Complex Cleanup: The Environmental Legacy of Nuclear Weapons Production

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COMPLEX CLEANUP

The Environmental Legacy of Nuclear Weapons Production

CONGRESS OF THE UNITED STATES
OFFICE OF TECHNOLOGY ASSESSMENT

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Foreword

Until recently, Federal regulations to control pollution and cleanup toxic wastes have been mainly focused on private industry. It is now clear that the Federal Government itself ranks high among the contributors to environmental contamination, from decades of inadequate attention to safe storage and management of toxic waste products. The environmental problems at the Department of Energy nuclear weapons facilities are among the most serious and costly to correct. Widespread contamination of soil and water, leaks from old waste burial grounds, and possible public health impacts from radioactive and hazardous releases have all contributed to congressional concerns about this problem and to a national search for feasible solutions.

The Senate Committee on Armed Services asked OTA to evaluate what is known about the contamination and public health problems at the Nuclear Weapons Complex and to investigate technological and other approaches to solutions. This report analyzes current and proposed methods of waste management and environmental restoration and evaluates the major DOE programs. It also discusses the prospects for improvement and describes certain initiatives that could enhance those prospects.

Because the characterization of the Weapons Complex waste and contamination problem is still in the early stages, it is not possible to identify and rank specific sites that represent the most serious or immediate risks. The data are not available, and even DOE has not been able to prepare a comprehensive and credible evaluation of the situation. The focus of this OTA report is therefore a comprehensive look at the problem as we now know it, the public concerns about the problem, and DOE's plans for addressing it. It focuses especially on the need for additional attention to those areas which DOE has neither the capability nor the credibility to handle. The environmental problems at the DOE Weapons Complex are serious and complicated. Decades will be required for cleanup of certain sites while others will never be returned to pristine condition. Some sites will require much long-term monitoring and control of contaminated soil and water.

Substantial assistance was received from many organizations and individuals during the course of this study. OTA sincerely appreciates the guidance received from our advisory panel, workshop participants, numerous reviewers, contributors, consultants, and contractors. We also received help in a variety of ways from the Department of Energy and its contractors during site visits and other meetings. They responded to numerous requests for data and reviewed draft documents. We also received data, comments, and other help from the Environmenta1 Protection Agency. Without this cooperation and expert advice, OTA would not have been able to accomplish this study.

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"Man is here only for a limited time, and he borrows the natural resources of water, land and air from his children who carry on his cultural heritage to the end of time. Indian people and non-Indians must have a responsibility to these resources for generations yet unborn. One must hand over the stewardship of his natural resources to the future generations in the same condition, if not as close to the one that existed when his generation was entrusted to be the caretaker. This is the challenge of highest order this nation faces today."[1]

INTRODUCTION

During World World II the Nation's scientific elite collaborated with the military to produce the first atomic bomb---a weapon of unprecedented destructive power that later became the key element of U.S. defense strategy. The development of nuclear weapons during and after the war required an enormous dedication of talent and resources, and was the focus of prodigious technical and scientific efforts. For decades the Nation's attention was directed toward producing such weapons to provide what military planners believed to be the necessary deterrent force to avoid a superpower war. The Department of Energy and its predecessor, the Atomic Energy Commission, diligently produced tens of thousands of warheads over the past five decades.

The success of this production system, however, came at a price that few who promoted this enterprise could have anticipated. Today, it is evident that the vast network of weapons facilities, located on thousands of square miles of Federal reservations in 13 States, has produced widespread contamination of the environment with toxic chemicals and radionuclides. Serious questions have been raised about the potential human health threats posed by such contamination.

Niels Bohr, a Nobel laureate and one of century's greatest physicists, maintained in 1 that an atom bomb could not be built witl ''turning the country into a gigantic factory.'' A years later, as Bohr was being shown around secret sites of the Manhattan Project, Edward Te wrote, ''. . .when Bohr came to Los Alamos, I prepared to say, 'You see. . .' But before I co open my mouth, he said, 'You see, I told yo couldn't be done without turning the whole cou into a factory. You have done just that.' ''[2]

It is difficult to appreciate the scale of what is now known as the Nuclear Weapons Complex unless one has actually viewed the vast, tumbleweed-tossed plains of the Hanford Reservation; seen the tank farm at Savannah River where more than 50 underground tanks-each as big as the Capitol dome-house the high-level radioactive waste that inevitably results from plutonium production; 01 visited the area of east Tennessee, known as Site X during World War II, where the equivalent of the annual timber output of Minnesota was used to build what was then the largest roofed structure in the world. It is difficult, without seeing them, to imagine the huge concrete rooms known as "canyons" in which weapon-grade plutonium is chemically separated from other constituents in irradiated fue elements behind thick protective walls, where the radioactivity is so intense that all work must be done by robotic manipulators.

The Nuclear Weapons Complex is an industria empire-a collection of enormous factories devotee to metal fabrication, chemical separation processes, and electronic assembly. Like most industrial opera tions, these factories have generated waste, much o it toxic. The past 45 years of nuclear weapons production have resulted in the release of vas quantities of hazardous chemicals and radionuclides to the environment. There is evidence that air groundwater, surface water, sediments, and soil, as well as vegetation and wildlife, have been contaminated at most, if not all, of the Department of Energy (DOE) nuclear weapons sites.

Although the Weapons Complex was developed in World War II as part of the Manhattan Project, major expansion occurred in the early 1950s. Today most of the operating facilities are more than 30 years old. Operations are in various stages o transition because of safety and environment

[1]Delano Saluskin, Yakima Indian Nation, whose tribal lands are adjacent to the Hanford Reservation.

[2]R. Rhodes, *The Making of the Atomic Bomb* (New York, NY: Simon & Schuster, 1986), p. 500.

problems that have diverted attention from the production mission and because of uncertainty about the future of the entire enterprise.

Contamination of soil, sediments, surface water, and groundwater throughout the Nuclear Weapons Complex is extensive. At every facility the groundwater is contaminated with radionuclides or hazardous chemicals. Most sites in nonarid locations also have surface water contamination. Millions of cubic meters of radioactive and hazardous wastes have been buried throughout the complex, and there are few adequate records of burial site locations and contents. Contaminated soils and sediments of all categories are estimated to total billions of cubic meters.

Descriptions of vast quantities of old buried waste; of contaminants in pits, ponds, and lagoons; and of the migration of contamination into water supplies serve to dramatize the problem. However, so far very little quantitative characterization of each site has been accomplished.

Many factors have contributed to the current waste and contamination problems at the weapons sites: the nature of manufacturing processes, which are inherently waste producing; a long history of emphasizing the urgency of weapons production in the interest of national security, to the neglect of environmental considerations; a lack of knowledge about, or attention to, the consequences of environmental contamination; and an enterprise that has operated in secrecy for decades, without any independent oversight or meaningful public scrutiny.

Public concern about these problems has now reached major proportions, and current environmental laws have forced the direction of attention and resources toward the goals of environmental restoration and safe waste management. No one fully understands the public health and environmental effects of the waste and contamination at the weapons plants, but the consensus is that they are serious enough to devote tens of billions of dollars to cleanup efforts. Even the meaning of cleanup is not fully understood, but it is generally agreed that little has really begun and several decades will be required for an acceptable level of restoration to be reached. In addition, the extent of contamination has not been fully documented, and future investigations are expected to uncover additional problems. Finally, although no consensus has been reached on how or where to dispose of it, most of the waste generated in the past and much of the waste generated in the future is clearly destined to remain at the site of generation—for decades to come.

THE ENVIRONMENTAL PROBLEM

Even though nuclear weapons production entails unique processes such as plutonium recovery, and has thus created radioactive waste and contamination not found in any other setting, many more common environmental problems are also present at the weapons sites. These problems are similar to those found at non-Federal industrial sites and manufacturing plants that have released toxic waste. Thus, DOE is not alone in its struggle to deal with hazardous waste and environmental contamination. Private industry has been trying to cope with the same type of problems that DOE faces today ever since the enactment of hazardous waste legislation in the 1970s and 1980s. The national program to clean up hazardous waste sites, known as Superfund, has not provided a road map for success. Common problems are the technical difficulties inherent in detecting and mapping the contamination at specific sites, uncertainties regarding the effectiveness of cleanup technologies, lack of qualified personnel, and ambiguities within the regulatory system. However, the scope and complexity of the contamination throughout the Weapons Complex present unprecedented challenges.

