 2). The other high-level residues (classified L-30/F-32 and L-50) also currently reside in this and adjacent reinforced concrete cellars of previously existing buildings (numbered 410, 413, and 414 in Figure 2). In 1986 the entire area holding the residues and waste (called the Wastes Containment Structure) was covered with what DOE has designated as an interim facility cap (Figures 2 and 3). The cap is designed to retard radon emissions and to reduce rainwater intrusion into the residues and wastes (Bechtel National, Inc., 1986a and 1986b).

In September 1986, the DOE issued a Record of Decision (ROD) (Office of Federal Register, 1986) for remedial actions at the NFSS that stated the following:

> Decision: For the radioactive wastes at the NFSS, the DOE has selected long-term in place management consistent with the guidance provided in the Environmental Protection Agency (EPA) regulation for uranium mill tailings (40 CFR 192) [Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings]. For the radioactive residues at NFSS, it is the DOE intent to provide for long-term in place management consistent with future applicable EPA guidance. If future analyses show that in place management cannot meet EPA guidance, long-term in place management of the residues would need to be replaced by another option which meets EPA guidance and is environmentally acceptable. Further NEPA [National Environmental Policy Act] review is anticipated subsequent to additional

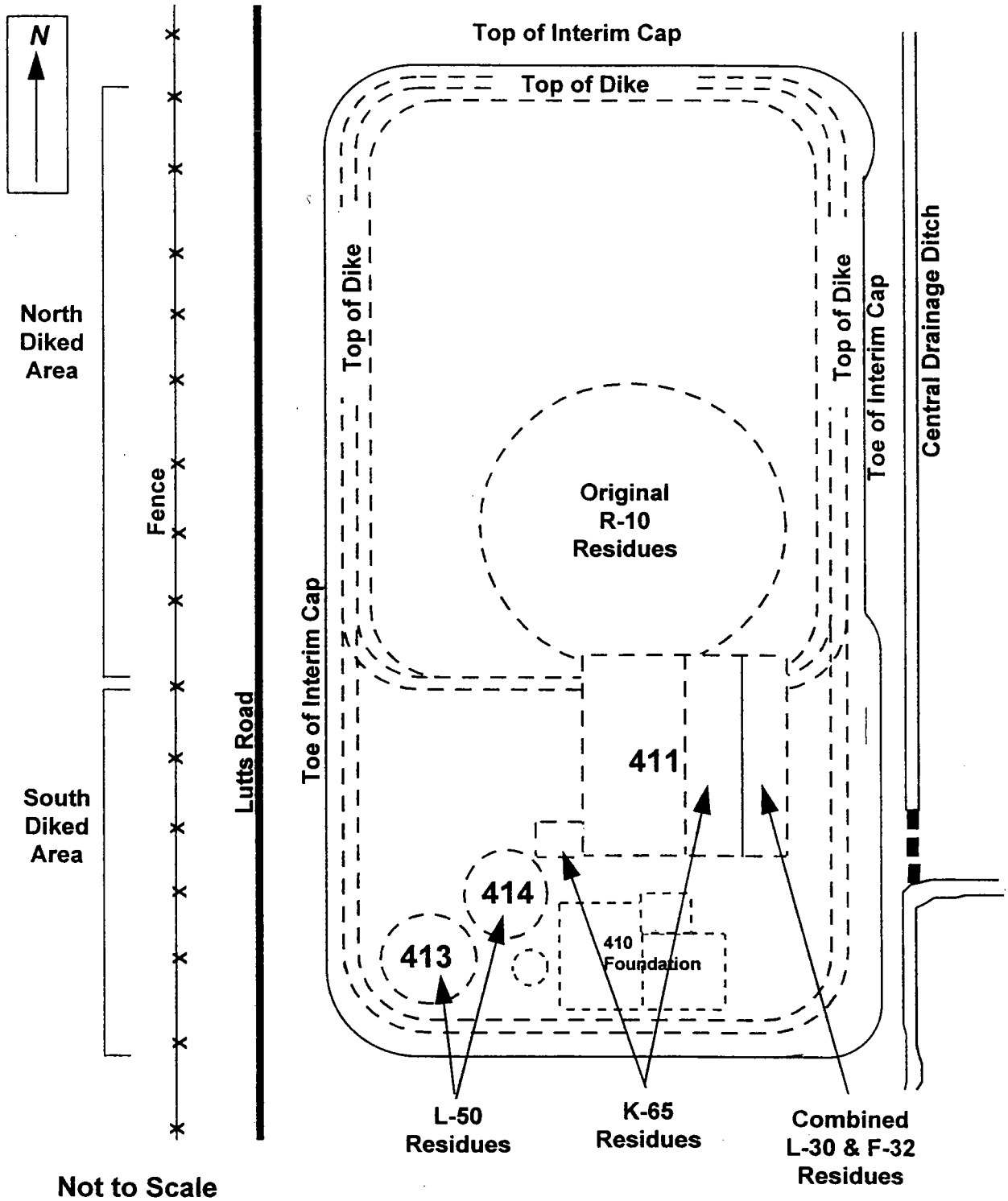


FIGURE 2. Plan View of the Waste Containment Structure (WCS), Showing Location of Cellars of Buildings 410, 411,413, and 414 that Contain Residues (after U.S. Department of Energy, 1986)

TABLE 2. Management Alternatives for NFSS Residue and Wastes (U.S. Department of Energy, 1986)

Alternative	Name
1	No Action
2a	Long-Term Management at NFSS: Modified Containment
2b	Long-Term Management at NFSS: Modified Containment plus Modified Form
3a	Long-Term Management at Arid Site (Hanford)
3b	Long-Term Management at Humid Site (Oak Ridge)
4a	Long-Term Management of Residues at Hanford, Wastes at NFSS
4b	Long-Term Management of Residues at Hanford, Ocean Dispersal of Wastes
4c	Long-Term Management of Residues at Oak Ridge, Wastes at NFSS
4d	Long-Term Management of Residues at Oak Ridge, Ocean Dispersal of Wastes

From U.S. Department of Energy, 1986

design of the long-term in place management project for the radioactive residues. The resulting remedial actions at NFSS are described in the 1986 FEIS.

The New York State Department of Health and Environmental Protection and the U.S. Environmental Protection Agency (EPA) have expressed concern over the plan of action put forth in an exchange of letters with DOE (letters included in U.S. DOE, 1986, Appendix K). The central point of these letters was that the concentration of ^{226}Ra in the K-65 residues was so high that 40 CFR 192 was not applicable, and that the management of these residues should follow 40 CFR 191 (Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastess). The letters expressed lesser concern with the lower-level radioactive residues and wastes. This does not address the issue of how the NFSS residues should be defined based on current regulations, however.

1986 FINAL ENVIRONMENTAL IMPACT STATEMENT (FEIS)

DOE and its contractor have delineated and compared alternatives for managing the NFSS residues and wastes and have described conceptual design and technical aspects of addressing the alternatives (U.S. Department of Energy, 1986, pp. 2-1 through 2-30 and Appendixes C,D, and E). Table 2 lists the alternatives for NFSS considered in the FEIS.

The environmental impacts associated with each alternative were analyzed in the 1986 FEIS in terms of three time periods, both for radiological and non-radiological materials. The time period designations and periods chosen are: 1) Action Period: approximately 10 years; 2) Maintenance and Monitoring Period: 10 to 200 years; and 3) Long-Term Period: 200 to 1000 years. Two cases identified for the Long-Term Period were: Case A - Loss of Monitoring, Maintenance, and Corrective Action; and Case B - Loss of All Controls. The 10 to 200 years maintenance and monitoring period was used by DOE as the reference for the analysis made in the 1986 FEIS.

Implementation of any of the alternatives was projected to permanently commit some land to management of at least the NFSS residues and, in some alternatives, the NFSS wastes as well. The near-surface burial of the NFSS wastes and residues was stated by DOE to commit "the federal government (or its successor) to perpetual care of the burial sites because the residues and wastes would remain hazardous for thousands of years" (U.S. Department of Energy, 1986, p. 2-26). In all cases, extended care costs were projected through the end of the Maintenance and Monitoring Period (200 years), ranging from $8.6 to $26 million total, and with a sinking fund of $8.6 to $26 million for the Long-Term Period (beyond 200 years).

The following information concerning alternatives, radon release, transportation, risks, and selection of primary alternative represents a very brief summary of the material primarily found in the 1986 FEIS (U.S. Department of Energy, 1986) and the 1994 Failure

Analysis Report (Bechtel National, Inc., 1994a). It is included to provide background for the rest of the report.

Alternatives

Alternatives 1, 2a, and 2b (Table 2) leave the wastes and residues at NFSS. Alternative 3a moves the residues and wastes to the Hanford Reservation, Richland, WA. Alternative 3b moves the residues and wastes to Oak Ridge National Laboratory, Oak Ridge, TN. Alternatives 4a and 4b move the residues to the Hanford Reservation, with the wastes disposed at NFSS or by ocean disposal, respectively. Alternatives 4c and 4d move the residues to Oak Ridge, with waste disposed at NFSS or by ocean disposal, respectively. Only Alternative 2b requires substantial modification of the residues. In one modification option, the residues are processed to recover resources present in them (uranium, cobalt, nickel, molybdenum, and lead). The vitreous slag from this process is presumed to contain most of the radioactivity (U.S. Department of Energy, 1986, p. C-4). Other options are direct vitrification of the residues, in-situ vitrification, and solidification in bitumen, resins, or concrete.

In the vitrification option, the vitrified material and precipitates containing the radium and thorium would be re-buried in the diked containment area at NFSS. The 1986 FEIS identifies numerous uncertainties associated with residue modification, including resource recovery efficiencies, radioactive contamination of recovered resources, and characteristics of all waste products from the recovery process.

The alternatives and their effects that were presented in the 1986 FEIS are summarized below for convenience; the 1986 FEIS and related documents should be consulted for more complete and detailed information.

Alternative 1 - No Action. Erosion of the interim protective cap is expected to occur after the cessation of maintenance and monitoring. It is projected that after 1,000 years there would be increased ^{222}Rn release due to loss of cap integrity; however, these releases are expected to present insignificant health effects. The predominant health threat after 1,000 years would be to the "resident intruder" who might build a house in the contaminated materials, inhale air containing ^{222}Rn gas and its radioactive decay daughter products, eat contaminated food grown in an on-site garden, and drink contaminated water from a well located at the edge of the contaminated area. A projected dose of 8,000 rem/year to the bronchial epithelium from the inhaled radon and its daughter products would likely result in death of such a resident intruder within a few years. Migration of radiological and chemical contamination of ground water at NFSS would possibly be slow and localized. In the long term, the subsurface clay cutoff wall surrounding the buried residues and wastes would likely provide little or no retardation of contaminant migration.

Alternative 2a - Long-Term Management at NFSS: Modified Containment. A long-term cap would replace the interim cap and the site would be maintained and monitored for 200 years. The site would be reduced in size to 16 hectares (0.16 km^2), with the

remaining 61 hectares (0.61 km^2) to be released by DOE for other use. The 1986 FEIS states that if controls cease at 200 years, the long-term cap would delay exposure of the contaminated materials. After 1,000 years, even after the most erosive land use, there likely would be a cover over the contaminated materials. As in Alternative 1, doses to the public would be from ^{222}Rn, and are expected to be very small. The potential resident intruder would receive the same high radiation dose as in Alternative 1. The integrity of the cap could be jeopardized by "gullying", slumping, extended drought, severe earthquake, or biotic intrusion. Migration of contamination of ground water at NFSS by ^{226}Ra and by other hazardous chemicals would probably be slow and localized.

Alternative 2b - Long-Term Management at NFSS: Modified Containment plus Modified Form. The interim cap would be removed and the residues excavated and processed. The residues in modified form would then be re-buried on site. This alternative would result in increased ^{222}Rn and particulate releases during excavation and processing. As a result, the radiation doses to the general public and the concomitant health effects would be greater than in Alternatives 1 and 2a. Assuming that ^{222}Rn emissions from the modified residues are reduced by a factor of 10, the dose to the resident intruder would be reduced proportionately, although still critical. However, cumulative doses to critical organs of workers and the general public would likely result in negligible health effects. There would be more transportation-related injuries and deaths and radiation health effects associated with occupational exposures than for the alternatives that do not involve handling and processing the residues, however. Processing the residues would not markedly change impacts on ground water, which would be about the same as for Alternative 2a.

Alternative 3a - Long-Term Management at Arid Site (Hanford). Both the residues and the wastes would be excavated from the NFSS containment area and transported by trucks to a DOE waste management site at Hanford Reservation. This alternative would result in increased ^{222}Rn and particulate releases which would affect the general public surrounding NFSS, at the Hanford site, and along the route followed between the two sites. However, radiological health effects to the general public are expected to be insignificant. Radiological health effects to workers are expected to be higher than those to the general public, but would also be negligible. Releases of ^{222}Rn from the arid soil-covered trenches at Hanford would be much higher than from the clay-covered containment at NFSS, but the health effects would still be expected to be negligible. Because the burial area at Hanford is larger than at NFSS, and because the residues will not be concentrated in one area as at NFSS, the resident intruder's bronchial epithelium dose would be less at Hanford than at NFSS. Nonetheless, a resident intruder at Hanford could have a significant health risk. There will be more transportation-related injuries and deaths than for the alternatives that do not involve transporting the residues. Removal of the residues will markedly reduce future impacts on ground water at NFSS.

Alternative 3b - Long-Term Management at Humid Site (Oak Ridge). Both the residues and the wastes would be excavated from the NFSS containment area and transported by trucks to a DOE waste management site on the DOE reservation near Oak Ridge, TN, for

burial. This alternative would result in increased ^{222}Rn and particulate releases which would affect the general public surrounding NFSS, at the Oak Ridge site, and along the route followed between the two sites. The resulting health effects to both the public and resident intruder would be virtually the same as for Alternative 2b. Vertical migration of radiological and chemical contaminants from residues and wastes would be expected to be very slow at the Oak Ridge site. Because of the larger ground water flow at Oak Ridge than at NFSS, the ground water contaminants would likely be diluted more than at NFSS, unless the ground water becomes saturated in both cases as it flow through the radium and thorium salts. It is predicted that ground water contamination will not occur in 1,000 years. No significant non-radiological ground water contamination is expected.

Alternative 4a - Long-Term Management of Residues at Hanford, Wastes at NFSS. The residues that underlie the wastes (Figure 3) would be excavated, packaged, and transported to the DOE Hanford site (as in Alternative 3a) and the wastes would remain at NFSS. Because only the residues would be moved from NFSS, only one-tenth as many truck trips would be required as in Alternative 3a. Because the residues contain about 99 percent of the radionuclide inventory at NFSS, the radiological impact of this alternative would be about the same as that for moving both residues and wastes. [The Committee notes that this is not necessarily true; the fact that the residues are about 10 times as concentrated means that the dose would be higher during each shipment, and the resultant exposure dose rate and total dose to an individual would be higher.] The number of additional adverse health effects is expected to be extremely low. The risk to the resident intruder at NFSS would be substantially reduced because only the wastes would remain at NFSS.

Alternative 4b - Long-Term Management of Residues at Hanford, Ocean Disposal of Wastess. The residues would be excavated, packaged, and transported to the DOE Hanford site, as in Alternative 4a. All remaining wastes would be excavated and transported in bulk by trucks to a dock in New York or New Jersey where they would be loaded onto barges and transported to the 106-Mile Ocean Wastes Disposal Site for disposal [Site 106, managed by the EPA, is a designated waste-disposal site 110 nautical miles (204 km) southeast of the entrance to the New York harbor and 90 nautical miles (167 km) east of Cape Henlopen, DE]. The impacts at Hanford would be the same as those for Alternative 4a for all time periods. However, the total population doses to the general public would be greater for this alternative than for any of the other alternatives, due to the assumed particulate releases from the NFSS wastes as they are transported through the densely populated New York metropolitan area. Nonetheless, the impact would be insignificant. The concentrations of both radiological and chemical contaminants from the wastes is expected to be negligible and generally indistinguishable from the naturally occurring concentrations of these elements in the ocean.

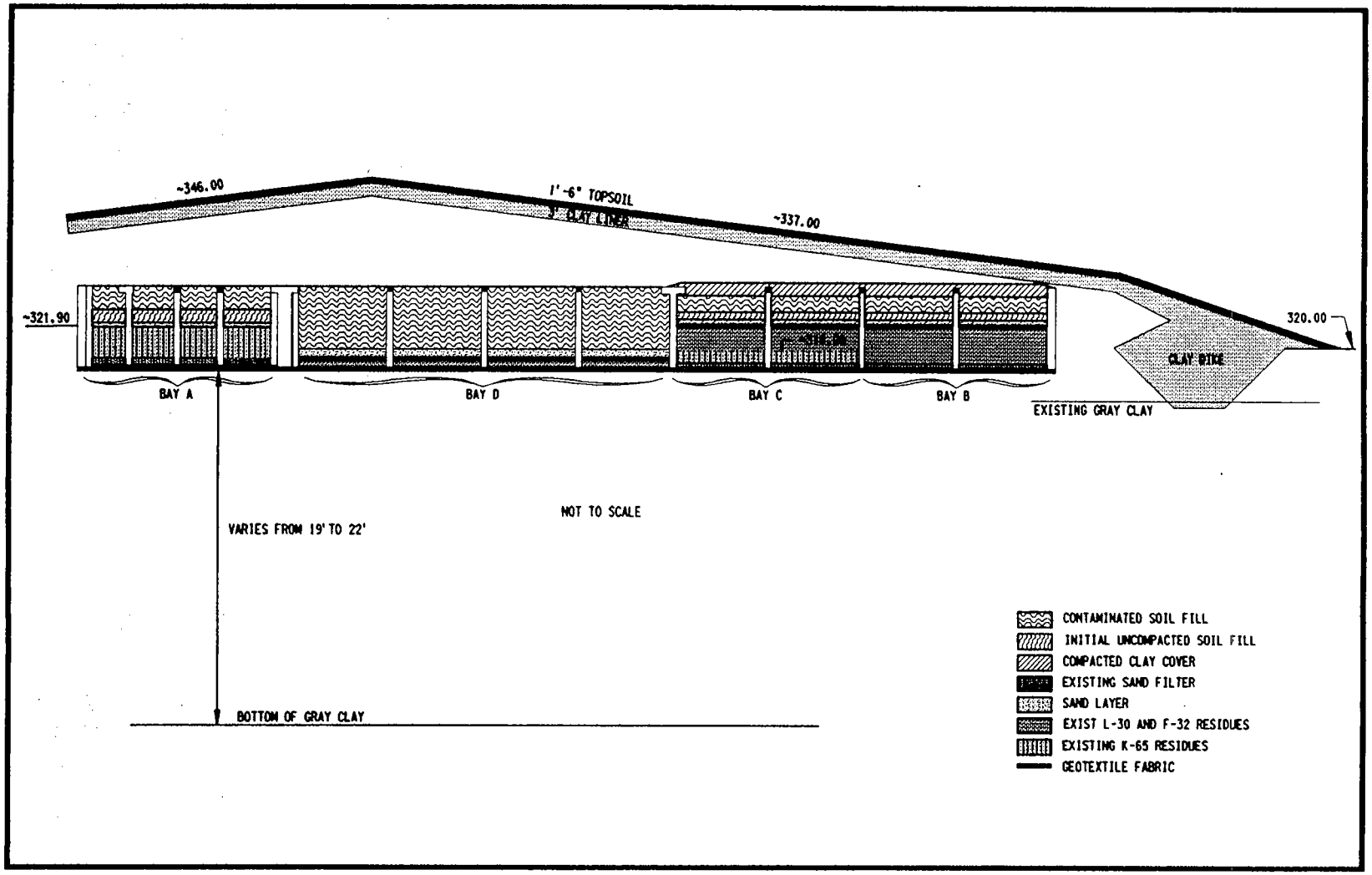


FIGURE 3. East-West Cross Section Through Building 411 of Interim Waste Containment Structure (after Bechtel National, Inc., presentation to Committee, October 1994)

Alternative 4c - Long-Term Management of Residues at Oak Ridge, Wastes at NFSS. The residues would be excavated from the NFSS containment area and transported by truck to a DOE waste management site on the DOE reservation near Oak Ridge, TN, forburial. This alternative would result in increased ^{222}Rn and particulate releases that would affect the general public surrounding NFSS, at the Oak Ridge site, and along the route followed between the two sites. The risk to a resident intruder at Oak Ridge would be somewhat higher than that for Alternative 3b because the residues would not be diluted by the relatively large volume of waste. Ground water impacts at NFSS would be reduced, and at Oak Ridge they would be the same as for Alternative 3b.

Alternative 4d - Long-Term Management of Residues at Oak Ridge, Ocean Disposal of Wastess. Alternative 4d is identical to Alternative 4c except that the NFSS wastes would be disposed in the ocean instead of remaining at NFSS. During all time periods the impacts at Oak Ridge would be the same as those discussed for Alternative 4c. The impacts at the ocean disposal site and the surrounding metropolitan area would be the same as discussed for Alternative 4b.

Radon Release

Releases of ^{222}Rn gas through the 200th year after burial range from negligible for Alternatives 1, 2a, 2b, 3b and 4d, up to 300 $pCi/m^2/sec$ at Hanford for Alternatives 4a and 4b. The relatively higher releases at Hanford are primarily the result of the arid climate at the DOE Hanford site and the separation of the wastes from the residues at NFSS prior to shipment to Hanford, thus producing a more concentrated residue for burial. After burial for 1,000 years, the ^{222}Rn releases are still negligible for Alternatives 2a, 2b, 3b, 4c and 4d; they rise to 1,100 $pCi/m^2/sec$ at Hanford for Alternatives 4a and 4b, and to 9.6 and 110 $pCi/m^2/sec$ for Alternatives 1 and 3a, respectively.

Transportation

According to the 1986 FEIS (U.S. Department of Energy, 1986, pp. 4-93 to 4-95), the largest health risks would occur during transportation as a result of transportation accidents. The values used in the analysis were an injury rate for truck accidents of $5.1 \times 10^{-7}/km$ and a fatality rate for truck accidents of $3.0 \times 10^{-8}/km$. The data do not separate driver health effects from public health effects. Alternative 3a would have the greatest risk, with an estimated 4 deaths and 66 injuries. Most of the risk is associated with transportation of the bulky, slightly contaminated waste. Removal of the residues only from NFSS (Alternatives 4a and 4c) would result in one-tenth of the risk incurred by removing all contaminated materials from the NFSS.

The Committee learned that shipping casks would be available for transporting residues off-site from NFSS from both Scientific Ecology Group, Inc., and Chem-Nuclear Systems, Inc. (letter of July 14, 1994, from P.R. Huber, Bechtel Oak Ridge Corporate Center, to R.S. Andrews, giving cask data and availability). It is not clear from the 1986 FEIS to what extent the capacities and physical sizes of these casks were taken into account in calculating the number of shipments required for shipping residues and bulk wastes. The

number of shipments, and therefore the number of shipping accidents, is determined by those factors. Thus, the Committee believes that there is some uncertainty remaining about the shipping accident analysis.

Estimated occupational injuries and deaths for the alternatives are given in Table B-1 in Appendix B of this report (some tables are included in Appendix B as references).

Calculated Risks

Workers. Additional adverse radiological health effects, including fatal cancers and genetic effects, were estimated for each of the disposal alternatives (Table B-2 in Appendix B), based on projected radiation doses from the residues and wastes to workers and the general public. For workers, the estimated health effects during the Action Period (~ 10 years) ranged statistically from 0.0013 (1.3×10^{-3}) to 0.24. The lowest number of such effects occurred for Alternatives 1 and 2a, in which neither residues nor wastes were removed from the NFSS. Modification of residue form as proposed in Alternative 2b raised the projected number of health effects to 0.10. Alternative 3a had the highest risk, estimated at 0.24 adverse health effects in workers during the 10-year period.

During the Maintenance and Monitoring Period (10 to 200 years) no significant doses to workers were estimated except at the Hanford site, where much higher releases of radon-222 gas were projected. The cumulative dose of 290 organ-rem to the bronchial epithelium during the 190-year period was projected to result in 0.032 (3.2×10^{-2}) adverse health effects. No occupational doses or health effects were projected, based on the assumption that monitoring and maintenance activities would cease after 200 years (U.S. Department of Energy, 1986, p. 4-7 to 4-10).

General Public. For the general public, the additional adverse health effects from doses from the residues and wastes were calculated for three different period of time, for each of the alternatives (Table B-2 in Appendix B). In the 10-year Action Period, the estimates ranged from <0.0000005 (5×10^{-7}) for Alternatives 1 and 2a to 0.30 and 0.28 for Alternatives 4b and 4d, respectively. For these latter alternatives, the health effect estimates were based on collective doses projected to result from particulate releases from NFSS wastes during transport to ocean disposal, together with ^{222}Rn releases during the removal of the residues and their reburial at Hanford or Oak Ridge (U.S. Department of Energy, 1986, p. 2-22 and 4-3 to 4-7).

For the Maintenance and Monitoring Period (10 to 200 years), the projected adverse radiological health effects in the general public ranged from <0.0000005 (5×10^{-7}) for all alternatives except 3a, 4a and 4b to 0.036 (3.6×10^{-2}) for Alternatives 4a and 4b. For these alternatives (4a and 4b), health effect estimates were based on collective doses projected to be at highest levels primarily due to the greater diffusion of ^{222}Rn gas out of the residues in the arid climate at Hanford (U.S. Department of Energy, 1986, p. 4-3 to 4-7).

Additional adverse health effects in the general public during the Long-Term Period (200 to 1,000 years) were estimated only for the year 1,000 in terms of effects per million persons per year, based on the assumption of cessation of all controls in the year 200 and the development of erosive land use until the year 1,000. The lowest level of health effects, <0.0000005 (5×10^{-7}) effects per million persons per year, was projected for Alternatives 2a, 2b, 3b, 4c and 4d. The level of 0.00021 (2.1×10^{-4}) effects per million persons per year for Alternative 1 was derived from collective doses to the general public resulting from predicted erosion of the cap and exposure of the wastes (U.S. Department of Energy, 1986, p. 4-3 to 4-7). The highest level, 0.0061 (6.1×10^{-3}) effects per million persons per year, projected for Alternatives 4a and 4b, was attributed to higher collective doses again resulting primarily from greater ^{222}Rn gas releases in the arid climate at Hanford.

According to the 1986 FEIS (U.S. Department of Energy, 1986, p. 4-3 to 4-7), for all time periods and for all alternatives the doses to the general public will be insignificant in terms of increased risk of adverse health effects (fatal cancers plus genetic defects). The greatest risk is projected to result from doses incurred during the Action Period, estimated to be 0.30 health effects for the worst case (Alternative 4b) in a population of several million people.

Resident-Intruder. Additional adverse radiological health effects were projected to occur in the situation where controls cease and one or more intruders reside in a house built in the contaminated residues and/or wastes, as given in Tables B-2 and B-3 (Appendix B). The resident-intruder would, as a result of breaking through the covering cap, incur a very large dose to the bronchial epithelium from inhalation of ^{222}Rn diffusing out of the residues, and from its short-lived decay products. The doses estimated for each of the alternatives are given in Table B-3 (Appendix B). Doses associated with other pathways (e.g., food or drinking water) were calculated to be very small in comparison.

The dose to the bronchial epithelium of the resident-intruder would result in death within a few years in the worst cases, where individual doses on the order of 8,000 rem/year are projected (Alternatives 1 and 2a at the NFSS). As long as the residues are located near the surface, regardless of their location or form, the ^{222}Rn working levels (WL) in the resident-intruder's house are projected to be extremely high (compared to a normal range of 0.001-0.067 WL) (U.S. Department of Energy, 1986, p. 4-7 and 4-36 to 4-38).

Lower values of dose to the resident-intruder given in Table B-3(Appendix B) were calculated when the form of the residues were modified to reduce diffusion and release of ^{222}Rn gas to the atmosphere (Alternative 2b), or when residues and wastes were dispersed over a large area at Oak Ridge or Hanford (Table B-4 in Appendix B). No estimates of adverse health effects, including death, were given in the 1986 FEIS for these reduced levels of dose to the bronchial epithelium from ^{222}Rn and its decay products.

An additional intruder scenario was provided in the 1994 Failure Analysis Report (FAR) (Bechtel National, Inc., 1994a) for the NFSS. Estimated doses for this scenario

(applicable to Alternative 2a) are given in Table B-3 (Appendix B). In this case, exploratory drilling takes place on a random basis, and it was assumed that an exploratory borehole was drilled into the K-65 residues over a period of 48 hours. The receptor is the driller who is exposed to radioactive materials including radium and thorium brought to the surface in the drill cuttings. The projected dose to the driller was estimated to be 0.507 rem from direct exposure, with a negligible contribution from the inhalation of ^{222}Rn and its decay products during the 48-hour exposure period.

Selection of Primary Alternative

DOE selected Alternative 2a as its choice for managing the NFSS residues and wastes. In this alternative, a long-term (permanent) cap replaces the interim cap and the site is maintained and monitored for 200 years. The site will be reduced in size to 16 hectares (0.16 km^2), the area of the Wastes Containment Structure (Figure 4).

Figure 4 is a diagram of the NFSS site showing both the site and the surrounding area, including the toxic chemical and landfill disposal areas. The proposed long-term cap is made up of layers designed to protect the residues from the effects of weather, especially of rain and freezing, and protective subsurface dike of clay to slow intrusion of horizontally-flowing water into the Wastes Containment Structure (WCS). Design requirements for the existing and long-term caps are listed in Table B-5 (Appendix B).

Interim Cap. At present, a temporary cap, called the interim cap, covers the WCS (Figure 3). This interim cap was designed to reduce, but not eliminate, water infiltration and to minimize radon release to the atmosphere. The interim cap consists of two layers. The lower layer rests on the engineered clay dike of the WCS and consists of 0.9 m (3 ft) of low-permeability, compacted clay, sloped to enhance drainage away from the waste storage area. The upper layer of the cap is 0.15 m (6 inches) of compacted topsoil covered with grass to inhibit erosion, over a fill layer of 0.3 m (12 inches) of loosely compacted general fill material. Both soil layers serving to inhibit frost-heave damage to the underlying clay layer. The clay cover has a water permeability of 10^{-7} cm/sec, and constitutes the principal barrier against moisture intrusion and radon migration from the WCS. The clay dikes and cutoff walls constructed around the waste materials provide a barrier to horizontal radionuclide migration. The cutoff walls penetrate the gray clay sedimentary layer that forms the bottom of the containment structure.

DOE calculations indicate that the amount of radiation from the topsoil layer would be 0.061 $pCi/m^2/sec$, compared to radon releases of 0.24 $pCi/m^2/sec$ from naturally occurring radium in soil (Bechtel National, Inc., 1986a, p. 44). In the 1986 FEIS, DOE indicated that the NFSS site will remain under its ownership and control, and that monitoring, maintenance and corrective actions, as needed, will continue for 200 years. It is claimed that erosion or other adverse impact will not reduce the 25 to 50 year service life of the interim cap, because any damage from erosion, settling, frost heaves, cracking, or biotic intrusion will be repaired under the active maintenance and monitoring program.

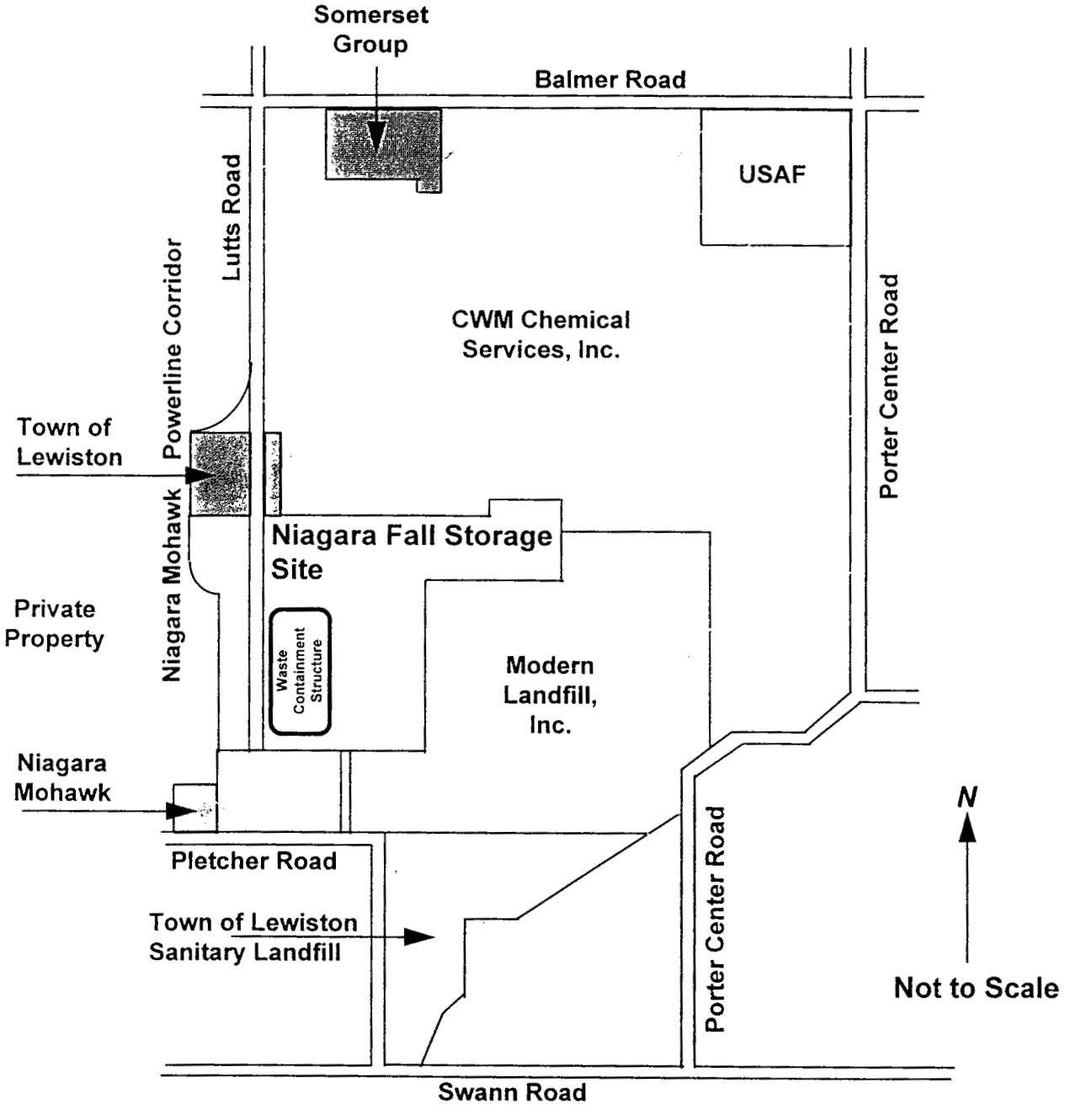


FIGURE 4.
Land Use Adjacent to NFSS (after Bechtel National, Inc., presentation to Committee, October 199

Permanent (Long-Term) Cap. The preferred alternative selected by DOE for managing the NFSS residues and wastes, described in the 1986 FEIS (Alternative 2a) and elsewhere, is to modify the existing cap to produce the long-term cap (also called the permanent cap) over the existing WCS (Figure 5) (Bechtel National, Inc., 1986b). As shown in Figure 6, the existing topsoil layer would be completely removed, and 0.3 m (1 ft) of clay soil would be added and compacted on top of the existing interim cap clay layer to provide a total thickness of 1.2 m (4 ft). A 0.23-m (9-inch) sand-and-gravel transition layer will be placed over the clay and under a 1 m (3 ft) layer of rock material. This rock layer will consist of an intrusion barrier of well-graded, large rock not exceeding 0.5 m (1.5 ft) maximum thickness, emplaced in two 0.5 m (1.5 ft) thick compacted rock lifts. The surface of the rock layer will be filled with smaller rock as a choke course, and another 0.23 m (9 inches) sand-and-gravel will be placed over the rock layer to function as a transition between the intrusion barrier and the overlying layer. The surface layer will consist of 0.3 m (1 ft) of soil overlain by 0.15 m (6 inches) of topsoil. The transition layers will lie parallel to the slope of the clay blanket to provide internal drainage for the cap.