Environmental problems resulting from nuclear weapons production at the Weapons Complex have been discussed and debated over the past few years. DOE has now directed its attention to these issues and has stated publicly that it recognizes their seriousness and extent, and that it intends to expend vast resources to remediate past contamination and establish sound waste management practices for the future.

DOE is thus faced with the enormous task of environmental restoration of sites within the Weapons Complex. That task has begun. Detailed plans addressing the size and scope of the problem, and the time and resources required, have been developed only recently. DOE has prepared a Five-Year Plan that describes its goals, strategies, and specific programs for assessment and cleanup of contaminated sites and facilities to meet standards prescribed in Federal and State laws. The first Five-Year Plan was issued in 1989 and covered fiscal years 1991-95. The Five-Year Plan issued in 1990 updates the 1989 plan and covers fiscal years 1992-96. The 1990 Five-Year Plan calls for expenditures totaling more than $30 billion on environmental restoration and waste management activities for fiscal years 1992 through 1996, but most believe that this represents only the discovery phase of a program that could require hundreds of billions of dollars to complete.

DOE Weapons Complex facilities-both large and small-are spread across the Nation, from South Carolina to Washington State, and are located in both remote and populated regions. The Feed Materials Production Center (Fernald), which has produced uranium metal for weapons, is a 1,450-acre site, a relatively small facility located 20 miles northwest of Cincinnati, OH, in a rural area with a number of farms. The Rocky Flats Plant in Colorado, which has been producing plutonium 'triggers' for weapons, is also a small facility situated close to densely populated suburbs of Denver.

Other sites are much larger than Fernald or Rocky Flats. The Hanford Reservation encompasses approximately 360,000 acres in the Columbia River Basin of southeastern Washington State. Hanford's primary mission has been to produce weapons-grade plutonium; it produced plutonium for the atom bomb dropped on Nagasaki during World War II. The Savannah River Site, built in the 1950s, produces tritium and plutonium. It consists of 192,000 acres on the north bank of the Savannah River. Most of the immediate plant environs are rural, and the surrounding area, which is heavily wooded, ranges from dry hilltops to swampland. More than 20,000 people me employed at Savannah River, making it the largest plant (in terms of employment) in the DOE Weapons Complex.

The Oak Ridge Reservation covers approximately 58,000 acres in eastern Tennessee. Oak Ridge carries out several activities including the production of weapons components. The area immediately around the reservation is predominantly rural except for the City of Oak Ridge. The City of Knoxville is about 15 miles away. The Idaho National Engineering Laboratory (INEL), where reactor fuel is reprocessed to recover uranium, has a number of facilities and conducts a variety of other activities. The largest site in terms of area, INEL covers 570,000 acres in southeastern Idaho. The site boundary is about 22 miles from the City of Idaho Falls.

Each of these sites has significant environmental contamination problems, but only in the last few years have meaningful efforts been initiated to understand the nature and extent of the contamination and to develop more effective approaches for managing waste and reducing future contamination. The application of these efforts is just beginning, and the results are not yet evident except at a few locations. At most of the sites, characterization programs-efforts to identify and quantitatively map the contamination-will continue for 5 years or more before the full extent and concentration of contaminants in the environment can be known and remediation measures can be selected. Technical, institutional, and regulatory factors will all contribute to the complexity of DOE environmental restoration and waste management programs for many years to come.

The cleanup of the Weapons Complex is framed by, and to a large extent being measured against, the goals and procedures established by a body of State and Federal environmental laws and regulations that have been developed during the past two decades. Over the last 5 years, DOE has gradually been required to acknowledge that cleanup of the Nuclear Weapons Complex is subject to regulation by the Environmental Protection Agency (EPA) and the States to the extent that hazardous materials are involved or a site is placed on the Superfund priority list.

The regulatory context within which cleanup must proceed is complicated. In some instances the applicable regulations are very precise and prescriptive; in other instances there is ambiguity about how to interpret the law. For some situations, there areas yet no promulgated regulations to guide cleanup managers. EPA is attempting to use the interagency agreements negotiated with individual States and the DOE facilities to resolve jurisdictional overlaps and disputes about which statute to use and whose jurisdiction takes precedence. Three party agreements are in place at three of the Weapons Complex sites and are being negotiated at some others. where applicable, they serve as a timetable for cleanup actions and an indication of priority concerns.

The possibility that historic releases of contaminants, and current or future exposure to contaminants in the environment, might contribute to adverse health effects among off-site populations if an issue of great concern to affected communities

Information about historic releases of contaminants that have long since decayed or dispersed is relevant to health impact assessments because past exposure may increase the risks associated with current or future exposure. DOE has historically avoided public notification of releases from the weapons plants and their possible health effects. This practice has created substantial public distrust of DOE's methods and motivation.

DOE has maintained that no current contamination scenarios pose an "imminent threat' to the public health. Information about the type, extent, and concentration of current contamination, and data describing the environmental transport pathways of known centarninants, are still quite limited, however. Information about off-site contamination or the potential for off-site human exposure is especially lacking. DOE's assertion that the contamination poses no imminent health risks may be correct but is not substantiated by scientific evidence. Further, the possibility of chronic public health impacts resulting from weapons site pollution has not been addressed, and there exists no comprehensive plan for evaluating such effects.

DOE is now committed to complying with all relevant environmental regulations and is devoting enormous resources to achieving this goal. Yet the present regulatory-driven approach to the cleanup of the Weapons Complex places far more emphasis on characterizing the contamination than on investigating health impacts and may prove ill-suited to identiying public health concerns, evaluating contamination scenarios according to their potential for adverse health effects, or establishing health-based cleanup priorities.

Responsibility for conducting site-specific health studies is scattered throughout several Federal and State agencies, and limited resources have been allocated for such efforts. The current approach to health investigations mandated by environmental laws and agreed to in interagency negotiations is likely to omit many important health objectives.

THE OFFICE OF TECHNOLOGY ASSESSMENT FINDINGS

Over the past year the Office of Technology Assessment (OTA) has studied current and proposed approaches to waste management and environmental restoration at the Nuclear Weapons Complex. OTA's analyses focused on the following areas: 1) evaluating immediate problems and needs that could benefit most in the near term from additional emphasis and resources, 2) assessing technologies for waste management and environmental restoration, and 3) investigating approaches for setting priorities and allocating resources. OTA has also evaluated institutional, management, and regulatory issues relating to these matters and has assessed prospects for the future and the opportunities for enhancing these prospects. Box A presents the key findings from this assessment.