GEOLOGY AND HYDROLOGY

Detailed descriptions of the geology and hydrology of the region encompassed by the NFSS, prepared before the 1986 FEIS (Bechtel National, Inc., 1982 and 1984), have been augmented by extensive drilling, geophysical surveying, and monitoring since residues and wastes were consolidated in the Wastes Containment Structure and covered by the interim cap (Bechtel National, Inc., 1994a). The regional bedrock geology, summarized in Figure 7, is composed of Ordovician and Silurian sedimentary rocks underlain by pre-Cambrian gneiss. In the area of the NFSS, the gently-dipping Ordovician Queenstone Formation shales have been eroded to a plain by glacial activity and covered by greater than 12 m of Quaternary glacial and glaciolacustrine sedimentary deposits, including units identified as brown clay, gray clay, sand and gravel, and red silt. Current interpretation of the stratigraphy of these surficial deposits are shown in Figure 8.

Discontinuous, random sand lenses occur in the brown clay unit and have been identified as potential pathways for contaminant migration (Bechtel National, Inc., 1991). The engineered clay soil cutoff walls for the interim cap, and for the proposed long-term cap, are therefore imbedded into an excavation that extended at least 0.6 m into the underlying gray clay sedimentary unit. The clay sedimentary units beneath the containment area are expected to retard (but not eliminate) migration of radionuclides from the residues and wastes. Because the clay layers, including the gray clay layer, are known to contain sand lenses, the estimates of contaminant migration in the 1986 FEIS were based on the assumption that the average hydraulic properties of the underlying clayey materials were between those for clay and sand (U.S. Department of Energy, 1986, p. 4-61 to 4-62). For the long term, the conservative assumption was made that the cutoff wall offers no significant long-term barrier beyond that of the surrounding sedimentary deposits.

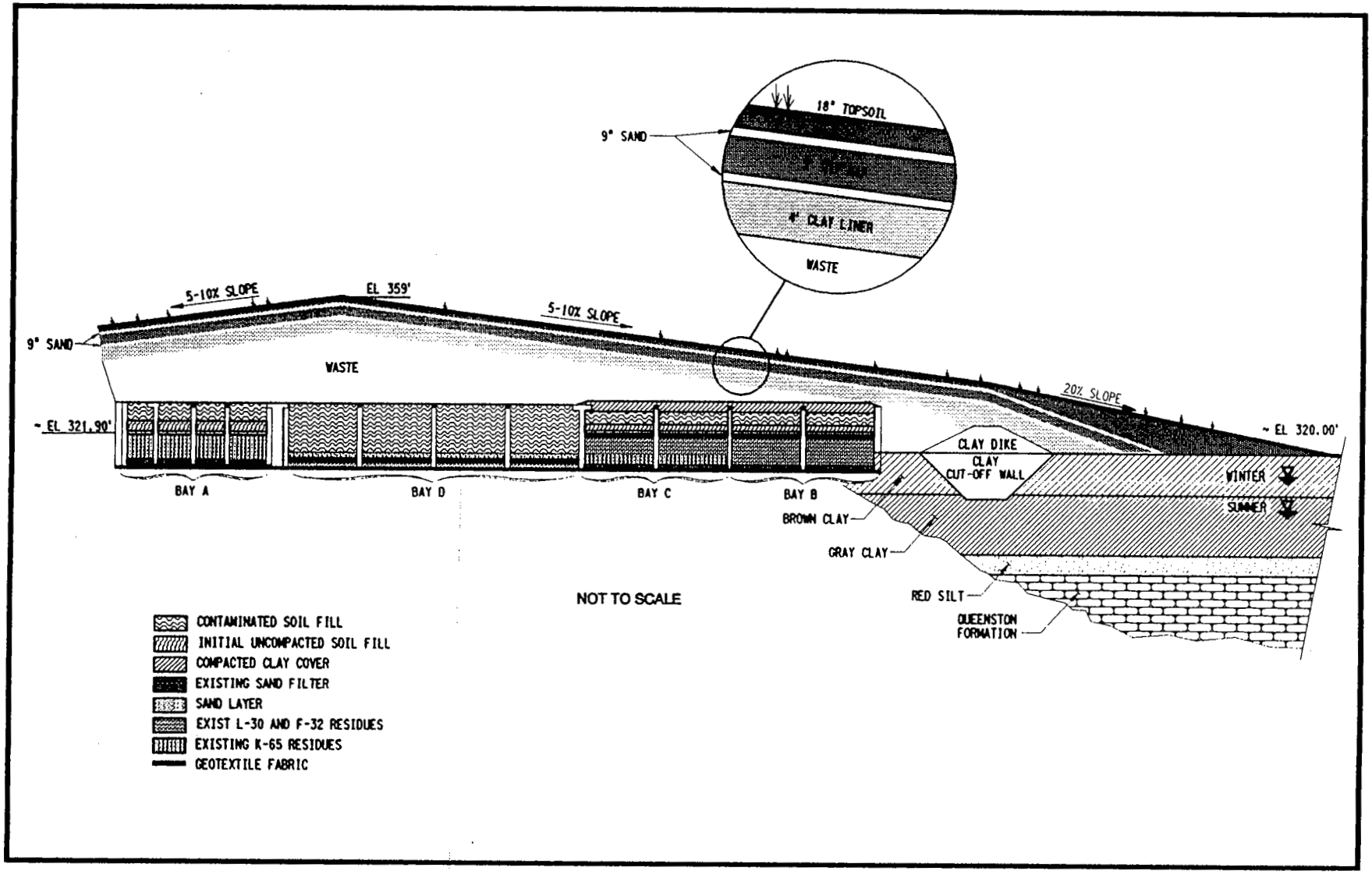


FIGURE 5. East-West Cross Section Through Building 111 of Proposed Long Term Waste Containment Structure (after Bechtel National, Inc., presentation to Committee, October 1994)

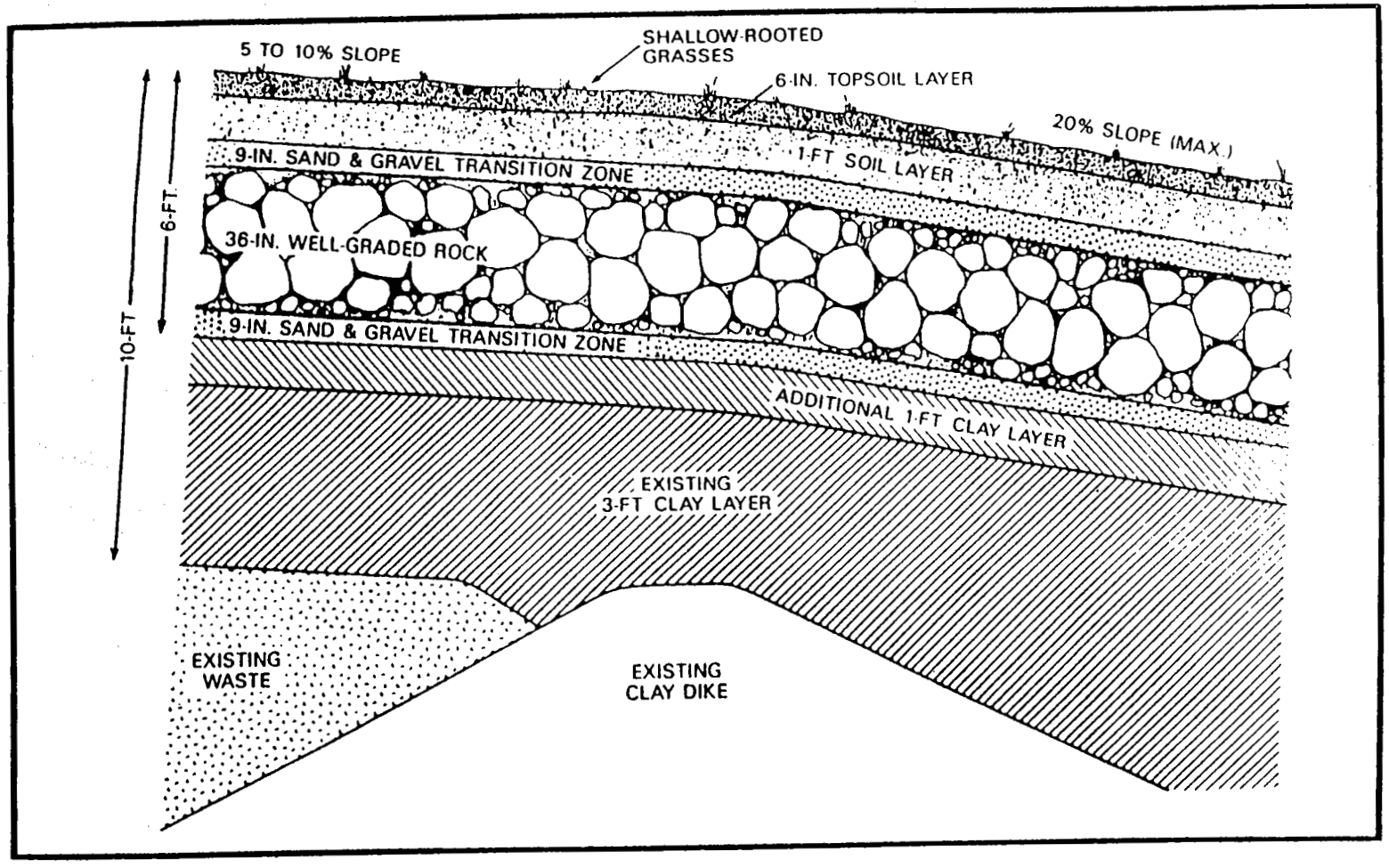
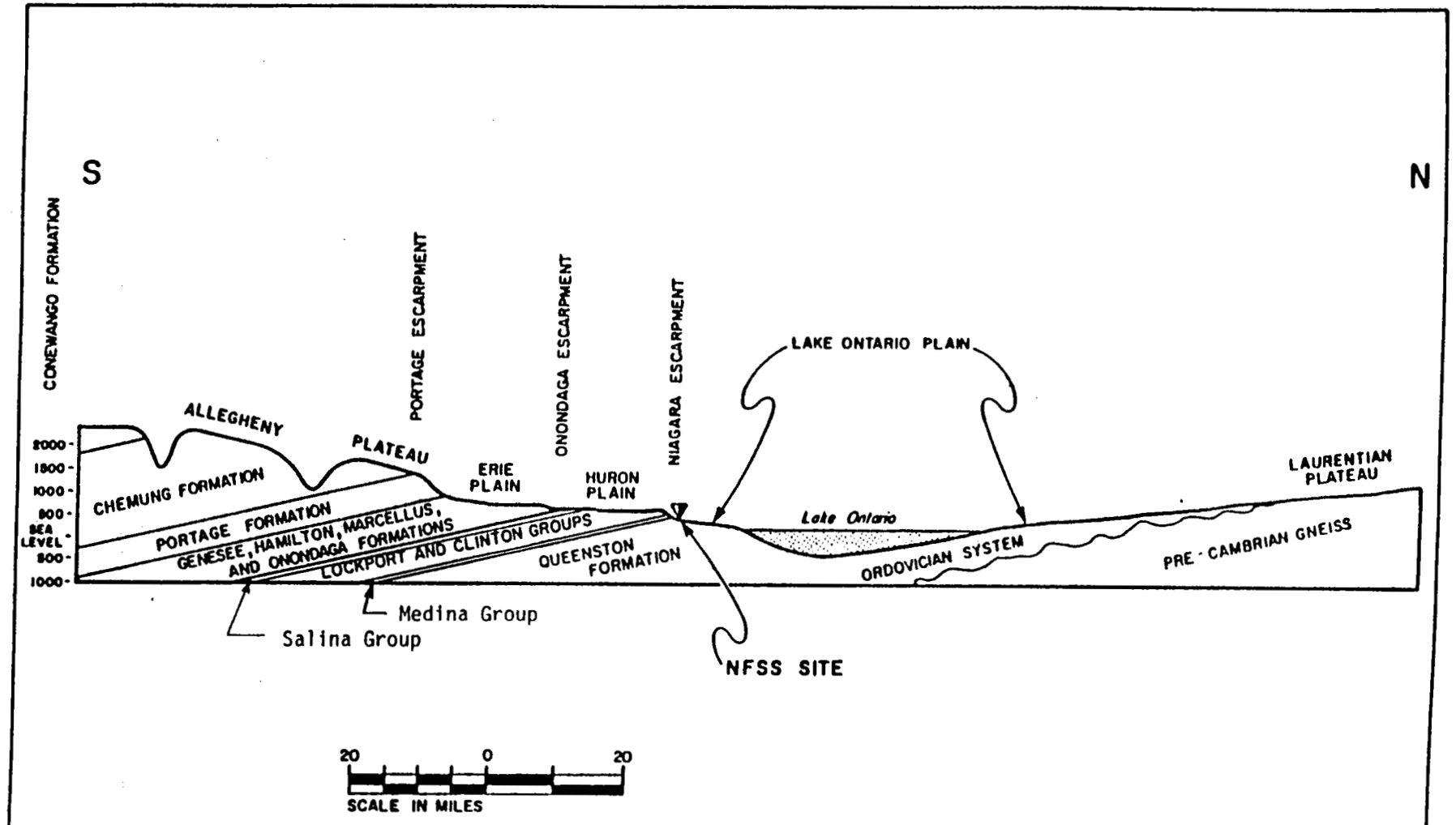


FIGURE 6. Detailed Cross Section of Proposed Long Term Waste Containment Structure (Bechtel National, Inc., 1986b)



Notes:

1. Modified from Kindle and Taylor, 1913.
2. Surficial Deposits are not shown.

NIAGARA FALLS STORAGE SITE	
ALLEGHENY PLATEAU TO LAURENTIAN PLATEAU NORTH - SOUTH SECTION	

FIGURE 7. North-South Cross Section of Bedrock Geology in Vicinity of NFSS (Bechtel National, Inc., 1984)

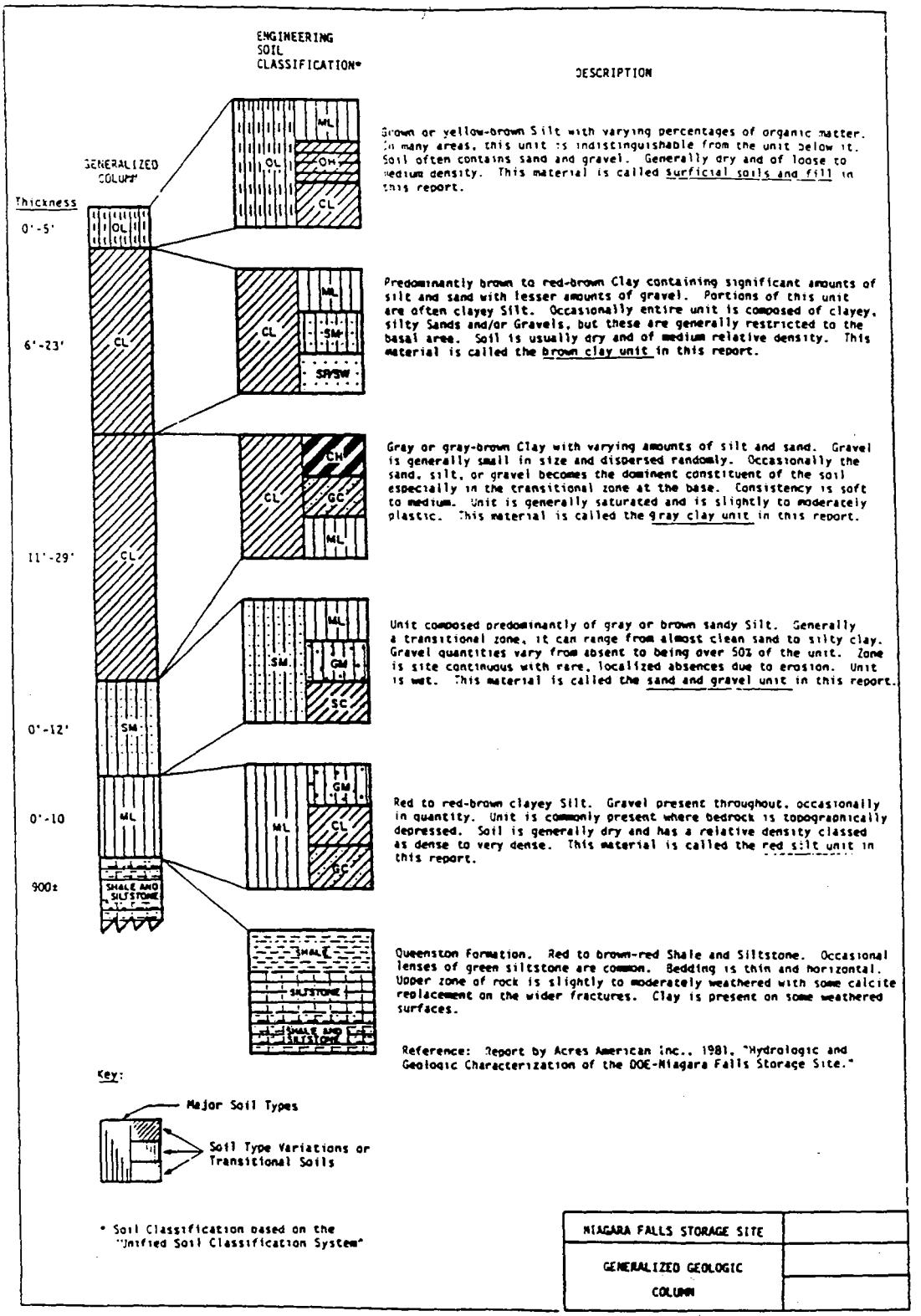


FIGURE 8. Generalized Near-Surface Geological Column (Bechtel National, Inc., 1984)

Ground water underlying the NFSS does not provide a viable source of potable water at the present because in the shallow unconsolidated sediments it is of poor quality and because bedrock units underlying the area which contain ground water typically have low permeability. Also, at present there is an abundance of potable water available to the area from other sources (Lakes Erie and Ontario, and the Niagara River). A few wells have been registered in the area, but none are presently used for drinking water.

Horizontal ground water gradients in the water bearing units at the NFSS, of which two have low permeabilities and one contains poor quality water, indicate a flow direction toward the north-northwest, perpendicular to the strike of the Paleozoic rock units, at a rate of less than 0.3 m/year. However, the Committee understands that the effects of pumping at the Modern Landfill facility just to the east of the NFSS, begun in 1991, have been noticed in the NFSS monitoring wells, and may lead to changes in the flow direction.

CURRENT MAINTENANCE AND MONITORING

For the Maintenance and Monitoring Period (10 to 200 years), DOE has committed programs to ensure that the Wastes Containment Structure (WCS) is maintained, radioactive releases to the environment are monitored, and periodic corrective remedial actions will be taken, as necessary. The programs also provide surveillance of the NFSS to protect against human intrusion into the contaminated materials, and to minimize unfavorable interactions between the NFSS and the surrounding communities and neighbors. The 1986 FEIS recommends continued site investigations to determine seasonal variations in the environment and the geohydrology of the sediments underlying the Wastes Containment Structure, noting that such investigations are difficult to perform in the heterogeneous conditions at the NFSS (U.S. Department of Energy, 1986, p. 4-68).

Both performance monitoring and environmental monitoring programs have been instituted at the NFSS. The performance monitoring program, which has a limited duration, and which is distinct from the environmental monitoring program, was established to test the validity of the main engineering elements of the WCS function to minimize rainfall infiltration, to prevent pollution of ground water, and to prevent radon emanation (Bechtel National, Inc., 1990). The environmental monitoring program at NFSS includes sampling networks for radon concentrations in air, external gamma radiation exposure, and total uranium and ^{226}Ra concentrations in surface water, sediments, and ground water (Bechtel National, Inc., 1994b); results are reported annually.

The primary concern of both programs is with ^{222}Rn gas escaping from the WCS. However, monitoring wells at several depths are also monitored to see if radioactive materials are moving underground with water movement. Non-radioactive, toxic substances such as lead and barium are not monitored. Table B-6 (Appendix B) shows the existing monitoring network (Bechtel National, Inc., 1994a).

Recent data indicate that certain types of monitoring for radioactive materials in ground water at the NFSS have been curtailed. In 1993 and 1994, there were 43 ground water sampling locations (Figure 9), of which only 9 were sampled for total uranium content, and only 11 were sampled for ^{226}Ra. Of the 43 locations, 13 were located at the perimeter of the WCS, and 28 were on-site but outside the WCS. The Committee was told that the reductions in sampling frequency were due to lack of detection of ^{226}Ra above background levels. [Data in the 1994 Failure Analysis Report (Bechtel National, Inc., 1994a) indicate that ^{226}Ra is not expected to migrate beyond the perimeter of the WCS until the 5,000 to 10,000 year time frame.]

The Committee was also told that installation of the permanent cap would result in loss of the 13 WCS perimeter sampling locations. Thus, materials moving in ground water would have to traverse longer distances before detection in the 28 sampling locations now outside the WCS, or in new wells to be installed.

LONG-TERM MAINTENANCE AND MONITORING

In its September 1986 Record of Decision (ROD) for remedial actions at the NFSS, DOE selected long-term in-place management of the residues and wastes in the WCS, consistent with appropriate federal guidance and regulations. For the Long-Term Period (200 to 1,000 years) following the earlier periods during which the residues and wastes will continue to be managed, DOE has considered two cases involving different degrees of loss of control over the NFSS site (U.S. Department of Energy, 1986). In both cases, monitoring, maintenance, and corrective actions would cease after 200 years, but in one alternative, DOE would lose control over access, land use, and ownership as well. Potential impacts beyond 1000 years and needs for their management were not addressed due to uncertainties relative to such factors as degree of control, location and density of populations, environmental conditions, and limits on current predictive capabilities (U.S. Department of Energy, 1986, p. 4-7).

Although the cessation of maintenance and monitoring starting at 200 years was selected as a reference point for purposes of analysis, DOE has strongly indicated the intent of the federal government to take perpetual care of the NFSS residues and wastes (U.S. Department of Energy, 1986). Nevertheless, the provision of maintenance and monitoring over the thousands of years that the residues and wastes would remain radioactively hazardous was stated to be an unreasonable assumption, and 100 years has been selected as the boundary for application of administrative controls after closure at high-level radioactive waste repositories (40 CFR Part 191). The adverse impact of death from doses to resident intruders at the NFSS could only be prevented if controls are maintained for many thousands of years or if a different method of long-term management (e.g., greater confinement) was implemented (U.S. Department of Energy, 1986, p. 4-7).

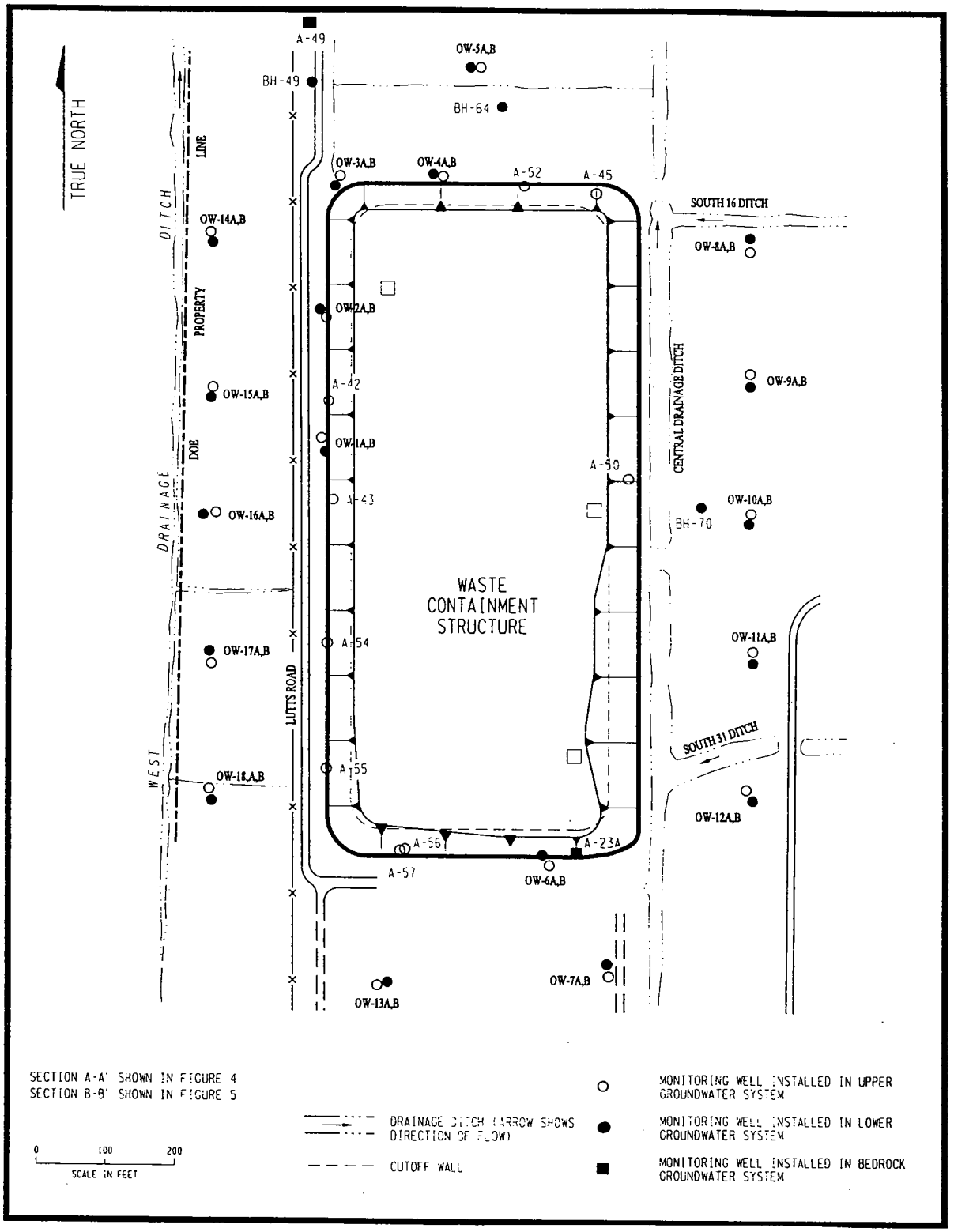


FIGURE 9. Monitoring Well Locations (Bechtel National, Inc., 1991)

The Committee notes with interest DOE's establishment of a Long-Term Surveillance and Maintenance (LTSM) Program of "off-site" DOE radioactive waste disposal sites, including those under the Uranium Mill Tailings Remedial Action Program (UMTRAP) and the Formerly Utilized Sites Remedial Action Program (FUSRAP), that appears to be applicable to NFSS. DOE's Grand Junction, Colorado, Projects Office was designated as the LTSM Program Office. The draft guidelines are not clear as to whether the degree of custodial surveillance, monitoring, maintenance, and corrective actions would be equivalent to DOE's present activities at the NFSS, nor what the expected duration of the LTSM Program would be (200 years, 1,000 years, or longer).

ADJACENT SITES

The NFSS is bounded on two sides by major waste disposal facilities, the Chemical Wastes Management (CWM) Chemical Services, Inc. (formerly Model Cities Landfill), and Modern Landfill, Inc (Figure 4). The CWM site is a repository for hazardous waste regulated under RCRA, and Modern Landfill receives wastes not classified as hazardous wastes under RCRA but not necessarily materials without health risk. Current site plans and ongoing monitoring do not address the present or long-term potential impacts of these sites on the residue and waste storage at NFSS. This is particularly important, given the time frame (perpetual care), uncertainty of hydrology, and the potential public health impacts of the wastes at these sites. The Committee found no evidence that these sites are impacting the waste at NFSS at the present time. However, there is currently no routine testing done to monitor pollutant migration which may impact the NFSS, and little information available on the current or long-term health risks posed by these neighboring sites.

RADIOACTIVE CONTENT OF RESIDUES AT NFSS

As has been mentioned previously, "residues" are distinguished from "wastes" at the NFSS, the term "residues" being applied to those contaminated materials that have a high ^{226}Ra concentration. The average concentration, inventory, and distributions of ^{226}Ra and ^{230}Th are given in Table B-7 (Appendix B). Of primary concern from a long-term health risk potential are the 1,974 Ci of ^{226}Ra and the 288 Ci of ^{230}Th located in the high concentration K-65, L-30/F-32 and L-50 residues. Most of the radioactivity (1,881 Ci of ^{226}Ra and 195 Ci of ^{230}Th) is in the K-65 residues, with concentrations of ^{226}Ra at 100 to 200 times the concentration of radium present in more common uranium tailings. The ratio of curie content of ^{226}Ra to ^{230}Th in the K-65 residues is about 9.6 to 1, due to removal of thorium from the K-65 ores during processing. In other residues the radium and thorium are in secular equilibrium, i.e., with curie ratios of 1 to 1.

The projected total inventories of ^{226}Ra and ^{230}Th in the Wastes Containment Structure (WCS) over the next 10,000 years, based on radioactive decay, are given in Tables B-8 and B-9 (Appendix B), assuming that the residues remain in place. In the next 1,000 years, the total ^{226}Ra inventory in the WCS will decay from 1,982 to 1,388 Ci; after 10,000 years, the ^{226}Ra inventory will decay to 294 Ci. Due to its much longer half-life, the total ^{230}Th inventory will decay from 296 to 294 Ci in the next 1,000, and to 272 Ci after 10,000 years. Thus, by 10,000 years from now about 93 percent of the ^{226}Ra remaining in the WCS would be that produced by thorium in secular equilibrium.

The Committee has also considered how the removal of selected residuals from the NFSS (e.g., for disposal) would affect the radioactive content of the WCS (Tables B-10 and B-11, Appendix B). Removal of the K-65 residues alone would reduce both the ^{226}Ra and ^{230}Th contents to about 100 Ci; with further removal of L-30/F-32 and L-50 residues, the contents would be further reduced to about 8 Ci. The associated volume of the removed residues ranges from 3,000 m^3 ($\sim$3,900 yd^3) for the K-65 residues to 11,000 m^3 ($\sim$14,400 yd^3) for the K-65, L-30/F-32 and L-50 residues.

The R-10 residues, mixed with soil and having low concentration of radioactivity, have been classified as wastes and were not considered for removal by the Committee. The effects of selected removals on $_{226}Ra$ and ^{230}Th inventories are shown in Figures 10 and 11 for the K-65 and L-30/F-32 combined residues (the L-50 values would be approximately identical to the bottom curve in each figure and were not shown in the interest of clarity).

FERNALD RESIDUES

The DOE site at the Fernald Environmental Management Project (FEMP) has K-65 and other residues similar to those at the NFSS, as given in Table 3. The residues at the FEMP site are stored in large, cylindrical storage facilities (silos). All of the K-65 residues at the NFSS and in Silo 1 at the FEMP site were produced at the Mallinckrodt Chemical Works in St. Louis. Of the K-65 residues in Silo 2, some were produced by Mallinckrodt, and some by processing at the FEMP site. Silos 1 and 2 at the FEMP site contain 3,770 Ci of ^{226}Ra and 685 Ci of ^{230}Th.

A very different approach has been adopted for managing the FEMP residues from that proposed by DOE for managing the NFSS residues. The fact that the FEMP residues are still in the silos and can be more readily removed by slurrying than the NFSS residues, which have been interred in an underground storage facility, is a significant difference between the sites and cannot be ignored when comparing and contrasting the disposal approaches (National Research Council, 1992, p. 7).

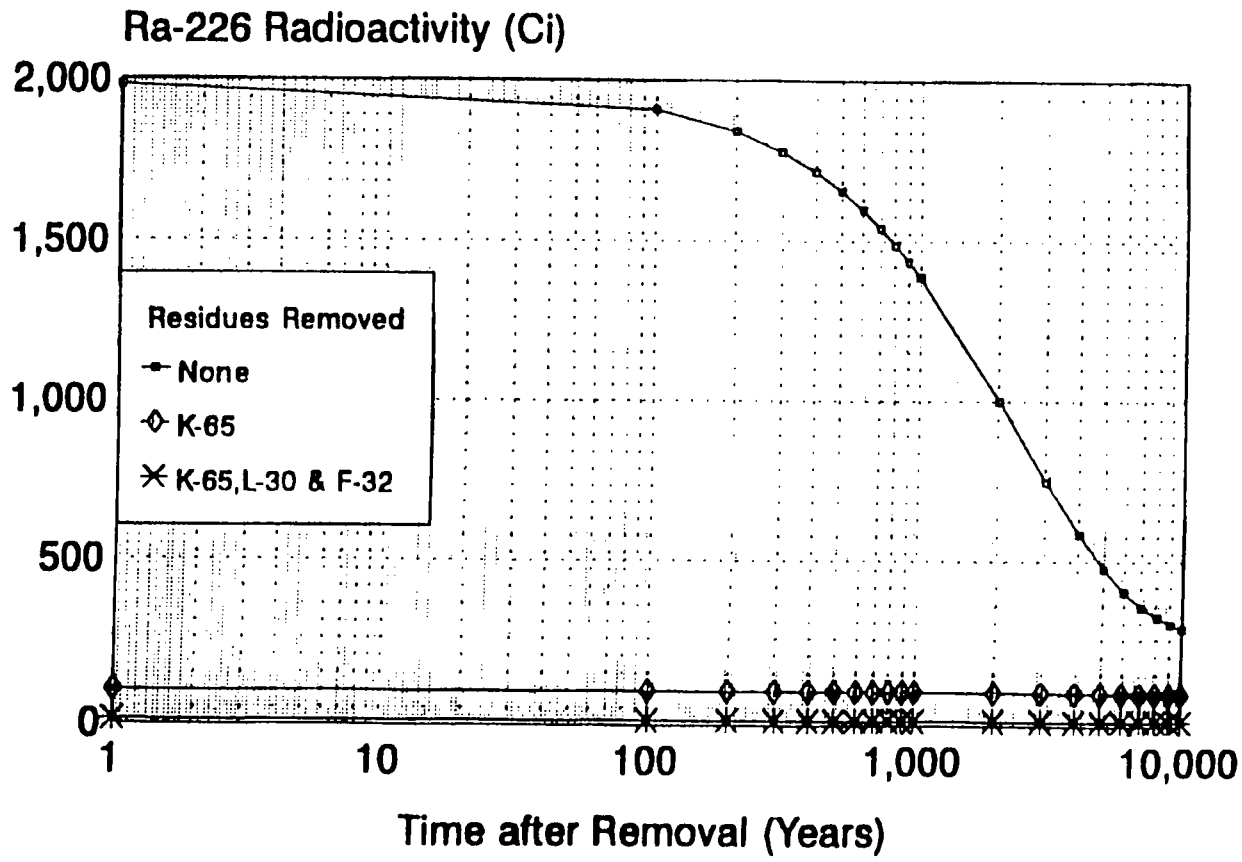


FIGURE 10. Radium-226 Activity in the NFSS Waste Containment Structure After Removal of Selected Residues in Year 1