The environmental restoration program underway at the Weapons Complex is in the very early stages, and little actual cleanup work has been done. At a few sites, some simple containment and stabilization activities have been performed by capping or by removing contaminated soil and storing it elsewhere in a more controlled form. Many remediation measures have limited capabilities; thus many sites may never be returned to a "contaminant-fkee' condition or a condition suitable for unrestricted public access. *OTA's analyses show that it may be impossible with current technology to remove contaminants from certain groundwater plumes and deeply buried soil or, even impossible, it may be extremely expensive or require prolonged periods of operation. In these cases,* some aggressive efforts may be required to contain the materials and prevent further migration to the extent possible, while at the same time monitoring carefully any changes in conditions. *In the future, much more containment technology and point-of-use monitoring and control will have to be applied to some sites.*

Technologies that could effectively remediate certain sites with extensive or complex contamination of soil, groundwater, sediments, and surface water either are not available or cannot be applied with the resources now contemplated. New technologies may be available in the future, but the most promising are still in the very early stages and will require many years of research, development, and testing at specific sites. *OTA's analysis shows that whereas investing in promising new technologies may be productive, it should not delay immediate efforts to contain contamination that has the potential for wider dispersion or rapid migration and to establish programs that continually monitor contaminant movements.*

Box A—Key Findings

- The waste and contamination problems at the DOE Weapons Complex are serious and complicated, ; many public concerns about potential health and environmental impacts have not yet been addressed.
- DOE, other Federal agencies, and the States are trying to carry out their legally mandated clea responsibilities, but they presently lack the necessary personnel and infrastructure, and they have ye develop an effective process for public involvement in setting priorities and making important decisic Despite recent laudable efforts at changing the DOE culture, substantial credibility and public accepta problems continue to hinder progress.
- The environmental program now underway at the Weapons Complex is in the very early stages, and li actual cleanup has been done. It may be impossible with current technology to remove contaminants fr many groundwater plumes and deeply buried soils within reasonable bounds of time and cost. Many si may never be returned to a condition suitable for unrestricted public access.
- Despite DOE statements about the lack of imminent off-site health threats due to the contamination, possi public health effects have not been investigated adequately. The current regulatory process is not suffici to effectively identify urgent health-based remediation needs or to comprehensively evaluate possible pul health impacts. Among the missing elements are a coherent strategy for evaluating potential off-site hun exposure to radioactive and hazardous contaminants, a coordinated and scientifically sophisticated appro for evaluating potential health impacts from contamination, and an open process for public involvemen identifying risks and setting priorities for reducing risks.
- Because of the limitations of existing cleanup technologies it is prudent to invest in promising n developments; however, such efforts should not delay addressing situations in which containment ; monitoring are warranted now. OTA finds that a technology development program will be most benefic if it is focused on the most serious contamination problems identified by possible health risks.
- DOE's stated goal—to clean up all weapons sites within 30 years—is unfounded because it is not based meaningful estimates of work to be done, the level of cleanup to be accomplished, or the availability technologies to achieve certain cleanup levels. Neither DOE nor any other agency has been able to prep reliable cost estimates for the total cleanup.
- DOE currently has large quantities of radioactive and hazardous waste in storage at all sites, often un marginal conditions. There will be an increasing need to store waste safely on-site for fairly long peri until disposal alternatives are available. Adequate and workable standards and criteria for improved stor and treatment on-site are urgently needed.

OTA also finds that it may be more effective to invest substantial time and resources in the intensive development of a few technologies designed to address the most serious contamination problems than to make smaller investments in a range of potential innovations. In addition, conventional technologies require testing and evaluation at actual waste sites to confirm their effectiveness or understand their limitations.

OTA analysis indicates that the DOE goal stated in the Five-Year Plan and elsewhere—to clean up all weapons sites within 30 years—is unfounded because it is not based on meaningful estimates of the work to be done or the level of cleanup to be accomplished at the end of that time. The extent of environmental restoration work required at each site by current regulations and cleanup standards will not be known until characterization activities and other studies are completed. Some situations could require investigation and remediation beyond that specified in current regulations. Furthermore, acceptable cleanup levels have yet to be determined for many DOE weapons sites. *Without knowledge of the cleanup levels to be achieved by the end of 30 years, or the technologies required to achieve such levels, DOE cannot develop reliable cost estimates for the total cleanup.* Thus 30 years may prove too short a time to complete the cleanup to a reasonable degree, and the enormous resources required to clean up within that period may not be available. Some of the sites may never be restored to a condition permitting public access and use; thus, cleanup goals would need to be revised.

OTA has reviewed the current approach to waste management throughout the Weapons Complex, with particular attention to the disposal of some of the more hazardous and toxic materials in storage or being generated---specially high-level radioactive waste, transuranic waste, and mixed radioactive and hazardous waste. OTA has also reviewed the status of regulations and standards that are vital to major decisions on waste disposal. *Until safe geologic disposal capabilities are available, there will bean increasing need to store waste safely on-site for long periods (decades) and to provide more detailed and careful contingency plans for such storage.* The prospects for improving operating and management practices and reducing the risk of future contamination are also discussed. *If past problems are to be avoided, future waste management practices must meet stringent criteria for safe storage, treatment, and disposal.*

OTA has analyzed the environmental contamination and public health problems throughout the DOE Weapons Complex, as they are understood today. *The analysis shows that, despite some DOE statements about the lack of immediate health threats, public health concerns have still not been investigated adequately by DOE or by other government agencies.* Off-site health impacts are a plausible, but unproven, consequence of environmental contamination from the Nuclear Weapons Complex. Published reports and available data can neither demonstrate nor rule out the possibility that adverse public health impacts have occurred or will occur as a result of weapons site pollution. Investigations beyond those already completed or planned will be necessary to pursue questions about the occurrence of off-site health effects and to produce the information required to identify the most pressing cleanup priorities.

OTA has not attempted to conduct its own investigation of actual or potential public health threats. It has noted, however, that a more aggressive and coordinated investigatory process-conducted by qualified and independent parties, with early and continuous public involvement-that can assess public health issues and trace public concerns about health impacts to their possible sources is necessary to identify problems requiring immediate attention and to demonstrate more convincingly that public health is being protected. *OTA has concluded that current health assessment efforts are unlikely to efficiently produce the data necessary to set health-based environmental restoration priorities.* OTA has also noted that research on the biological consequences of weapons site contamination has not received the attention or resources necessary to understand the potential health impacts of contamination and to establish appropriate cleanup goals.

OTA has reviewed the status of major cleanup efforts throughout the Weapons Complex and noted the objectives that those efforts must meet. At every major site in the complex, radioactive and hazardous contaminants are present in soil, sediments, waste burial grounds, groundwater, or surface water. In many cases, these contaminants are migrating toward nearby populations; in some cases, off-site contamination of groundwater, sediments, and surface water has been detected. Contaminants include a wide range of radionuclides, metals, organic compounds, and other substances that could have adverse health consequences if they reach human receptors in sufficiently large concentrations.

OTA has concluded that what is needed is an aggressive, scientifically sophisticated, site-specific, and open evaluation of possible off-site health effects by independent environmental health professionals. Identification of those situations that pose a significant threat of current or future off-site exposure, and hence have the potential for adverse health effects, might provide a manageable near-term focus for remediation. Exposure assessments could provide some immediate health-based priorities to guide environmental restoration and technology development, in addition to identifying the direction of-or possible lack of need for—further health investigations.

Although such an approach could divert certain functions from DOE to another agency, it would do so in an area where DOE has little capability and credibility-an area that is currently neglected and crucial to public support of the cleanup as a whole. There may be concerns that such a process would delay cleanup work now underway. In certain cases, however, a delay in remediation might be warranted and could lead to improved outcomes if actual health impacts are better understood. *Unless and until the contamination-related health issues of most concern to the public are recognized and addressed, the most ambitious, sophisticated, and well-meaning cleanup plans and activities will likely meet with skepticism, suspicion, and legal challenges.*

Finally, OTA notes that, despite recent laudable efforts, significant changes in DOE's practices are still necessary to develop credibility and public acceptance of its plans for waste management and environmental restoration. To achieve the needed changes, aggressive efforts are required in the following areas: substituting independent, external regulation for DOE self-regulation wherever feasible; providing long-term, capable, independent oversight in matters for which DOE continues to retain primary responsibility; making information openly available and easily accessible to the public; and promoting active and continuos public involvement—at the National, State, regional, and local levels-in decisions about waste management and environmental restoration objectives, priorities, and activities.

POLICY INITIATIVES TO IMPROVE CLEANUP PROSPECTS

DOE, other Federal agencies, and the States are attempting to carry out their legally mandated responsibilities with respect to waste management and environmental restoration at the Weapons Complex. The cleanup effort is being hampered, however, by three fundamental problems. First, the technical and institutional resources and processes to make and implement sound, publicly acceptable decisions are not presently in place. Moreover, current agency plans do not adequately address these missing elements. Second, DOE's current decisions lack credibility because of past failures by DOE and its predecessor agencies to deal effectively with environmental contamination and to make full public disclosure regarding the contamination and its impact. Yet, the current decisionmaking process does not include adequate mechanisms for involving the public effectively in environmental restoration and waste management decisions. Third, the current approach to cleanup does not include a coherent and comprehensive strategy for evaluating potential off-site human exposure to Weapons Complex waste and contamination and for investigating potential health impacts due to the contamination. As a result, no reliable basis exists for understanding, identifying, and reducing potential public health risks; addressing community concerns about health impacts; and setting health-based funding priorities.