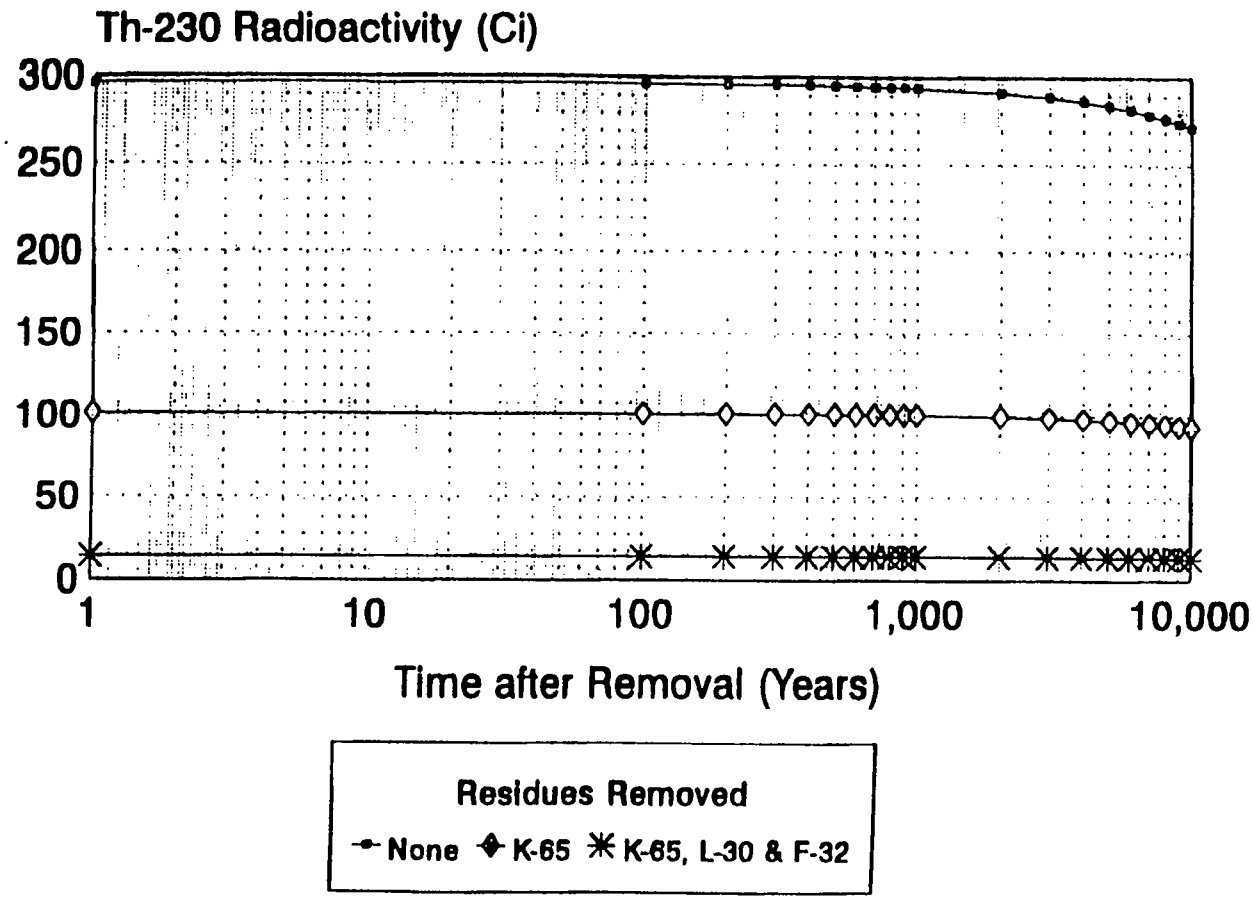


FIGURE 11. Thorium-230 Activity in the NFSS Waste Containment Structure After Removal of Selected Residues in Year 1

TABLE 3. Comparison of K-65 Residues at NFSS and Fernald Environmental Management Project (FEMP) (U.S. Department of Energy Fernald Site Office, 1994)

Facility	Location	Residue/Waste Origin	Total Volume m^3 (yd^3)	Total Mass (dry)[1] (MT)	Ra-226 Inventory[1] Mean (Ci)	Th-230 Inventory[1] Mean (Ci)
NFSS-WCS	Bldg. 411	K-65 MCW[2]	3,000 (3,925)	3,450	1,881	195
FEMP	Silo 1	K-65 MCW[2]	3,280 (4,290)	6,724	2,630	403
	Silo 2	K-65 MCW[2] & FEMP	2,840 (3,715)	5,822	1,140	282
FEMP	Silo 3	cold metal oxides (from FEMP raffinate waste streams)	3,900 (5,101)	8,841	26.3	453

[1] Based on a volume of 3,000 m^3 and any dry mass density of 1,050 g/cm^3 for Bldg. 411, a volume of 3,280 m^3 and a dry mass density of 2.050 g/cm^3 for Silos 1, a volume of 2,840 m^3 and a dry mass density of 2.050 g/cm^3 for Silos 2, and a volume of 3,900 m^3 and a dry mass density of 2.267 g/cm^3 for Silos 3.

[2] Mallinckrodt Chemical Works,St. Louis, MO.

The disposal approach adopted by the FEMP site is to sluice the residues out of the silos with water and to vitrify them by adding sufficient glass frit to make a waste disposal form that meets disposal site acceptance criteria. The vitrified residues, probably in the form of small glass spheres (marbles) would then be shipped off-site. A pilot plant is being built at the FEMP site to demonstrate the vitrification step, and initial operation is expected in 1996. The performance criteria and acceptability of the final waste form have not yet been established.

DEFENSE SITE vs NON-DEFENSE SITE

Because FEMP is designated as a DOE "defense" site, the vitrified residues can be shipped to the Nevada Test Site (NTS) for disposal (U.S. Department of Energy Office of Environmental Management, 1995, p. OH 14 to OH 15). This is not true of the residues at the NFSS because NFSS is not a designated defense site, but rather is classified as a Formerly Utilized Site [Manhattan Engineer District/Atomic Energy Commission] Remedial Action Program (FUSRAP) site. While there may be merit in such a distinction in the context of managing and funding DOE's vast waste management complex, the Committee sees little technical reason for maintaining the distinction in the case of managing NFSS and the FEMP residues which are very similar in origin and content.

CONCLUSIONS AND DISCUSSION

1) Available site sampling and monitoring information indicates that there is no immediate hazard to the off-site public from the residues in their present configuration.

A variety of sources of risk must be considered, including those from contaminants in the air, soil, and water. Potential contaminants in the air include ^{222}Rn, volatile organic compounds (VOCs), and airborne particulates; in the water and soil, potential contaminants could include radioactive and toxic inorganic and organic chemicals.

The radionuclides ^{226}Ra (and its daughters) and ^{230}Th in the K-65 residues are the principal radioactive contaminants at NFSS. In addition to amounts, consideration of the properties of the materials that contain the ^{226}Ra and ^{230}Th is important to determine to a large extent the physical and chemical behavior of those elements in and around the waste containment facility, as well as the behavior of their decay daughters. The daughter product of ^{226}Ra of greatest importance with respect to the safety of the off-site public is ^{222}Rn.

The fact that radon is a noble gas means, first, that it is not reactive with other chemicals to produce an immotile non-gaseous compound, and second, that its safe containment in a permeable burial system such as exists at NFSS must rely on its short half-life (3.82 days) and its decay to non-gaseous daughters. Therefore, if the diffusion path of ^{222}Rn from the residues is such that it takes on the order of 38 days (about 10 decay half-lives) before it leaves the protective cap, the amount reaching the air above the cap will be reduced about 1,000-fold. It is, therefore, highly desirable to have a cap on the residues that imposes a residence time of the ^{222}Rn in the cap that is long relative to the ^{222}Rn half life. Air monitoring results to date show that radon activity levels are well within acceptable levels for breathing, both on the NFSS and in surrounding areas.

Water samples from monitoring wells on the site and in surrounding areas show that radioactive species have not entered the ground water system in amounts much in excess of background levels, and that their concentrations are well within acceptable limits. Soil samples taken around the site show small amounts of radioactive contamination, especially where residues and wastes were stored in drums on the surface prior to consolidation and more permanent storage. However, the levels of radioactivity are so low as to be of negligible concern.

For all of the alternatives considered, the health risks from radiation estimated in the 1986 FEIS are stated to be negligible both for the general public and for workers involved in operations required to carry out the alternatives. The calculated on-site well contamination by ^{226}Ra, 1,000 years after burial of the residues, ranges from none for Alternatives 3a, 3b, 4b and 4d to 1,100 pCi/l for Alternative 1; the on-site well contamination by ^{226}Ra reaches peak concentrations at the times shown in Table 4.

TABLE 4. Peak ^{226}Ra Concentrations and Times of Occurrence (U.S. Department of Energy, 1986, Table 2.2, pp 2-4 abd 2-5)

Alternative	Concentration 1000 years from now, pCi/l	Time to reach maximum concentration, years
1	1,100	1,800
2a	380	3,600
2b	42	3,600
3a	none	35,000
3b	none	7,000
4a	Hanford-none; NFSS-3.6	Hanford-35,000; NFSS-3,600
4b	none	Hanford-35,000
4c	Oak Ridge-none; NFSS-3.6	Oak Ridge-7,000; NFSS-3,600
4d	none	Oak Ridge-7,000

Source: U.S. Department of Energy, 1986 (Table 2.2, pp 2-4 and 2-5)

2) The high-level residues (i.e., those classified as K-65, L-30/F-32 combined, and L-50) pose a potential long-term risk to the public, given the existing environmental conditions and future unpredictability, if they are left permanently at the NFSS.

The continuing high levels of radioactivity of the K-65 residues, the cumulative uncertainties in understanding and predicting local geological and hydrological behavior, the indeterminate nature of future land and water use and future demographics, the unpredictable physicochemical behavior of the residues such as possible complexation with reactants in the soil and colloid or pseudocolloid formation, and the large potential risk to the public, all argue decisively against leaving the residues at the NFSS permanently. Although the Committee considers containment-in-place of radioactive waste protected by engineered barriers as a potentially acceptable technology, it recognizes that the source and its configuration, environmental conditions, and potential long-term risks to public and environmental safety and health are unique to each site. Thus, the applicability of containment-in-place must be based on site-specific factors. The extraordinarily high concentrations of radium and its daughters, especially of radon, and the presence of substantial concentrations of ^{230}Th with a half life of 75,400 years dictate that a potential for unacceptable radiation exposure will remain for a time far in excess of the 1,600-year half life of ^{226}Ra.

Incomplete knowledge of the details of the local geology (e.g., of the presence and extent of sand lenses in the glacial clays and of pathways for radium-laden water to reach underlying rock layers where it could be channeled away from the site) is cause for concern about the adequacy of coverage of this issue in the 1986 FEIS. This concern is compounded by the realization that ground water seasonally intrudes the residues, and that pumping activities at the adjacent landfill alter the flow pattern of the ground water (Bechtel National, Inc., personal communication).

The possibility of home construction and other types of human occupancy and land use near and on the site long after the period of site maintenance, monitoring, and institutional control has expired must be taken very seriously, considering the potential consequences of intrusion into or exposure of the buried K-65 residues.

Finally, the uncertainty in predicting the long-term physicochemical behavior of the residues in the complex matrix of clay, as well as the behavior of sulfate salts of the radium, thorium, lead, and other components of the residues, makes for an uncertain prediction of the behavior and thus of the long-term safety of the NFSS.

Contamination of the surface soil occurred primarily during storage on the ground of the R-10 residues before they were moved into the Wastes Containment Structure. This would be a problem only if an intruder, such as a child, ingested small amounts of the soil. It does, however, lead to residual contamination on the site that may interfere with

monitoring measurements and potentially lead to erroneous conclusions about what is happening to the NFSS residues.

In the 1986 FEIS, it is assumed that a farm pond is constructed immediately downstream of the waste-containment area. It is also assumed that the pile of contaminated materials is the entire watershed for the pond, that the cap has been entirely lost, and that 100 mg/l of suspended solids in the pond originate from the contaminated materials. Estimates of concentrations in surface water of dissolved and particulate forms of inorganic and organic substances are given in the 1986 FEIS (U.S. Department of Energy, 1986, Section 4.4.3.1, p. 4-73 to 4-81). The dissolved concentrations include contributions from both surface runoff and ground water seepage into the pond. For most but not all of the elements, the main contribution to the total concentration is made by the suspended solids. Even when the residues are exposed, the total concentration of most elements is below 0.1 ppm, which is at or below regulatory limits. Exceptions include lead, iron, manganese, and nickel.

During processing of the high grade pitchblende ores at the Mallinckrodt Chemical Works, the radium was precipitated as radium sulfate, along with lead sulfate (the ores contained about 6 percent lead) from a nitric acid dissolution of the ore. Barium was added to the solution from which the radium had been precipitated, causing precipitation of barium sulfate, which scavenged residual radium sulfate from the uranium solution. Uranium was then extracted using diethyl ether. The aqueous raffinate (waste stream) after uranium extraction contained the bulk of the thorium that precipitated. Thus, most of the $_{226}$Ra and ^{230}Th in the residues is contained in insoluble sulfate salts. This does not mean, however, that all of the residues are sulfates, nor that the behavior of the radium and thorium in the residues would be those of the pure sulfate salts (Russell, 1994). The K-65 residues are present with two distinct types of materials. Approximately 73 percent is characterized as "slimes" (particle size less than 37 micrometers), and the remainder is sand. Most of the ^{226}Ra is in the slimes fraction (U.S. Department of Energy, 1986, Table 3.6, p. 3-15).

The 1986 FEIS assumes that the ground water system is isotropic and homogeneous and that the flow is uniform in one direction. This is known not to be true at the present time because of the pumping taking place at the contiguous sanitary land fill. Although there is no good information on the future duration of pumping, it will almost certainly not continue for periods that are long compared to the proposed site maintenance and monitoring period. Transport and concentrations of contaminants in the ground water were calculated by solving a mass transport equation that includes convective transport, molecular diffusion, hydraulic dispersion, chemical sorption, and radioactive decay.

The mobility of the ^{226}Ra and ^{230}Th in the containment facility depends primarily on the movement of ground water through the facility. The chemical compounds of the radium and thorium in the residues may move either by dissolution to produce ions which are then transported by the ground water or as undissolved particulates which are carried by the ground water. If the radium and thorium are transported as dissolved ions, they are subject

to limitations on their rates of movement by their solubilities, the rate of ground water movement through the residues, and the sorption and desorption of radium and thorium on the medium through which they move. The latter phenomenon is a very important retardation mechanism and is dependent upon the distribution coefficients of the ions and the capacity of the medium. A distribution coefficient (K_d) of 100 cm^3/g is assumed in the 1986 FEIS for radium in the clay sediments at both NFSS and Oak Ridge; this is considered to be a conservatively underestimated value. A value 10 times lower was assumed for the sandy soil at Hanford.

If the radium and thorium are transported as undissolved particulates, they are subject to limitations on their rates and extent of movement by the relative sizes of the particulates and the pores through which they move (sieving action). If they behave as colloids they are subject to a type of transport mechanism entirely different from either of the two noted above. Colloids typically are considered to be charged solid particles of less than 10 micrometers effective diameter, and they may be either hydrophilic or hydrophobic, depending on whether they are surrounded with loosely-bound water molecules. In general, hydrophilic colloids are much more stable in aqueous media than hydrophobic colloids. Polymer-induced flocculation has been shown in laboratory batch studies to be very effective in agglomerating clay colloids. Colloidal clay species could carry contaminants sorbed on their surface; behavior of contaminants carried in this way would be very hard to predict (Nuttall and Long, 1993).

For ground water contamination over times up to and including the period designated long-term in the 1986 FEIS (200 to 1,000 years) the radionuclide of greatest concern is ^{226}Ra. Concentrations of ^{226}Ra in ground water were modeled for thicknesses of clay in the interim cap corresponding to the conceptual cap designs discussed in Section 2 of the 1986 FEIS. Only clay was considered in the model because the layers of sand, gravel, etc. will not significantly inhibit water infiltration into the residues (U.S. Department of Energy, 1986, p. 4-62).

The following is from the 1986 FEIS (U.S. Department of Energy, 1986, p. 4-63):

> In summary, the clay of the interim cap (Alternative 1) and the additional clay in the preferred long-term cap (Alternatives 2a and 2b) are expected to reduce (but not eliminate) water infiltration into the buried wastes and residues. The existing clayey soils beneath the containment area are expected to retard (but not eliminate) migration of radionuclides from the wastes and residues. Because the clay layers (including the so-called "gray clay" layer) are known to contain sand lenses, the average hydraulic properties of the underlying clayey materials are conservatively assumed to be between the properties of clay and sand. [The Committee notes that this is not conservative if the sand lenses are continuous through the clay for some distance beyond the waste facility, or if the distance between adjacent lenses is short.] Furthermore, over the long term, it is conservatively assumed that the properties of the

cutoff wall are the same as for the surrounding soils--i.e., that the cutoff wall offers no significant additional long-term barrier. Thus, the migration of contaminants may actually be slower than predicted in this analysis.

In the extremely long term (times in excess of about 5,000 years), ^{230}Th is the isotope of greatest concern because it provides a continuing supply of ^{226}Ra. The distribution coefficient (K_d) values used in the retardation calculations are very important in assessing the potential health effects of storing the residues at NFSS. Good data are available on K_d values for thorium for site ground water conditions, including recent measurements made at the request of the Committee (Bechtel National, Inc., 1994a), that result in increased confidence that ionic thorium will be transported very slowly from the storage facility. However, the high charge on the thorium ion suggests the possibility of colloid formation, and the rate and mechanism of transport of colloids is extremely difficult to predict, but in general, colloids may be expected to follow the ground water movement.

3) The proposed actions of replacing the interim cap with a "permanent" cap and of long-term site maintenance and monitoring do not address the potential risks to the public for periods of time commensurate with the duration of that risk. That is, the approximately 300-year period (or even a thousand years) covered by those actions is short compared to the half-life of ^{226}Ra (1,600 years), and very short compared to the half-life of ^{230}Th (75,400 years).

The time-dependent characteristics of the residues at NFSS are basic to any discussion of the health and environmental issues associated with the site. In particular, the half lives of the sources of radiation are of paramount importance, as are their rates of movement. The radioactive isotopes ^{226}Ra and ^{230}Th are the primary sources of radiation at NFSS; ^{222}Rn, a chemically inert gas, is a very important secondary source of radiation. The isotope ^{222}Rn has a relatively short half life, and quickly establishes secular equilibrium with ^{226}Ra, after which time it decays with the half life of ^{226}Ra. The isotope ^{226}Ra is the daughter of ^{230}Th, but because ^{230}Th has such a long half life, it takes a long time to reach secular equilibrium. However, in only 1,585 years the ^{226}Ra reaches 50 percent of its original amounts, during which time the amount of ^{230}Th decreases only about 1.5 percent. All three radioisotopes are energetic alpha particle emitters. Table 5 gives the half lives of the isotopes of major interest at NFSS.

From the values in the table it is apparent that over short time periods the principal radiation sources are ^{226}Ra and ^{222}Rn. However, over very long times ^{230}Th becomes the primary source of radiation because it is a continuing source of the ^{226}Ra and ^{222}Rn daughters. Therefore, it is important to consider the behavior of the ^{230}Th, parent of ^{226}Ra, as well as ^{226}Ra itself. (There are ten radioisotopes in the ^{230}Th decay chain, some of which are very energetic gamma emitters. The very short half lives of these radioisotopes ensure that theyare all in secular equilibrium with the parent ^{226}Ra, and thus that they are major contributors to the dose attendant with ^{226}Ra.)

TABLE 5. Half-Lives of Principal NFSS Radioisotopes

^{230}Th	75,400 years
^{226}Ra	1,600 years
^{222}Rn (in secular equilibrium with ^{226}Ra)	3.8235 days

The residues are assigned different classifications based on the U_3O_8 content of the originating ore (U.S. Department of Energy, 1986, Table 3.5, p. 3-14). Those classified as K-65 have approximately 88 percent of the total ^{226}Ra in the residues. Those classified as L-30 contain about 10 percent of the total ^{226}Ra in the residues and were derived from ores containing about 10 percent U_3O_8, and those classified as L-50 were derived from ores containing about 7 percent U_3O_8. Of the total approximately 11,000 cubic meters of residues, the K-65 residues comprise 28 percent, and the L-30 residues comprise 55 percent.

In addition to the radioisotopes, there are substantial concentrations of non-radioactive elements in the residues. For example, of the total K-65 residues, 3 percent is barium, 5.6 percent is lead, and 1 percent is molybdenum. Although the concentrations of these and other elements differ somewhat among the several residues, they are similar in all the residues (U.S. Department of Energy, 1986, Table 3.7, p. 3-17).

The interim cap at NFSS was designed to "ensure that the rate of radon emanation from the buried contaminated waste is negligible (far below the allowable limit)." Maintenance of the containment facility over a 25- to 50-year service life is expected to repair any damage from erosion, settling, frost heaving, cracking, or biotic intrusion (Bechtel National, Inc., 1986a, p. 44).

A radon diffusion coefficient of 0.00016 cm^2/sec was used for calculating ^{222}Rn releases from damp clay and damp residues and wastes (25 percent moisture) at NFSS and Oak Ridge. A diffusion coefficient of 0.0036 cm^2/sec was used for calculating releases from drier (13 percent moisture) NFSS wastes and residues at Hanford and topsoil and stony soils at NFSS and Oak Ridge. This dependence of diffusion coefficient on moisture content is cited as the reason for the significant difference between radon releases at the Hanford site and the Oak Ridge site.

The interim cap consists of (among other things) a 0.5 m layer of soil, underlain by 0.9 m layer of clay. The radon flux through the interim cap surface, exclusive of naturally occurring radon, was calculated to be 0.061 $pCi/m^2/sec$. The radon flux from natural sources in the topsoil was stated to be 0.24 $pCi/m^2/sec$ (Bechtel National, Inc., 1986a, p. 44). The combined flux of 0.301 $pCi/m^2/sec$ would be well below the DOE and EPA limit of 20 $pCi/m^2/sec$.

Volatile organic compounds (VOCs) are not a particular problem at NFSS. The amount of organic wastes on the site is relatively small. Organic compounds were not produced or used in handling or moving the residues at NFSS, and there do not appear to be significant amounts of such materials on site from previous uses of the site.

This particulates-to-air pathway for contaminant exposure is most likely to occur when the residues are exhumed, treated, and packaged for shipment, and are reburied. Exposure from particulates is also likely during a transportation accident if the shipping package is breached.

There is little explicit discussion of perched water in random sand lenses in the brown clay in the 1986 FEIS. It is, however, likely that there is perched water at the NFSS site. Its impact, if any, on the site analysis is not clear.

4) An important alternative, that of solidifying the high-level residues on site and shipping the solidified residues to an off-site location, has not been considered, even though this alternative was chosen for managing essentially identical residues of common origin currently stored in silos at the Fernald Environmental Management Project (FEMP) site in Ohio. If this alternative is considered, the occupational as well as public health and safety aspects are important. Inputs from waste treatment technology projects, such as the project for handling similar residues now being implemented at the FEMP site, will provide important information for making such assessments.

Of the alternatives considered for managing the K-65 residues at NFSS, the one adopted as most desirable at the FEMP site was not considered at NFSS. That alternative is treatment of the residues and then shipment of them off-site. Although the situations are different at the two sites, the treat and then ship off-site alternative is worth considering at the NFSS because of the permanent removal of the residues from NFSS achieved thereby, and because the residues can in principle be fixed in a form safe both for shipment and final disposal.

Admittedly, the residue storage situation at the FEMP site is not the same as the situation at NFSS, and may in some respects be simpler for treating the residues than the situation at NFSS. The FEMP residues are still in silos from which they can be recovered by hydraulic mining before treating, whereas the NFSS residues must be exhumed from the storage facility in which they are buried before they can be treated. However, the exhumation operations have been examined in the 1986 FEIS for Alternative 2b. The costs of the treating and shipping operations at the two sites are considered below under Conclusion 7.

5) The present and potential future interactions between the NFSS and disposal sites adjacent to the NFSS, where non-radioactive toxic chemical and landfill wastes are currently disposed, have not been addressed adequately, either in the NFSS final environmental impact statement (FEIS) or in subsequent studies and documentation.

The NFSS is bounded on two sides by major waste disposal facilities, the Chemical Wastes Management (CWM) Chemical Services, Inc., to the north and Modern Landfill, Inc., to the east. Current site plans and ongoing monitoring do not address the present or long-term potential impacts of these sites on the waste storage at NFSS. This is particularly important given the time frame (perpetual care), hydrological uncertainty, and the potential public health impacts of the wastes at these sites. The Committee found no evidence that these sites are impacting the waste at NFSS at the present time. However, there is currently no routine testing done to monitor pollutant migration which may impact the NFSS site, and

little information is available on the current or long-term health risks posed by these neighboring sites.

The CWM site, parts of which have been used for waste disposal since 1942, is currently the subject of a Resource Conservation and Recovery Act (RCRA) corrective action to remediate and confine extensive chemical contamination of the ground water. Off-site migration of these chemical contaminants could impact the waste containment at NFSS. As part of the RCRA corrective action, a site risk assessment will be conducted. The results of the CWM risk assessment and other site investigations may have important implications for the management of the wastes at NFSS.

No information was available to the Committee concerning the long-term plans for closure of the neighboring facilities. The cessation of current pumping activities at these sites will undoubtedly impact area ground water dynamics. In addition, the long-term integrity of waste containment at these sites (300 to 1000 years) is unknown.

The Committee found no analysis of the long-term public health impacts of the neighboring facilities in the regulatory files. Under RCRA, risk assessments are conducted only for a period ending 70 years after facility closure. The scenario that has been analyzed for NFSS - erosion of the cap over hundreds of years followed by construction of a residence on the disposal the site - is equally likely at CWM and Modern Landfill, Inc. Indeed, these facilities have much larger surface areas than NFSS. Because the neighboring facilities contain long-lived toxic materials such as lead, arsenic, and polychlorinated biphenyls, this scenario might well have unacceptable consequences. The Committee notes the possible inconsistency in removing the residues at NFSS without analyzing toxic material behavior in the same scenario. This reflects a social decision that radioactive wastes are to be handled with a longer time horizon than chemical wastes. In the present situation we have not judged whether this differentiation is appropriate.

6) The potential future health hazards posed by non-radiological, toxic materials such as lead and barium that are constituents of the buried high-level residues at NFSS have not been adequately assessed.

The NFSS residues and wastes contain chemical elements and compounds that potentially could contaminate the environment. Selected concentrations of non-radioactive elements in the residues and organic compounds in the wastes are given in Tables B-12 and B-13 (Appendix B). Given the nature of these materials, additional analyses of their behaviors and potential health effects is required. This analysis should be consistent with full recognition of the unpredictability of human behavior over thousands of years into the future.

The K-65 residues contain a high concentration of lead - 56,000 ppm, or almost 6 percent. Environmental monitoring results for this site, particularly ground water tests, do not routinely report lead concentrations. Therefore it is not possible to assess the adequacy of current containment or trace the long-term migration of these contaminants through the

environment. Furthermore, it is by no means certain that the principal exposure pathway for lead would be via ground water. The K-65 residues also contain barium, cobalt, nickel and copper, rare earth elements, palladium, and molybdenum.

Although no organic chemicals are reported in the residues, they may exist in the NFSS wastes. Past activities at the site are reported to have included manufacture of trinitrotoluene, storage of chemical warfare substances and ammunition, boron isotope separation, and research, production, and burning of high energy fuels (Golder Associates, 1993). Limited monitoring suggests the presence of some organic solvents (U.S. Department of Energy Oak Ridge Operations, 1992). More complete analysis is necessary to evaluate potential risks. Periodic chemical analysis of environmental samples for the full range of EPA priority pollutants would be appropriate to evaluate potential chemical risks. This would also identify the presence of compounds, such as organic solvents, which might affect the mobility of the residues.

7) There are substantial uncertainties in the estimates of costs and associated risks for managing the residues at NFSS that have not been fully addressed.

In the 1986 FEIS, installation of the permanent cap with present residues and waste configuration was estimated to cost $4.2 million (Alternative 2a); if all the residues were excavated, treated, solidified, and returned to the WCS, followed by permanent cap installation, the cost was estimated to rise to $14.4 million (Alternative 2b). If, on the other hand, all wastes were retained at the NFSS but all the residues were excavated and shipped to Hanford (Alternative 4a) or to Oak Ridge (Alternative 4c) for storage, the estimated Action Period costs were $27 million and $17 million, respectively - the differences are attributable to transportation and disposal costs. The total volume of the residues being shipped to Hanford or Oak Ridge would be 11,000 m^3.

For all alternatives in the 1986 FEIS involving excavation of residues, the expected number of adverse effects (fatal cancers plus genetic defects) from exposure to radiation range from 0.10 to 0.24. The estimated number of transportation-related deaths and injuries for these alternatives were much higher, ranging from 0.11 to 3.9 deaths and 0.19 to 66 injuries (U.S. Department of Energy, 1986, p. 4-96, Table 4.61).

The Committee reviewed these estimates, along with two more recent estimates involving removal of only the K-65 residues from the NFSS (letter of September 2, 1994, from R.E. Kirk, DOE Oak Ridge National Laboratory, to R.S. Andrews). Both new estimates are based on the excavation and removal of 2,450 m^3 (3,210 yd^3), 82 percent of the 3,000 m^3 (3,925 yd^3) of K-65 residues at NFSS. One of these estimated alternatives treatments involves placing the K-65 residues into steel drums, then into containers, and shipping the filled containers to a facility at Yucca Mountain, NV, at an estimated cost of about $85 million. The second involves treatment of the K-65 residues at the NFSS and subsequent shipment of the processed residues to a National Laboratory for disposal, at a total cost of $30 million. The type of treatment is not specified, nor the form of the treated

material. The L-30, F-32 and L-50 residues would remain at the NFSS. No risk estimates have been provided for these alternatives.

The older cost estimates are not directly comparable to the newer ones. The newer set is preliminary and is presented in terms of 1994 dollars, rather than the 1982 dollars used in the 1986 FEIS. Nevertheless, the $85 and $30 million estimates of K-65 residue removal in this set are substantially higher than the similar estimates of $27 and $17 million given in the 1986 FEIS for removal of all the residues and their disposal at Hanford or Oak Ridge, respectively. Comparable estimates of costs and associated risks to workers and the public for the removal, treatment, and disposal of the K-65 residues at the FEMP site, comprising 6,120 m^3, are not yet available. When such estimates, along with new data and monitoring results, become available, assuming that the wastes are kept on-site at the NFSS and that all the high-level residues are treated and shipped off-site, other, more desirable alternatives for long-term disposal of NFSS residues may have emerged. Further, the Committee sees little technical reason for using different waste management practices for the FEMP residues and the NFSS residues based on "defense" versus "non-defense" designations, respectively.

8) Current site monitoring activities are inadequate for the determination of long-term site integrity and potential future risks to the public and the environment from the movement off site of radioactive and non-radioactive wastes in the NFSS containment structure, as well as the possible influx of waste materials from the disposal sites adjacent to the NFSS.

Of the 43 ground water sampling locations at the NFSS, 13 are located at the perimeter of the Wastes Containment Structure (WCS) and 28 are on-site but outside the WCS. In 1993 and 1994, only 9 locations were sampled for total uranium content and only 11 sampled for ^{226}Ra. Reductions in sampling frequency were based on a lack of previous monitored values above background levels and the expectation that ^{226}Ra would not migrate beyond the perimeter of the WCS until the 5,000- to 10,000-year time frame. No attempt was made to monitor toxic, non-radioactive materials such as lead. Even after the high-level residues have been removed from the site, continued monitoring and maintenance will probably be necessary because of the close proximity of residences and public facilities.

Installation of a permanent cap would result in the loss of the 13 WCS-perimeter sampling locations, resulting in long migration distances for materials moving in the ground water before detection. Moreover, in the 1986 FEIS, DOE has indicated that monitoring efforts would cease after 200 years unless DOE assumes perpetual care of the residues and wastes at the NFSS.

RECOMMENDATIONS

The Committee makes the following recommendations for future actions to be taken by DOE in its continuing efforts to manage the NFSS K-65 residues in a way that best protects the public and environmental health both in the short and long terms, while at the same time providing cost-effective management and disposal of the residues.

1) Following completion of related or similar treatment technology studies such as the FEMP vitrification demonstration and related cost-risk-benefit studies, a program should be developed by DOE for removal, treatment, and disposal off-site of the NFSS high-level residues (i.e., those classified as K-65, L-30/F-32, and L-50 residues). Since there is no immediate hazard to the off-site public from the residues in their present configuration, such studies will help ensure proper handling of the residues when they are removed for disposal, as well as to provide an example for future remediation of other sites containing radioactive residues.

2) After removal of the high-level residues, remaining wastes should be buried under a suitable protective cap.

3) The adequacy of site monitoring and maintenance activities necessary to ensure the safety of the public and the integrity of the NFSS should be assured. An alternative NFSS monitoring strategy should be developed to measure and track the transport of radiological and chemical contaminants from the NFSS waste containment structure, as well as those reaching the NFSS from contiguous waste disposal areas off site, both prior to and following removal of the residues.

The Committee notes that there are a number of organizations and persons concerned with the NFSS disposal activities, including residents and citizen groups, local and state officials and elected representatives, and adjacent business interests. These and other interested persons and groups should be kept informed of and be invited to participate in planning for activities at the NFSS to the maximum extent practicable.

ABBREVIATIONS

Terms	
CWM	Chemical Wastes Management Chemical Services, Inc. (formerly Model Cities Landfill
DOD	Department of Defense
DOE	Department of Energy
EPA	Environmental Protection Agency
FAR	Failure Analysis Report (Bechtel National, Inc., 1994)
FEIS	Final Environmental Impact Statement
FEMP	Fernald Environmental Management Project
FUSRAP	Formerly Utilized Sites Remedial Action Program
K_d	distribution coefficient
LOOW	Lake Ontario Ordnance Works
LTSM	long-term surveillance and maintenance
NAS/NRC	National Academy of Sciences/National Research Council
NEPA	National Environmental Policy Act
NFSS	Niagara Falls Storage Site
NTS	Nevada Test Site
RCRA	Resource Conservation and Recovery Act
ROD	record of decision
UMTRAP	Uranium Mill Tailings Remedial Action Program
VOC	volatile organic compounds
WCS	Waste Containment Structure
WL	working level (unit of measure for documenting exposure to radon decay products -- 1 WL is equal to ~ 200 pCi/l of radon daughters)
40 CFR 191	Title 40, Code of Federal Regulations, Part 191 - Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastess
40 CFR 192	Title 40, Code of Federal Regulations, Part 192 - Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings

Units

Ci (pCi)	curie (picocurie = 10^{-12} curie)
g	gram
l	liter
m, cm, km	meter, centimeter, kilometer
ppm	parts per million
rem	unit of dose equivalent (1 rem = 0.01 sievert)
sec	sec

Radionuclides

^{226}Ra	radium-226
^{222}Rn	radon-222
^{230}Th	thorium-230
^{234}U	uranium-234
^{235}U	uranium-235
^{238}U	uranium-238

REFERENCES CITED

Bechtel National, Inc. 1982 (December). Geologic and Hydrologic Data Compilation for the Niagara Falls Storage Site. Report to Argonne National Lab, Environmental Impact Studies, by Bechtel National, Inc., Oak Ridge, TN.