For these reasons, *OTA finds that effective cleanup of the Weapons Complex in the next several decades is unlikely and that significant policy initiatives are required if those prospects are to be improved. These* initiatives should be directed toward improving the performance of DOE and other government entities involved in conducting or regulating waste management and environmental restoration activities, and enhancing the credibility and public acceptability of the decisionmaking processes for waste management and environmental restoration.

The policy initiatives outlined below, and summarized in box B, are aimed mainly at improving and strengthening the decisionrna'hg process for setting and meeting cleanup objectives. Congressional oversight could improve the performance and coordination of involved agencies and provide more effective approaches to safe waste storage and disposal, technological development, public access to information, and other aspects of the cleanup. The conduct of health assessments by independent entities with environmental health expertise could improve prospects for establishing health-based priorities to be used in the decisionnmking process. Establishing site-specific advisory bodies to provide independent public policy and technical oversight could improve prospects for open, credible, and cooperative decisionmaking processes on key aspects of the cleanup. Substituting independent regulatory authority for DOE's self-regulation in radioactive waste management activities could enhance the credibility and quality of current and future waste management decisions.

The following policy initiatives could improve cleanup prospects and provide better assurances that sound waste management practices will prevail in the future:

I. ***Increase congressional oversight of environmental restoration and waste management activities that require improved performance by the responsible agencies.***

Congress could increase its oversight of DOE, EPA, and other relevant Federal agencies to ensure that the agencies implement existing legislative authority to effectively conduct and properly coordinate waste management and environmental restoration activities. This oversight could usefully be directed toward the responsible agencies to improve their performance in the following areas that could benefit from prompt attention:

Box B—Policy Initiatives To Improve Cleanup Prospects

I. Increase congressional oversight of environmental restoration and waste management activities that require improved performance by the responsible agencies.

Congress could increase its oversight of DOE, EPA, and other Federal agencies to develop and implement improved programs to deal promptly with the following matters:

- strengthen agency personnel,
- plan for safe waste storage,
- improve technology development,
- increase public access to information,
- coordinate and accelerate standard-setting, and
- strengthen site monitoring programs.

II. Enhance the structure and process for assessing the public health impacts of Weapons Complex waste and contamination.

Congress could establish the following institutional mechanisms to evaluate potential off-site health impacts:

- a new and separate health assessment office,
- health "Tiger Teams" to conduct exposure assessments at each site, and
- a national independent environmental health commission.

III. Develop a structure and process to provide public participation in key cleanup policy and technical decisions.

Congress could establish the following institutional mechanisms:

- advisory boards with technical staff at each site and
- a national coordinating and advisory board.

IV. Establish a national mechanism to provide outside regulation of DOE radioactive waste management programs.

Congress could authorize an institution to regulate those aspects of radioactive waste management activities now subject exclusively to DOE's authority. These functions could be given to:

- a new national body or
- an existing body such as the Nuclear Regulatory Commission or EPA.

1. Strengthen Agency Personnel

Agencies need to act as soon as possible to specify personnel requirements and develop strategies for meeting personnel needs. Congress could encourage DOE, EPA, and other involved agencies in cooperation with the States, to prepare a coordinated plan that identifies personnel needs for the cleanup program and outlines a process for developing the cadre of professionals required.

2. Plan for Safe Waste Storage

Repository delays have affected key aspects of DOE HLW and TRU waste management strategies; regulations pertaining to mixed waste require changes in some of DOE's earlier plans. To enhance prospects for safe on-site storage of waste, DOE could prepare a detailed plan for long-term storage of high-level and transuranic waste and for storing and treating mixed radioactive and hazardous waste.

3. Improve Technology Development

The procedure for developing and implementing more effective technologies could be improved by more focused analysis of the requirements and alternative solutions for the most important cleanup problems. DOE could accelerate efforts to structure a program clearly identifying immediate technological needs and timely solutions to the more urgent contamination problems.

4. Increase Public Access to Information

New procedures are needed to provide the public with all information relevant to waste management and environmental activities. DOE could accelerate its declassification efforts relevant to waste management and environmental restoration; promptly make requested material available; and notify interested parties of meetings, hearings, comment periods, and the availability of new materials.

5. Coordinate and Accelerate Standard-Setting

Adequate standards relevant to the cleanup, especially those for radioactive soils and sediments and for mixed waste, need to be developed in a timely manner. DOE, EPA, and other involved agencies could establish more effective coordination among and within agencies and assign appropriate staff to set, apply, and enforce health-based standards.

6. Strengthen Site Monitoring Programs

If some sites or portions of sites cannot be cleaned to the point of unrestricted use, institutional controls (including continuous monitoring and oversight, as well as notification and warnings) will be necessary to ensure that the public and the environment are not adversely affected. DOE could strengthen its programs for monitoring and control of those sites that may continue to have contamination.

II. *Enhance the structure and process for assessing the public health impacts from Weapons Complex waste and contamination.*

Congress could establish a structure and process to evaluate potential health impacts from the weapons facilities as a basis for setting cleanup priorities.

To implement this initiative, Congress could establish a new office within the Department of Health and Human Services (HHS), EPA, or other agency to coordinate and direct site-specific health assessments, and State-organized health studies. Congress could direct this office, as its first task, to establish health "Tiger Teams" to conduct comprehensive assessments of the potential for human exposure to contamination at each site. To provide the necessary expert advice to this office, Congress could further establish a national, independent environmental health commission reporting to Congress to provide guidance regarding exposure assessments, health effects evaluations, and health research needs related to the cleanup. Congress could require DOE to make information about past environmental releases and current contamination available to the Tiger Teams, the scientific community, and the public.

This policy initiative could strengthen the assessment of potential off-site health impacts and thus improve the prospects that health-based priorities will be established and implemented. The initiative could provide accelerated, scientifically rigorous exposure assessments to determine the most urgent health issues posed by the contaminants and establish a coordinated approach to site-specific assessments that efficiently and comprehensively evaluates the past, current, and potential public health impacts of contamination. Exposure assessments with broad public involvement could better equip the responsible agencies and the public to develop and implement health-based cleanup priorities in a timely manner. Finally, this initiative could improve the prospects that specific community concerns about off-site health effects are addressed.

III. *Develop a structure and process to provide public participation in key cleanup policy and technical decisions.*

Congress could establish a structure and process to provide public participation in key cleanup policy and technical decisions.

To implement this policy initiative, Congress could establish advisory boards with full-time technical staff at each site to provide both policy and technical advice to DOE, EPA, HHS, and the States. These boards could consider issues relating to cleaning up past contamination, assessing and reducing public health risks, and safely storing and disposing of past waste. By having access to the information, technical support, and other resources needed to participate effectively in all aspects of the cleanup decisionmaking process, the boards could foster openness, trust, and cooperation among interested parties which is not being achieved at present. Congress could also establish a national board including representatives from the site-specific boards to coordinate the activities of the site-specific boards and provide advice to the headquarters level of involved Federal agencies regarding national policy and technical issues.

This policy initiative addresses the need for effective public involvement in environmental restoration decisions at each of the sites. OTA believes that those decisions could be improved by providing independent input to key policy and technical issues and by involving the public in the development of site-specific, health-based cleanup priorities.

IV. *Establish a national mechanism to provide outside regulation of DOE radioactive waste management programs.*

Congress could authorize an institution other than DOE to regulate those aspects of the radioactive waste management activities now subject exclusively to DOE authority and over which no other agency now has such authority.

To implement this policy initiative, Congress could either establish a permanent, full-time, independent national commission having regulatory and enforcement authority with respect to radioactive waste management activities at the Weapons Complex or authorize an existing body such as the Nuclear Regulatory Commission or EPA to exercise these functions.

This policy initiative could improve the credibility and effectiveness of the decisionmaking process for waste management by limiting DOE self-regulation and providing appropriate independent regulation of the treatment, storage, and disposal of radioactive waste.

CONCLUSION

Progress in cleaning up the waste and contamination at the Weapons Complex is being hampered by a paucity of data and qualified personnel, inadequate efforts to assess possible off-site health impacts, lack of ready technical solutions, and public skepticism about government agency decisions and activities relating to waste management and environmental restoration. The policy initiatives outlined above are aimed at improving and strengthening the decision-making process for setting and meeting cleanup objectives.

Increased congressional oversight could improve prospects for enhancing the agency infrastructure, accelerating standard-setting, and providing more effective approaches to site characterization and remediation, waste storage and disposal, technological development, priority setting, and other aspects of the cleanup. The direction and coordination of site-specific health assessments by an independent and authoritative entity could improve prospects for achieving scientifically sound and credible evaluations of possible off-site health impacts, resolving community health concerns and developing health-based cleanup priorities. Establishing site-specific advisory bodies to provide independent policy and technical advice could improve prospects for open, credible, and cooperative decisionmaking on key aspects of the cleanup. Substituting independent regulatory authority for DOE's self-regulation in radioactive waste management activities could enhance the credibility and quality of waste management decisions.

Although the cleanup will be a long and difficult task, OTA's analyses indicate that the policy initiatives outlined above could significantly improve the prospects that sound and credible cleanup decisions will be made.

Chapter 1

Introduction

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Chapter 1
Introduction

GENERAL

The Department of Energy (DOE) Nuclear Weapons Complex consists of 14 facilities in 13 States,[1] on military reservations covering 3,350 square miles and employing more than 100,000 people (see figure 1-1 and table 1-1).[2] Since the middle of this century, these facilities have been producing uranium materials and irradiating them in nuclear reactors, reprocessing these materials to separate weapons constituents, manufacturing and finishing weapons components, producing special parts, assembling and testing weapons, conducting research and designing new weapons, and recycling parts when weapons are retired. In the 1990s, the legacy of producing tens of thousands of warheads over the past five decades is widespread environmental contamination from the waste products of this process, accompanied by a pervasive concern among local communities and others over possible public health threats, and an uncertain fate for waste generated in the future.

Poorly contained hazardous and radioactive wastes from weapons production have contaminated groundwater, soil, sediments, and surface water and have also been released into the air surrounding weapons plants. Factors contributing to contamination include manufacturing processes that are inherently waste producing; a history of emphasizing the urgency of weapons production for national security, to the neglect of health and environmental considerations; ignorance of, and lack of attention to, the consequences of environmental contamination; and decades of self-regulation, without independent oversight or meaningful public scrutiny. In late 1989, commenting on the serious problems he faces in managing DOE defense programs, Secretary of Energy James D. Watkins said that . the [waste management and environmental] problems have resulted from a 40-year culture cloaked in secrecy and imbued with a dedication to the production of nuclear weapons without a real sensitivity for protecting the environment."3

THE WEAPONS COMPLEX

Work performed at the DOE Weapons Complex has traditionally been divided into four categories:

1. weapons research and development at three national laboratories, Ios Alamos and Sandia in New Mexico and Lawrence Livermore in California;
2. nuclear materials (plutonium and tritium) production and processing at the Hanford Plant in Washington State and the Savannah River Site in South Carolina, along with uranium processing at the Feed Materials Production Center in Ohio and the Idaho National Engineering Laboratory;
3. warhead component production at the Rocky Flats Plant in Colorado, the Y-12 Plant in Tennessee, the Mound Plant in Ohio, the Pinellas Plant in Florida, the Kansas City Plant in Missouri, and the Pantex Plant (final assembly) in Texas; and
4. warhead testing at the Nevada Test Site.

Although the Weapons Complex was developed in World War II as part of the Manhattan Project, a major expansion occurred in the early 1950s. Today, most operating facilities are more than 30 years old. Operations are in various stages of transition because of safety and environmental problems that have diverted attention from production and because of the uncertain future of the entire enterprise.

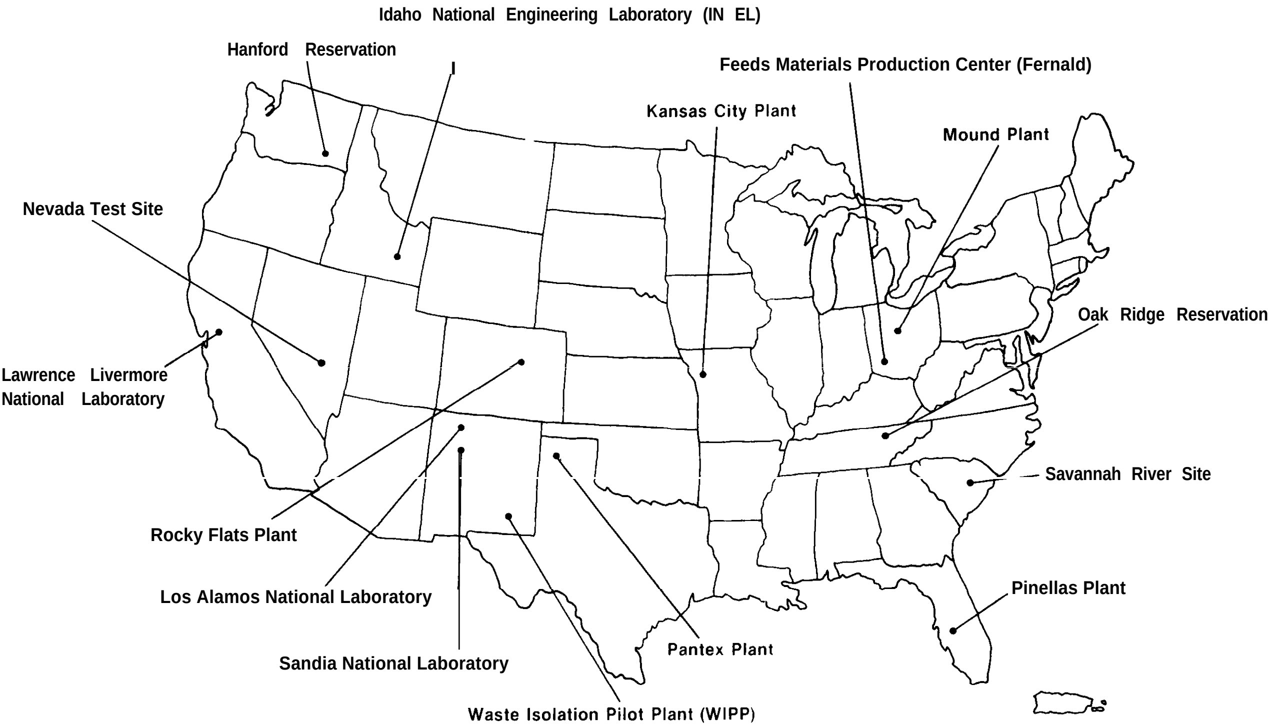
Environmental and health problems resulting from nuclear weapons production at these facilities have been discussed and debated over the past few years. DOE has now directed its attention to these problems, has acknowledged their seriousness and

[1]This definition of 14 facilities in the Nuclear Weapons Complex generally agrees with DOE's definition of major facilities grouped under defense programs but excludes some smaller operations as well as those under other DOE programs. Other reviews have included additional facilities, such as the Portsmouth and Paducah Gaseous Diffusion Plants, or have counted some facilities in one reservation separately, and thus have resulted in a larger number. In addition, 15 locations are identi.tied in figure 1-1 and table 1-1 because of inclusion of the Waste Isolation Pilot Plant.

[2]To obtain some idea of the size of the Weapons Complex, it may be helpful to realize that the Nevada Test Site covers an area larger than the State of Rhode Island and that the Oak Ridge Reservation Sandia National Laboratory, and Los Alamos National Laboratory each occupy an area approximately the size of Washington DC.