Bechtel National, Inc. 1984 (June). Geologic Report, Niagara Falls Storage Site, Lewiston, New York. Report DOE/OR/20722-8 (DE84013459), Oak Ridge, TN.

Bechtel National, Inc. 1986a (May). Design Report for the Interim Wastes Containment Facility at the Niagara Falls Storage Site, Lewiston, New York. Report DOE/OR/20722-21 (DE86012601), Oak Ridge, TN.

Bechtel National, Inc. 1986b (October). Addendum to the Design Report for the Interim Wastes Containment Facility at the Niagara Falls Storage Site: Long Term Containment Option, Lewiston, New York. Report DOE/OR/20722-21 ADD.1 Draft, Oak Ridge, TN.

Bechtel National, Inc. 1990 (June). Performance Monitoring Report for the Niagara Falls Storage Site Wastes Containment Structure, Lewiston, New York, July-December 1988 and Calendar Year 1989. Report DOE/OR/20722-270, Oak Ridge, TN.

Bechtel National, Inc. 1991 (April). Well A-42 Investigation Report for the Niagara Falls Storage Site, Lewiston, New York. Surplus Facilities Management Program (SFMP) Contract No. DE-AC05-81OR20722, Oak Ridge, TN.

Bechtel National, Inc. 1994a (December). Failure Analysis Report for the Niagara Falls Storage Site, Lewiston, New York. Bechtel National, Inc., Oak Ridge, TN.

Bechtel National, Inc. 1994b (June). Niagara Falls Storage Site Environmental Surveillance Report for Calendar Year 1993, 1397 Pletcher Road, Lewiston, New York. Report DOE/OR/21949-379, Oak Ridge, TN.

Golder Associates. 1993 (January). RCRA Facility Investigation CWM Model City Facility.

National Research Council. 1992. Report of the Committee on an Assessment of CDC Radiation Studies: Dose Reconstruction for the Fernald Nuclear Facility. National Academy Press, Washington, DC.

Office of the Federal Register National Archives and Records Administration. 1986. Department of Energy, Office of Secretary: Record of decision for remedial actions at the Niagara Falls Storage Site, Lewiston, NY. Federal Register 51(172):31795-31797.

Russell, J. 1994 (June 22). Letter from John Russell, Booz-Allen & Hamilton Inc. to John E. Patterson, U.S. Department of Energy, EM-421, Subject: Contract No. DE-AC01-92EW40006, "Briefing for the National Academy of Science Panel - Alternatives for Management of K-65 Residues at the Niagara Falls Storage Site," June 28-30, 1994.

U.S. Department of Energy. 1986. Final Environmental Impact Statement - Long-Term Management of the Existing Radioactive Wastes and Residues at the Niagara Falls Storage Site. Report DOE/EIS-0109F (DE86008418), Washington, DC.

U.S. Department of Energy Fernald Site Office. 1994 (February). Feasibility Study Report for Operable Unit 4, Fernald Environmental Management Project, Fernald, Ohio. Report DOE/EIS-0195D Final, Fernald, OH.

U.S. Department of Energy Oak Ridge Operations. 1992 (1 July). Site Inspection Report for the Niagara Falls Storage Site, Lewiston, New York. Site Inspection Report transmitted by R.E. Kirk, Former Sites Restoration Division, DOE Oak Ridge Operations, Oak Ridge, TN, to H. Shannon, Region 2 Docket Coordinator, U.S. Environmental Protection Agency, New York, NY., CCN 091195 - 01.

U.S. Department of Energy Office of Environmental Management. 1995 (March). Estimating the Cold War Mortgage: The 1995 Baseline Environmental Management Report. Report DOE/EM-0232, Washington, DC.

APPENDIX A: BIBLIOGRAPHY

Artates, L.M. 1994 (12 May). Environmental Surveillance Data for Niagara Falls Storage Site (NFSS), 1993. Bechtel National Inc. FUSRAP Technical Memorandum No. 158/94-00 02, Oak Ridge, TN.

Bechtel National, Inc. 1982-1986. Geotechnical Post-Construction Report, Niagara Falls Storage Site [Volume 1, July-October 1982; Volume 2, September-November 1983; Volume 3, August- October 1984; Volume 4, June-November 1985; Volume 5, June-November 1986]. Surplus Facilities Management Program (SFMP) Contract No. DE-AC05-81OR20722, Oak Ridge, TN.

Bechtel National, Inc. 1984. Engineering Evaluation of Alternatives for the Disposition of Niagara Falls Storage Site, Its Residues and Wastess. Report DOE/OR/20722-1, Oak Ridge, TN.

Bechtel National, Inc. 1986 (January). Rationale for Selecting a Natural Clay Liner System at the Proposed NFSS and WSS Wastes Management Facilities. Report DOE/OR/20722-48 Revision 1, Oak Ridge, TN.

Bechtel National, Inc. 1986 (April). Environmental Monitoring Plan for the Niagara Falls Storage Site and the Interim Wastes Containment Facility. Report DOE/OR/20722-86, Oak Ridge, TN.

Bechtel National, Inc. 1986 (April). Niagara Falls Storage Site Annual Site Environmental Monitoring Report, Calendar Year 1985. Report DOE/OR/20722-98, Oak Ridge, TN.

Bechtel National, Inc. 1986 (May). Design Report for the Interim Wastes Containment Facility at the Niagara Falls Storage Site, Lewiston, New York. Report DOE/OR/20722-21 (DE86012601), Oak Ridge, TN.

Bechtel National, Inc. 1990 (May). Niagara Falls Storage Site Environmental Report for Calendar Year 1989. Report DOE/OR/20722-264, Oak Ridge, TN.

Bechtel National, Inc. 1991 (August). Niagara Falls Storage Site Annual Environmental Report for Calendar Year 1990, Lewiston, New York. Report DOE/OR/21949-289, Oak Ridge, TN.

Bechtel National, Inc. 1992 (March). Performance Monitoring Report for the Niagara Falls Storage Site Wastes Containment Structure, Lewiston, New York, Calendar Year 1990. Report DOE/OR/21949-303, Oak Ridge, TN.

Bechtel National, Inc. 1992 (July). Performance Monitoring Report for the Niagara Falls Storage Site Wastes Containment Structure, Lewiston, New York, Calendar Year 1991. Report DOE/OR/21949-348, Oak Ridge, TN.

Bechtel National, Inc. 1992 (September). Niagara Falls Storage Site Annual Environmental Report for Calendar Year 1991, Lewiston, New York. Report DOE/OR/21949-343, Oak Ridge, TN.

Bechtel National, Inc. 1993 (May). Niagara Falls Storage Site Environmental Report for Calendar Year 1992, 1397 Pletcher Road, Lewiston, New York. Report DOE/OR/21949-367, Oak Ridge, TN.

Berube, R.P. 1994 (June 10). Memorandum to J.E. Baublitz, Acting Director, Office of Environmental Restoration, Department of Energy -- Subject: Acceptance of 40 CFR 191 as an ARAR at Fernald. Deputy Assistant Secretary for Environment, Department of Energy, Washington, DC.

Boeck, W.L. 1994 (April 20). Letter to J.L. LaFalce, Congressman, U.S. House of Representatives. Lewiston, NY.

Campbell, L.F., and G. D. Coxon. 1985. The Niagara Falls Storage Site Remedial Action Project. Bechtel National, Inc., presentation at the American Nuclear Society Annual Meeting, June 11, 1985, Boston, Massachusetts.

Crotwell, G.P. 1993 (June 16). Letter to U.S. Department of Energy, Oak Ridge Operations Office, Attention: William M. Seay -- Subject: Niagara Falls Storage Site - Changes to the Environmental Monitoring Plan. Bechtel National, Inc., Oak Ridge, TN.

Daggett, C.J. 1986 (June 25). Letter to J. LaGrone, Manager, Oak Ridge Operations, Department of Energy. Regional Administrator, U.S. Environmental Protection Agency Region II, New York, NY.

Environmental Protection Agency. 1982 (October). Final Environmental Impact Statement for Remedial Action Standards for Inactive Uranium Processing Sites (40 CFR 192), Volume I. Washington, DC.

Giardina, P.A. 1990 (November 5). Letter to R. Hargrove, Chief, Environmental Impacts Branch, U.S. Environmental Protection Agency Region II. Radiation Branch Manager, U.S. Environmental Protection Agency Region II, New York, NY.

Gilbert, T.L., C. Yu, Y.C. Yuan, A.J. Zielen, M.J. Jusko, and A. Wallo, III. 1989 (June). A Manual for Implementing Residual Radioactive Material Guidelines. A Supplement to U.S. Department of Energy Guidelines for Residual Radioactive Material and Formerly Utilized Sites Remedial Action Program and Surplus Facilities Management Program Sites. Argonne National Laboratory Report ANL/ES-160, DOE/CH/8901, Argonne, IL.

Grumbly, T.P. 1994 (June 20). Letter to J.C. Merino, Councilman, Town of Lewiston, NY. Assistant Secretary for Environmental Management, U.S. Department of Energy, Washington, DC.

Grumbly, T.P. 1994 (June 23). Letter to J.J. LaFalace, U.S. House of Representatives. Assistant Secretary for Environmental Restoration, U.S. Department of Energy, Washington, DC.

Hargrove, R.W. 1994 (April 29). Letter to R.S. Andrews, Staff Officer, National Research Council. Chief, Environmental Impacts Branch, U.S. Environmental Protection Agency Region II, New York, NY.

Hargrove, R.W. 1994 (June 17). Letter to R.J. Catlin, Executive Director, Clinical and Laboratory Safety Department, The University of Texas. Chief, Environmental Impacts Branch, U.S. Environmental Protection Agency Region II, New York, NY.

Hargrove, R.W. 1987 (May 1). Letter to G.P. Turi, Division of Facility and Site Decommissioning Projects, Office of Nuclear Energy, U.S. Department of Energy. Federal Facilities Coordinator, Environmental Impacts Branch, U.S. Environmental Protection Agency, New York, NY.

Jones, M.G., C.R. Johnson, and J.A. Blanke. 1987 (July). Performance Monitoring Report for the Niagara Falls Storage Site Wastes Containment Structure, Lewiston, New York, Calendar Year 1986. Bechtel National, Inc., report DOE/OR/20722-159, Oak Ridge, TN.

Jorling, T.C. 1994. Letter to H. O'Leary, Secretary, U.S. Department of Energy. Commissioner, State of New York Department of Environmental Conservation, Albany, NY.

LaFalce, J.J. 1994 (May 19). Letter to R.J. Budnitz, Chairman, Committee on Remediation of Buried and Tank Wastes, National Academy of Sciences. Congress of the United States House of Representatives, Washington, DC.

LaFalce, J.J. 1994 (May 19). Letter to T.P. Grumbly, Assistant Secretary for Environmental Management, Department of Energy. Congress of the United States House of Representatives, Washington, DC.

Lide, D.R. [Editor-in-Chief]. 1990. CRC Handbook of Chemistry and Physics. 71st edition, CRC Press, Boca Raton.

Matuszek, J.M. 1984 (July 17). Letter to Axelrod -- Subject: U.S. Department of Energy Plans for Disposition of Radioactive Wastes at the Niagara Falls Storage Site (NFSS). Radiological Sciences Laboratory, NY Department of Health, Albany, NY.

Muszynski, W.J. 1993 (June 24). Letter to P.D. Grimm, Acting Assistant Secretary, Environmental Restoration and Wastes Management, Department of Energy. Acting Regional Administrator, Environmental Protection Agency Regional Office II, New York, NY.

Muszynski, W.J. 1992 (May 12). Letter to L. Price, Director, Former Sites Restoration Division, U.S. Department of Energy. Acting Regional Administrator, Environmental Protection Agency Regional Office II, New York, NY.

National Research Council. 1986. Scientific Basis for Risk Assessment and Management of Uranium Mill Tailings. National Academy Press, Washington, DC.

Nosenchuck, N.H. 1994 (April 28). Letter to R.S. Andrews, Senior Staff Officer, Board on Radioactive Wastes Management, National Research Council. Director, Division of Hazardous Substances Regulation, New York State Department of Environmental Conservation, Albany, NY.

Nuttall, H.E., and R.L. Long. 1993. Mobility of Radioactive Colloidal Particles in Groundwater, pp 237-251 in Radioactive Wastes Management and the Nuclear Fuel Cycle, Vol. 17(3-4).

Pastalove, B. 1985 (May 24). Letter to J.E. Baublitz, Director, Division of Remedial Action Project, Office of Nuclear Energy, Department of Energy. Chief, Environmental Impacts Branch, Environmental Protection Agency Regional Office II, New York, NY.

U.S. Department of Energy Fernald Site Office. 1994 (February). Proposed Plan for Remedial Actions at Operable Unit 4, DOE/EIS-0195D. Fernald Environmental Management Project final report, Fernald, OH.

Walka, R.M. 1984 (October 23). Letter to L.F. Campbell, Deputy Director, Technical Services Division, Department of Energy. Chief, Environmental Impacts Branch, U.S. Environmental Protection Agency Region II, New York, NY.

APPENDIX B: REFERENCE TABLES

TABLE B-1. Estimated Occupational Injuries and Deaths for the Alternatives (U.S. Department of Energy, 1986, Table 2.2, pp 2-4 and 2-5)

Alternative	Transportation		Other	
	Injuries	Deaths	Injuries	Deaths
1	None	None	0.13	0.0015
2a	0.19	0.11	12	0.0064
2b	0.19	0.11	24	0.012
3a	66	3.9	100	0.044
3b	22	1.4	100	0.042
4a	6.9	0.44	36	0.018
4b	22	1.3	85	0.038
4c	2.5	0.15	42	0.018
4d	17	1.0	91	0.040

TABLE B-2. Estimated Additional Radiological Health Effects for Alternatives (U.S. Department of Energy, 1986 - Sect. 4.1.4, Tables 4,24,4.3 and 4.5, and Paragraphs 4.1.1.2 and 4.1.2.3)

Alternative	Type of Management/ Disposal Action	Estimated Adverse Radiological Health Effects from Doses Incurred During				
		General Public			Workers	Resident Intruder [1]
		Action Period (~ 10 yr) (total)	Monit. & Maint. Period (10-200 yr) (total)	Year 1000 (per million persons/yr)	Action Period (~ 10 yr) (total)	(after 200 yr or loss of controls)
1	No Action	<0.0000005	<0.0000005	0.00021	0.0013	1 (per intruder)
2a	Long-Term Mgt. - Modified Containment	<0.0000005	<0.0000005	<0.0000005	0.0051	1 (per intruder)
2b	Long-Term Mgt. - Modified Containment and Form	0.017	<0.0000005	<0.0000005	0.10	(not estimated)
3a	Long-Term Mgt. At Arid Site	0.090	0.0039	0.00074	0.24	(not estimated)
3b	Long-Term Mgt. At A Humid Site	0.066	<0.0000005	<0.0000005	0.15	(not estimated)
4a	Storage of Residues and Long-Term Mgt. of Wastes	0.054	0.036	0.0061	0.18	(not estimated)
4b	Storage of Residues and Ocean Disposal of Wastes	0.30	0.036	0.0061	0.20	(not estimated)
4c	Storage of Residues and Long-Term Mgt. of Wastes	0.040	<0.0000005	<0.0000005	0.12	(not estimated)
4d	Storage of Residues and Ocean Disposal of Wastes	0.28	<0.0000005	<0.0000005	0.13	(not estimated)

[1] Death to resident intruder within a few years from large dose to bronchial epithelium from inhalation of short-lived radon-222 decay products

TABLE B-3. Estimated Adverse Radiological Health Effects and Doses to Intruder's Bronchial Epithelium or Lungs for Alternatives (U.S. Department of Energy, 1986 - Sect. 4, Paragraphs 4.1.1.2 and 4.1.2.3., and Table 4.24; Bechtel National, Inc., 1994a - Sect. 6.0)

Alternative	Type of Management/ Disposal Action	Disposal Site and Type of Disposed Wastes	Resident-Intruder Impacts[1]			Intruder - Exploratory Drilling[3]
			Working Level (WL)	Bronchial Epithelium Dose[2] (rem/yr)	Fatal Cancer[2] (per intruder)	External Dose (rem per 48-h drill period)
1	No Action	NFSS - residues	110	8,000	1	(not est.)
2a	Long-Term Mgt. - Modified Containment	NFSS - residues	110	8,000	1	0.507
2b	Long-Term Mgt. - Modified Containment and Form	NFSS - modified residues	11	800	(not est.)	(not est.)
3a	Long-Term Mgt. At Arid Site	Hanford - wastes and residues	5.2	400	(not est.)	(not est.)
3b	Long-Term Mgt. At A Humid Site	Oak Ridge - wastes and residues	6.4	480	(not est.)	(not est.)
4a	Storage of Residues and Long-Term Mgt. of Wastes	Hanford - residues	21	1,600	(not est.)	(not est.)
		NFSS- wastes	0.058	4.30	(not est.)	(not est.)
4b	Storage of Residues and Ocean Disposal of Wastes	Hanford - residues	21	1,600	(not est.)	(not est.)
		Ocean Site 106 wastes	-	-	(not applicable)	(not applicable)
4c	Storage of Residues and Long-Term Mgt. of Wastes	Oak Ridge - residues	29	2,200	(not est.)	(not est.)
		NFSS - wastes	0.058	4.30	(not est.)	(not est.)
4d	Storage of Residues and Ocean Disposal of Wastes	Oak Ridge - residues	29	2,200	(not est.)	(not est.)
		Ocean Site 106 wastes	-	-	(not applicable)	(not applicable)

[1] Loss of site controls projected at 200 years or later (up to 1,000 years or more)

[2] Death of resident intruder within a few years from large dose to bronchial epithelium from inhalation of short-lived radon-222 decay products

[3] Loss of site controls projected at 100 years.