[3]Statement of Admiral James D. Watkins, Secretary of Energy, before the Senate Committee on Energy and Natural Resources, Oct. 5, 1989.

Figure I-1—Department of Energy Weapons Complex



SOURCE: Office of Technology Assessment, 1991.

extent, and stated its intention to expend vast resources to remediate past centamination and to establish sound waste management practices for the future. DOE has responded to these environmental and waste management problems with a Five-Year Plan for environmental restoration and waste management, and a new organization to direct these efforts.[4]

DOE operates the weapons production facilities through its headquarters organization known as Defense Programs, which manages weapons production to meet the needs of the Department of Defense. Although owned by the Federal Government, the weapons facilities are operated by private companies under management and operations contracts with the Department of Energy. A new DOE headquarters organization known as Environmental Restoration and Waste Management has been established recently to direct waste management and environmental restoration efforts. Actual work at the sites is still carried on by the private companies that operate each facility under the direction of DOE field operations offices.

Although facilities in the DOE complex have much in common, there is no "typical" facility.[5] Each site has a unique combination of characteristics that shapes its particular waste and contamination problems and affects the way those problems are addressed. Relevant facility characteristics include its functions and management; its size, location, and proximity to populated areas; and its relationships with Federal and State regulators, neighboring communities, and the general public. These distinguishing features are discussed below.

[4] The 5-year planning process that DOE has instituted resulted in a series of documents that now constitute the most comprehensive, published discussion of environmental restoration and waste management throughout the Weapons Complex. Ch. 2 contains specific references to these publications.

[5] The following discussion of facilities within the DOE weapons Complex is summarized from data gathered by Office of Technology Assessment staff during visits, briefings, meetings, and inspections at each of the major sites.

Table I-I—The Weapons Complex (Principal Facilities List)

Type of facility	Facility	Location (State)	Size (square miles)	Management and operations contractor	Approximate current employment
Weapons research and design	Los Alamos National Laboratory	NM	75	University of California	7,400
	Sandia National Laboratory	NM	62	AT&T	8,500
	Lawrence-Livermore National Laboratory	CA	12	University of California	8,500
Materials production	Hanford Plant	WA	570	Westinghouse	13,500
	Savannah River Site	SC	300	Westinghouse	20,000
	Fernald	OH	0.2	Westinghouse	1,000
	Idaho National Engineering Laboratory	ID	893	EG&G/ Westinghouse	10,500
Wapons manufacturing	Rooky Flats Plant	CO	14	EG&G	6,000
	Oak Ridge Reservation	TN	58	Martin-Marietta	16,500
	Mound Plant	OH	0.3	EG&G	2,400
	Pinellas Plant	FL	0.2	General Electric	2,000
	Kansas City Plant	MO	0.5	Allied Signal Corp.	7,800
	Pantex Plant	T)(	14	Mason & Hanger-Silas Mason	2,800
Warhead testing	Nevada Test Site	NV	1,350	Reynolds Electric	8,400
Waste disposal	Waste Isolation Pilot Plant	NM	16	Westinghouse	650

SOURCE: U.S. Department of Energy.

Functions and Management

When they are operating, five facilities produce materials for nuclear weapons. The Feed Materials Production Center in Fernald, OH, is not currently operating but, in the past, it produced uranium metal ingots; the Hanford Plant, which is also shut down, handled the production of weapons-grade plutonium; the Y-12 Plant in Oak Ridge, TN, produces uranium metal and light elements; and the Savannah River Site (when operating) produces tritium and has in the past produced plutonium. Highly enriched uranium is recovered at the chemical processing plant in Idaho and at Y-12. Weapons components are produced at several facilities---ceramic and uranium components at Y-12, plutonium and beryllium components at Rocky Flats, and other components at the Kansas City, Mound, and Pinellas plants. Weapons assembly is completed at the Pantex Plant.

At this time, many material processing and weapons production operations at the facilities are shut down. DOE intends to evaluate the possibility of reopening and operating some of them safely, in compliance with applicable laws and regulations. Others, such as Fernald, will cease producing nuclear materials and will focus primarily on cleanup activities. A general review of modernization needs for the entire Weapons Complex is underway.

During the past 6 years, many of the weapons facilities have undergone changes in the contractors that operate them for DOE, and a fewer number of firms now operate these plants. Specifically, Westinghouse Hanford Co. replaced Rockwell Hanford Co. at Hanford in 1987; Westinghouse Materials Co. of Ohio replaced National Lead of Ohio at Fernald in 1985; Westinghouse Savannah River Co. replaced E.I. du Pent de Nemours & Co. at Savannah River in 1989; Martin Marietta Energy Systems replaced Union Carbide Corp. at Y-12 in 1984; Westinghouse Idaho Nuclear replaced Exxon Nuclear Idaho Co. at the Idaho Chemical Processing Plant (ICPP) in 1984 (EG&G Idaho is general contractor for the site); and,

Photo credit: U.S. Department of Energy

Hanford Reservation 300 area adjacent to the Columbia River.

in a highly publicized change apparently related to alleged violations of environmental laws and regulations, EG&G Rocky Flats Corp. replaced Rockwell International at Rocky Flats in 1989. Westinghouse is also the contractor for the Waste Isolation Pilot Plant in New Mexico.

Size and Location

DOE Weapons Complex facilities are spread across the Nation, from South Carolina to Washington State; they vary greatly in both size and proximity to populated regions. Fernald, which has produced uranium metal, and Rocky Flats, which produces plutonium "triggers," are relatively small facilities located near populated areas. The 1,450-acre Fernald site is 20 miles northwest of Cincinnati, OH, in a farming area. Although Rocky Flats covers about 6,550 acres, all major structures are concentrated in fewer than 400 acres. The plant is within 16 miles of downtown Denver, Boulder, and Golden, CO. About 80,000 people live within 3 miles of the facility.

Other sites are much larger. Hanford encompasses approximately 360,000 acres in southeastern Washington State: Richland, Pasco, and Kennewick (the Tri-Cities area, with a population of 140,000) are nearby, downstream on the Columbia River. Portland, OR (population 360,000), is about 230 miles downstream. Hanford's primaxy mission has been the production of weapons-grade plutonium. The Savannah River Site, which produces tritium and plutonium, consists of 192,000 acres on the north bank of the Savannah River. Built in the early 1950s, the site is approximately 13 miles south of Aiken, SC (population 15,000), and 20 miles southeast of Augusta, GA (population 50,000). The average population density in counties surrounding the site ranges from 23 to 560 people per square mile, with the largest population (more than 250,000) in the Augusta, GA, metropolitan area. Savannah River, which employs more than 20,000 people, is the largest plant (in terms of employment) in the Weapons Complex.

The Oak Ridge Reservation covers approximately 58,000 acres in Tennessee. Oak Ridge, among other activities, produces uranium and ceramic weapons components. The City of Oak Ridge (population 28,000) is adjacent to the Y-12 Plant;[6] Knoxville, TN (population 350,000), is about 20 miles to the east of Oak Ridge. The Idaho National Engineering Laboratory (INEL), which reprocesses naval reactor fuel to recover uranium-235 for reuse as fuel in the Savannah River production reactors, is the largest weapons site in terms of area, covering 570,000 acres in southeastern Idaho and overlapping five counties.

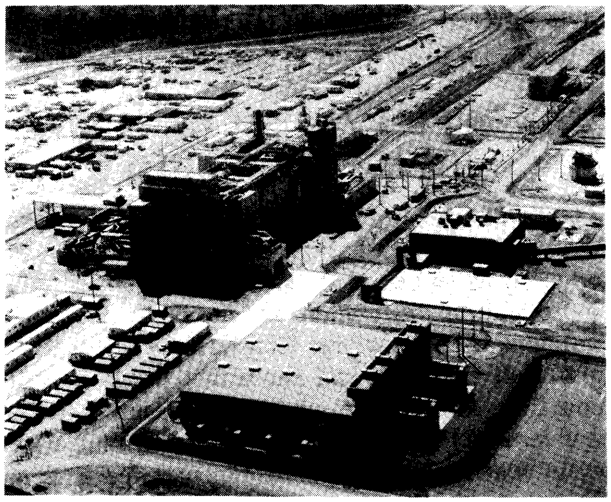


Photo credit: U.S. Department of Energy

Defense Waste Processing Facility at Savannah River.

Relationships With Regulators and With the Public

Nine of the Weapons Complex facilities are proposed or listed on the National Priorities List (NPL) for cleanup action under the Superfund law (CERCLA);[7] these and the remaining sites are also subject to the Resource Conservation and Recovery Act (RCRA).[8] Thus, waste management and environmental restoration programs at the facilities may come under different regulatory authorities, depending on whether the U.S. Environmental Protection Agency (EPA) or the State has primary jurisdiction, and on what State laws, regulations, or standards apply. The facilities are also at different stages with respect to formulating agreements with EPA or the States. Relationships among the parties range from the fairly adversarial mode that appears to exist in Ohio and EPA Region V (Fernald); through the relatively cooperative mode in Tennessee (Oak Ridge) or South Carolina (Savannah River) and EPA Region IV in Atlanta, which covers both facilities; to the negotiated accommodation developed through tri-party agreements in the State of Washington (Hanford) and in Colorado (Rocky Flats).

Other factors important to understanding the situation at each facility are the attitudes and concerns of the affected and interested public. Almost all of the sites, but especially Fernald, Rocky Flats, Hanford, Savannah River, and Oak Ridge, have experienced strongly articulated public concern and adversarial activity. More cooperative working relationships appear to have developed at those sites with programs formulated to obtain public input and consider public concerns. For example, the Oak Ridge facility has taken some positive steps to work with the public over the past several years (including an aggressive policy of openness and an advisory committee with local representatives). Hanford has made similar efforts, and other sites have programs or plans to improve public communications in the future.

Only in the last few years have significant efforts been initiated to understand the nature and extent of environmental contamination at the DOE Weapons Complex and to develop more effective approaches for managing waste and reducing future contamination. These efforts are just beginning, and the results are not yet evident except at a few locations. At most sites, characterization must continue for 5 years or more before the extent and concentration of contaminants in the environment can be known and the available remediation technologies can begin to be considered. Technical, institutional, and regulatory factors will all contribute to the complexity of DOE

[6] The term Y-12 originated during the wartime Manhattan Project. Y-12 is one of three distinct areas on the Oak Ridge Reservation. The others are K-25, which was the location of the large gaseous diffusion plant for separating uranium isotopes, and X-10, which is now the location of the Oak Ridge National Laboratory.

[7] Comprehensive Environmental Response, Compensation and Liability Act of 1980, 42 U.S.C.A. $9605-9657 (Pub. L. No. 96-51 O).

[8] Resource Conservation and Revovery Act of 1976, 42 U. S.C.A. $6901-6981 (Pub. L. No. 94-580).

environmental restoration and waste management programs for many years to come.

THE OFFICE OF TECHNOLOGY ASSESSMENT STUDY

Over the past year the Office of Technology Assessment (OTA) has studied both current and proposed approaches to waste management and environmental restoration at the DOE Weapons Complex. OTA's analyses focused on: 1) evaluating immediate problems and needs that would benefit most from additional emphasis and resources in the near term, 2) assessing technologies available for waste management or environmental restoration, and 3) investigating ways to determine priorities and allocate resources. Related institutional, management, and regulatory issues have also been evaluated. This report incorporates the results of those evaluations and attempts to assess the prospects for the future and the means of enhancing these prospects.

The body of this report contains four chapters:

1. introductory material,
2. description and evaluation of DOE cleanup programs,
3. description and evaluation of efforts to protect public health, and
4. discussion of policy initiatives to improve cleanup prospects.

The following subjects are summarized in appendix material:

- site contamination,
- example of groundwater contamination and cleanup,
- status of cleanup cost estimation, and
- ecological issues.

In addition, OTA intends to publish separate background papers on waste management, the regulatory framework for the cleanup process, and analyses of cleanup worker health issues.

Chapter 2

Status and Evaluation of U.S. Department of Energy Activities and Plans

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Chapter 2

Status and Evaluation of U.S. Department of Energy Activities and Plans

The public is only vaguely aware of the nature and extent of the waste and contamination problems at the Department of Energy (DOE) Nuclear Weapons Complex. In addition, the government's goals for cleanup of contaminated sites and safe management of radioactive and hazardous waste are defined in very broad, general terms. DOE is attempting to clarify this situation through its 5-year planning process and its activities in waste management and environmental characterization at thousands of contaminated sites throughout the Weapons Complex.

This chapter examines and evaluates DOE activity and planning in key areas that are directed toward either a better understanding of the problem or a more effective approach to solutions. These areas are environmental restoration, waste management, costs, priorities, public involvement, and technology. The status of current programs is discussed for each subject, followed by the Office of Technology Assessment (OTA) evaluation of those activities.

Although DOE continues to make progress in this monumental task, many obstacles hinder the selection and adoption of optimum and effective solutions. Over the long term, fundamental changes in the government's approach to cleanup of the Weapons Complex will be necessary, if publicly acceptable goals are to be achieved. In this chapter, OTA identifies some key obstacles and suggests possible avenues for change.

Photo credit: U.S. Department of Energy

Oil **Retention Ponds at** *Oak* **Ridge prior to remedial action.**

ENVIRONMENTAL RESTORATION OF CONTAMINATED SITES

Status

Overview

The Nuclear Weapons Complex is a collection of enormous factories devoted to metal fabrication, chemical separation processes, and electronic assembly. Like most industrial operations, these factories have generated waste, much of it toxic. Forty-five years of nuclear weapons production have resulted in the release of vast quantities of hazardous chemicals and radionuclides to the environment. Evidence exists that air, groundwater, surface water, sediments, and soil, as well as vegetation and wildlife, have been contaminated at most, if not all, nuclear weapons sites (1).

Contamination of soil, sediments, surface water, and groundwater throughout the Weapons Complex is widespread (2, 3, 4). Almost every facility has confined groundwater contamination with radionuclides or hazardous chemicals (see app. A). All sites in nonarid locations probably have surface water contamination. Almost 4,000 solid waste management units (SWMUs)[1] have been identified throughout the Weapons Complex—many of which require some form of remedial action. Substantial quantities of radioactive and mixed waste have been buried throughout the complex, many without adequate record of their location or composition. DOE

[1]The Environmental Protection Agency has defined an SWMU as "including any unit at the facility from which hazardous constituents might migrate, irrespective of whether the units were intended for the management of solid and/or hazardous wastes" (Hazardous Waste Management System, Final Codification Rule, 50 Fed. Reg. 28702,28712 (1985) (codified at 40 CFR $$260-62,264-66,270-71, 280)). An SWMU could be a unit such as a landfill, land treatment unit, waste pile, surface impoundment, container, tank, or incinerator. See 42 U.S.C.A. 6924(v) (West Supp. 1990).

Table 2-l—Examples of Nuclear Weapons Site Contaminants and Mixtures[a]

Inorganic contaminants:	Polychlorinated biphenyls, select polycyclic aromatic hydrocarbons
Radionuclides:	Tetraphenylboron
Americium-241	Toluene
Cesium-134, 137	Tributylphosphate
Cobalt-60	***Organic facilitators:***[b]
Plutonium-238, 239	Aliphatic acids
Radium-224, 226	Aromatic acids
Strontium-90	Chelating agents
Technetium-99	Solvents, diluents, and chelate radiolysis fragments
Thorium-228, 232	***Mixtures of contaminants:***[c]
Uranium-234, 238	Radionuclides and metal ions
Metals:	Radionuclides, metals, and organic acids
Chromium	Radionuclides, metals, and natural organic substances
Copper	Radionuclides and synthetic chelating agents
Lead	Radionuclides and solvents
Mercury	Radionuclides, metal ions, and organophosphates
Nickel	Radionuclides, metal ions, and petroleum hydrocarbons
Other:	Radionuclides, chlorinated solvents, and petroleum hydrocarbons
Cyanide	Petroleum hydrocarbons and polychlorinated biphenyls
Organic contaminants:	Complex solvent mixtures
Benzene	Complex solvent and petroleum hydrocarbon mixtures
Chlorinated hydrocarbons	
Methylethyl ketone, cyclohexanone, acetone	

[a]The contaminant list is being upgraded as new information becomes available.
[b]Facilitators are organic compounds that interact with and modify metal or radionuclide geochemical behavior.
[c]Information on mixture types is sparse, and concentration data are limited.