TABLE B-4. Areas Covered by NFSS Residues and Wastes for Alternatives (U.S. Department of Energy, 1986 - Table 4.16)

Alternative	Type of Management/ Disposal Action	Disposal Site	Type of Disposed Wastes	Area Covered by Residues & Wastes	
				m^2	acres
1	No Action	NFSS	K-65 residues & overlying wastes	1,700	0.4
			L-30/F-32 residues and overlying wastes	1,700	0.4
			Wastes only	29,000	7.2
			Total	**32,000**	**8.0**
2a	Long-Term Mgt. - Modified Containment	NFSS	K-65 residues & overlying wastes	1,700	0.4
			L-30/F-32 residues and overlying wastes	1,700	0.4
			Wastes only	29,000	7.2
			Total	**32,000**	**8.0**
2b	Long-Term Mgt. - Modified Containment and Form	NFSS	K-65 residues & overlying wastes	1,700	0.4
			L-30/F-32 residues and overlying wastes	1,700	0.4
			Wastes only	29,000	7.2
			Total	**32,000**	**8.0**
3a	Long-Term Mgt. At Arid Site	Hanford	Residues and overlying wastes	14,000	3.4
			Wastes only	81,000	20
			Total	**95,000**	**23.0**
3b	Long-Term Mgt. At A Humid Site	Oak Ridge	Residues and overlying wastes	14,000	3.4
			Wastes only	62,000	15
			Total	**76,000**	**18**
4a	Storage of Residues and Long-Term Mgt. of Wastes	Hanford	Residues	14,000	3.4
		NFSS	Wastes only	32,000	8.0
4b	Storage of Residues and Ocean Disposal of Wastes	Hanford	Residues	14,000	3.4
		Ocean Site 106	Wastes only	-	-
4c	Storage of Residues and Long-Term Mgt. of Wastes	Oak Ridge	Residues	14,000	3.4
		NFSS	Wastes only	32,000	8.0
4d	Storage of Residues and Ocean Disposal of Wastes	Oak Ridge	Residues	14,000	3.4
		Ocean Site 106	Wastes only	-	-

TABLE B-5. Design Requirements for the NFSS Waste Containment Structure (Bechtel National, Inc., 1994a - Table 4.1)

Description	Existing Cap	Long Term Cap	Dike and Cutoff Walls	Bottom	Remarks
1. Design Service Life	25-50 years	200-1000 years	200-1000 years	200-1000 years	
2. Safety Factor: Cutoff Walls **Slope Stability** **Static conditions** **Earthquake**	 1.5 1.0	 1.5 1.0	 -- --	 -- --	
3. Surface Drainage Slope **Top Surface** **Side Slopes**	 5-10% Max. 3H to IV	 5-10% Max. 3H to IV	 -- --	 -- --	
4. Surface Erosion Protection	Shallow-rooted grass	Shallow-rooted grass Riprap to elevation 98.4 m (323 ft)	--	--	
5. Intrusion Barrier Required	No	YES	--	--	
6. Frost Penetration	48 in.	48 in.	--	--	Assume bare ground
7. Radon Barrier Required	YES (20 $pCi/m^2/s$)	Yes (20 $pCi/m^2/s$)	--	--	
8. Radiation Barrier Required	YES (100 mrem/yr)	YES (100 mrem/yr)	--	--	
9. Component Construction	Topsoil/clay	Topsoil/rock layer/clay	Clay	Natural clay strata	
10. Clay Permeability	10^{-7} cm/s	10^{-7} cm/s	Approx 10^{-7} cm/s	Approx 10^{-7} cm/s	
11. Clay Adsorption Coefficient **Natural Uranium** **Radium-226**	5 ml/g 500 ml/g	5 ml/g 500 ml/g	5 ml/g 500 ml/g	5 ml/g 500 ml/g	

12. Inspection and Maintenance Required	Yes (design life)	Yes	No	No	
13. Earthquake Pseudostatic Coefficient	0.1g	0.15g	0.15g	--	
14. DOE Concentration Guide for Radionuclide Migration (groundwater concentration, uncontrolled areas) **Natural Uranium** **Radium-226, -228**	-- --	-- --	 600 pCi/1 30 pCi/1	 600 pCi/1 30 pCi/1	
15. Temperature Extremes	-29° to 34°C -20° to 94°C	-29° to 34°C -20° to 94°C	-29° to 34°C -20° to 94°C	--	
16. Rainfall per Year	74 cm (29 in.)	74 cm (29 in.)	--	--	
17. Wind Speed and Direction	(80 mph) southwest	(80 mph) southwest	--	--	
18. Anual Deep-Infiltration Rate	2.54 cm (1.0 in.)	2.54 cm (1.0 in.)	--	--	
19. Design Flood Plain Elevation	Elevation 96.6 m Flood (PMF) 98.4 m (373 ft)	Probable Maximum Flood (PMF) 98.4 m (373 ft)	Probable Maximum Flood (PMF) 98.4 m (323 ft)		
20. Groundwater Elevation (high)	--	--	--	Elevation 96 m (315 ft) m.s.1. (Exclusive of PMF)	
21. Snowfall Per Year	2.4 m (93 in.)	2.4 m (93 in.)	--	--	
22. Internal Cap Drainage Layer	None	Yes	--	--	
23. Waste Containment Consolidation	Minimize settlement (95% compaction)	Minimize settlement (95% compaction	95% compaction	--	
24. Shrinkage, Swelling, and Frost Action Requirements	Yes (3 to 5% in volume expansion)	Yes (3 to 5% in volume expansion	Yes (3 to 5% in volume expansion)	No	

25. Migration Limits	Not to exceed EPA primary drinking water standards in off-site groundwater	Not to exceed EPA primary drinking water standards in off-site groundwater	Not to exceed EPA primary drinking water standards in off-site groundwater	Not to exceed EPA primary drinking water standards in off-site groundwater	
26. Buffer Zone (measure from lateral limit of waste)	30.5 m (100 ft)	30.5 m (100 ft)	--	--	
27. Groundwater Hydraulic Gradient (saturated zone)	--	--	--	0.0015	

TABLE B-6. Monitoring Networks for Radioactive Materials at NFSS for Period 1985-1994 (Not Inclusive) (Bechtel National, Inc., 1994a)

Parameter	Number of Sampling Locations					Locations Not Sampled 1993-94	
	On Site Within WCS	On Site at WCS Perimeter	On Site Outside WCS	Off NFSS Site	Total Locations	Number	%
Radon in Air	?	0	3	14	17	0	0
External Gamma Exposure Rate	?	0	3	14	17	0	0
Total U & Ra-226							
- Surface Water	?	0	3	2	5	0	0
- Sediment	?	0	3	2	5	0	0
Total U in Groundwater							
- Upper Groundwater	1	8	15	0	24	17	71
- Lower Groundwater	0	5	13	1	19	17	89
- TOTAL	**1**	**13**	**28**	**1**	**43**	**34**	**79**
Ra-226 in Groundwater							
- Upper Groundwater	1	8	15	0	24	15	63
- Lower Groundwater	0	5	13	1	19	17	89
- TOTAL	**1**	**13**	**28**	**1**	**43**	**32**	**74**

TABLE B-7. Distribution of Radium-226 and Thorium-230 in the NFSS Waste Containment Structure (Bechtel National, Inc., 1994a - Table 3-1; U.S. Department of Energy, 1986 - Table 3.4)

Description	Volume			Ra-226			Th-230		
	m³ (yd³)	% of Total Vol.	Cumul. % of Total	Inventory (Ci)	% of Total Ci	Cumul. % of Total	Inventory (Ci)	% of Total Ci	Cumul. % of Total
K-65 residues	3,000 (3,925)	1.6	1.6	1,881	94.9	94.9	195	65.8	65.8
L-30 residues combined with	6,000 (7,850)	3.1	4.7	87	4.4	99.3	87	29.4	95.2
F-32 residues	500 (655)	0.3	5.8	0.2	0.0	99.6	0.2	0.1	97.3
L-50 residues	1,500 (1,960)	0.8	5.5	6	0.3	99.6	6	2.0	97.2
Contam. wastes R-10 residues and soil	45,000 (58,860)	23.6	29.4	5	0.25	99.85	5	1.7	99.0
Remaining Contaminated soils	134,500 (175,925)	70.6	100.0	3	0.15	100.0	3	1.0	100.0
TOTAL	**190,500 (249,175)**	**100.0**	-	**1,982.2**	**100.0**	-	**296.2**	**100.0**	-

TABLE B-8. Inventories of Radium-226 in the Waste Containment Structure Over the next 10,000 Years (Bechtel National, Inc., 1994a, Table 3-3)

Time (years)	Waste Material (Ci)	R-10 Residues and Soil (Ci)	L-50 Residues (Ci)	F-32 Residues (Ci)	L-30 Residues (Ci)	K-65 Residues (Ci)	Totals for WCS (Ci)
0	3	5	6	0.2	87	1881	1982.2
100	3.00	5.00	5.99	0.20	86.92	1809.45	1910.56
200	2.99	4.99	5.99	0.20	86.85	1740.92	1841.94
300	2.99	4.99	5.98	0.20	86.77	1675.29	1776.22
400	2.99	4.98	5.98	0.20	86.70	1612.43	1713.28
500	2.99	4.98	5.97	0.20	86.62	1552.23	1652.99
600	2.98	4.97	5.97	0.20	86.55	1494.56	1595.23
700	2.98	4.97	5.96	0.20	86.47	1439.33	1539.91
800	2.98	4.97	5.96	0.20	86.40	1386.43	1486.94
900	2.98	4.96	5.95	0.20	86.32	1335.77	1436.18
1,000	2.97	4.96	5.95	0.20	86.25	1287.24	1387.57
2,000	2.95	4.91	5.90	0.20	85.51	901.42	1000.89
3,000	2.92	4.87	5.85	0.19	84.77	650.52	749.12
4,000	2.90	4.83	5.80	0.19	84.04	487.16	584.92
5,000	2.87	4.79	5.75	0.19	83.31	380.61	477.52
6,000	2.85	4.75	5.70	0.19	82.59	310.91	406.99
7,000	2.82	4.71	5.65	0.19	81.88	265.14	360.39
8,000	2.80	4.67	5.60	0.19	81.18	234.90	329.34
9,000	2.77	4.62	5.55	0.18	80.47	214.73	308.32
10,000	2.75	4.59	5.50	0.18	79.78	201.11	293.91

TABLE B-9. Inventories of Thorium-230 in the Waste Containment Structure Over the next 10,000 Years (Bechtel National, Inc., 1994a, Table 3-4)

Time (years)	Waste Material (Ci)	R-10 Residues and Soil (Ci)	L-50 Residues (Ci)	F-32 Residues (Ci)	L-30 Residues (Ci)	K-65 Residues (Ci)	Totals for WCS (Ci)
0	3	5	6	0.2	87	195	296.2
100	3.00	5.00	5.99	0.20	86.92	194.83	295.94
200	2.99	4.99	5.99	0.20	86.85	194.66	295.68
300	2.99	4.99	5.98	0.20	86.77	194.49	295.42
400	2.99	4.98	5.98	0.20	86.70	194.33	295.18
500	2.99	4.98	5.97	0.20	86.62	194.16	294.92
600	2.98	4.97	5.97	0.20	86.55	193.99	294.66
700	2.98	4.97	5.96	0.20	86.47	193.82	294.40
800	2.98	4.97	5.96	0.20	86.40	193.65	294.16
900	2.98	4.96	5.95	0.20	86.32	193.49	293.90
1,000	2.97	4.96	5.95	0.20	86.25	193.32	293.65
2,000	2.95	4.91	5.90	0.20	85.51	191.65	291.12
3,000	2.92	4.87	5.85	0.19	84.77	190.00	288.60
4,000	2.90	4.83	5.80	0.19	84.04	188.36	286.12
5,000	2.87	4.79	5.75	0.19	83.31	186.73	283.64
6,000	2.85	4.75	5.70	0.19	82.59	185.12	281.20
7,000	2.82	4.71	5.65	0.19	81.88	183.53	278.78
8,000	2.80	4.67	5.60	0.19	81.18	181.94	276.38
9,000	2.77	4.62	5.55	0.18	80.47	180.37	273.96
10,000	2.75	4.59	5.50	0.18	79.78	178.82	271.62

TABLE B-10. Inventories of Radium-226 in the Waste Containment Structure Over the next 10,000 Years After Selected Residue Removals in Year 1 (after Bechtel National, Inc., 1994a, Tables 3-1 and 3-3)

Time (years)	Total Ra-226 Inventory in Residues & Wastes WCS (Ci)	Inventories of Remaining Ra-226 After Removals			
		K-65 Residues Removed (Ci)	K-65, L-30 & F-32 Residues Removed (Ci)	K-65, L-30, F-32 & L-50 Residues Removed (Ci)	All Residues Removed (Ci)
0	1982.2	101.2	14.0	8	3
100	1910.56	101.11	13.99	8.00	3.00
200	1841.94	101.02	13.97	7.98	2.99
300	1776.22	100.93	13.96	7.98	2.99
400	1713.28	100.85	13.95	7.97	2.99
500	1652.99	100.76	13.94	7.97	2.99
600	1595.23	100.67	13.92	7.95	2.98
700	1539.91	100.58	13.91	7.95	2.98
800	1486.94	100.51	13.91	7.95	2.98
900	1436.18	100.41	13.89	7.94	2.98
1,000	1387.57	100.33	13.88	7.93	2.97
2,000	1000.89	99.47	13.76	7.86	2.95
3,000	749.12	98.60	13.64	7.79	2.92
4,000	584.92	97.76	13.53	7.73	2.90
5,000	477.52	96.91	13.41	7.66	2.87
6,000	406.99	96.08	13.3	7.6	2.85
7,000	360.39	95.25	13.18	7.53	2.82
8,000	329.34	94.44	13.07	7.47	2.80
9,000	308.32	93.59	12.94	7.39	2.77
10,000	293.91	92.80	12.84	7.34	2.75
Removal Volume - m^3 (yd^3)	-	*3,000 (3,925)*	*9,000 (11,775)*	*11,000 (14,390)*	*56,000 (73,250)*

TABLE B-11. Inventories of Thorium-230 in the Waste Containment Structure Over the next 10,000 Years After Selected Residue Removals in Year 1 (after Bechtel National, Inc., 1994a, Tables 3-1 and 3-4)

Time (years)	Total Th-230 Inventory in Residues & Wastes WCS (Ci)	Inventories of Remaining Th-230 After Removals			
		K-65 Residues Removed (Ci)	K-65, L-30 & F-32 Residues Removed (Ci)	K-65, L-30, F-32 & L-50 Residues Removed (Ci)	All Residues Removed (Ci)
0	296.2	101.2	14.0	8	3
100	295.94	101.11	13.99	8.00	3.00
200	295.68	101.02	13.97	7.98	2.99
300	295.42	100.93	13.96	7.98	2.99
400	295.18	100.85	13.95	7.97	2.99
500	294.92	100.76	13.94	7.97	2.99
600	294.66	100.67	13.92	7.95	2.98
700	294.40	100.58	13.91	7.95	2.98
800	294.16	100.51	13.91	7.95	2.98
900	293.90	100.41	13.89	7.94	2.98
1,000	293.65	100.33	13.88	7.93	2.97
2,000	291.12	99.47	13.76	7.86	2.95
3,000	288.60	98.60	13.64	7.79	2.92
4,000	286.12	97.76	13.53	7.73	2.90
5,000	283.64	96.91	13.41	7.66	2.87
6,000	281.20	96.08	13.30	7.60	2.85
7,000	278.78	95.25	13.18	7.53	2.82
8,000	276.38	94.44	13.07	7.47	2.80
9,000	273.96	93.59	12.94	7.39	2.77
10,000	271.62	92.80	12.84	7.34	2.75
Removal Volume -m^3 (yd^3)	-	*3,000 (3,925)*	*9,000 (11,775)*	*11,000 (14,390)*	*56,000 (73,250)*

TABLE B-12. NON-RADIOACTIVE ELEMENT

Selected Non-Radioactive Elements in Residues				
Average Concentration, ppm				
Element	K-65	L-30	L-50	Acceptable Limit in Ground water, mg/L*
Barium	30,000	6,100	20,000	1.0
Boron	300	140	100	
Cerium	2,000	1,200	240	
Chromium +6	100	244	140	0.05
Cobalt	2,000	5,100	7,700	
Copper	500	2,300	2,400	1.0
Iron	5,000	26,000	20,000	0.3
Lanthanum	2,000	1,000	220	
Lead	56,000	13,000	4,900	0.025
Manganese	100	31,000	71,000	0.3
Molybdenum	10,000	860	300	
Neodymium	1,000	160	100	
Nickel	3,000	17,000	24,000	
Palladium	20	3.5	2.4	
Praseodymium	2,000	55	24	
Strontium	500	240	240	
(Uranium)	(3,800)	(5,000)	(790)	
Vanadium	2,000	2,400	2,400	
Zirconium	300	100	71	

Source: U.S. Department of Energy, 1986, Table 3.7.

* New York Department of Environmental Conservation Groundwater Quality Standards, Title 6, Part 703.

TABLE B-13. Organic Compounds (U.S. Department of Energy, 1986)

Estimated Concentration, ppb*		
Compound	Wastes	Acceptable Limit in Ground Water, ppb**
Polychlorobiphenols (PCBs)	<26	0.1
Lindane, etc.	<10	Not detectable
Toxaphene	<13	Not Detectable
Heptachlor	<10	Not Detectable
Chlordane	<10	0.1
Dieldrin	<10	Not Detectable
Phenol	<10	1
Benzo(a)pyrene	<10	Not Detectable

* Note: The symbol "<" indicates that some of the sample concentrations were reported as upper limits.

** New York Department of Environmental Conservation Groundwater Quality Standards, Title 6, Part 703, 9/1/78.