SOURCE: U.S. Department of Energy/Office of Health and Environmental Research, Subsurface Science Program, Co-Contaminant Chemistry Subprogram, "Draft Strategy Document," March 1990.

has estimated that buried transuranic waste totals about 0.2 million cubic meters and buried low-level radioactive waste, 2.5 million cubic meters (5). Most of this buried radioactive waste is also mixed with hazardous waste as defined by the Resource Conservation and Recovery Act (RCRA)[2] (so-called mixed waste).

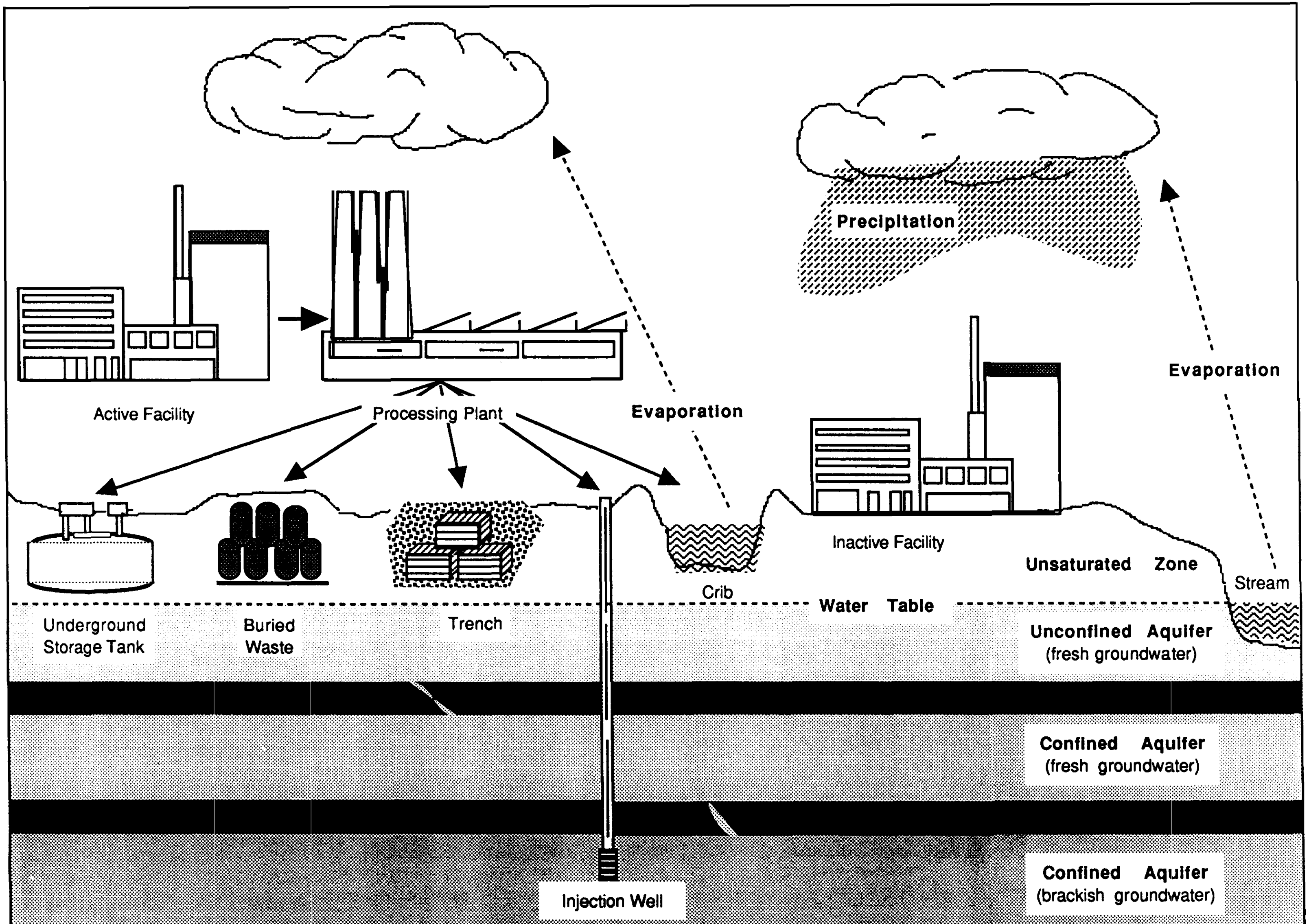
Contaminated soil and sediments of all categories are estimated to total billions of cubic meters. Table 2-1 shows the variety of radioactive and hazardous contaminants present at DOE sites. Appendix A identifies specific contaminants at each site. Figure 2-1 illustrates contaminant pathways into soil and groundwater, and table 2-2 lists the status of known centamination of soil, groundwater, surface water, and sediment at each of the sites. Appendix D discusses ecological issues related to this contamination.

Although these estimates of vast quantities of old buried waste; of contaminants in pits, ponds, and lagoons; and of the migration of contamination into water supplies serve to dramatize the problem, very little characterization of each site has been accomplished. DOE has stated that it is continuing to discover new problems.[3] Until characterization has been completed in accordance with applicable regulations—a process that OTA analysis shows will take about 5 years (see figure 2-2)-effective remediation measures cannot be initiated.

[2]Pub. L. No. 94580,90 Stat. 2795 (1976) (codified as amended at 42 U.S.C. §6901-07 (1982); 42 U.S.C. §§6911-16, 6921.31,694149,6951-54, 6961-64,6971-79,6981-86 (1982)); amended by Solid Waste Disposal Act Amendments of 1980, Pub. L. No. 96-482,94 Stat. 2334 (1980) (codified at 42 U.S.C. $6901-91(i) (1982)); Hazardous and Solid Waste Amendments of 1984, Pub. L. No. 98-616, 98 Stat, 3221, 3224 (codified at 4U.S.C. §6924 (1984)). Although RCRA referred only to the Amendments of 1980, the term is now used to include the Solid Waste Disposal Act of 1965 and its subsequent amendments. RCRA Section 1004(5) defines "hazardous waste" as any "solid waste or combination of solid wastes which, because of its quantity, concentration, or physical, chemical or infectious characteristics may (a) cause, or significantly contribute to, an increase in mortality or an increase in serious irreversible or incapacitating reversible illness; or (b) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed. " Pursuant to RCRA Section 3001, the Environmental Protection Agency has promulgated regulations that identify specific hazardous wastes, either by listing them or by identifying characteristics that render them hazardous.

[3]Secretary of Energy James D. Watkins, testimony at hearings before the Senate Committee on Energy and Natural Resources, May 2, 1990.

Figure 2-1—Examples of Groundwater Contamination Sources



SOURCE: Office of Technology Assessment, 1991.

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Table 2-2—Known Contamination at Weapons Complex Facilities

Facility	Contamination On-site	Contamination Off-site	Limited corrective measures
Oak Ridge Reservation	S, GW, SW, Se	SW, Se	s, Sw
Pinellas Plant	GW		
Savannah River Site	S, GW, SW, Se	SW, Se	GW
Feed Materials Production Center (Fernald)	S, GW, SW, Se	GW, Se	S, GW, SW
Mound Plant	S, GW, SW, Se	GW, SW, Se	S, SW, Se
las Alamos National Laboratory	S, GW		
Pantex Plant	GW		
Sandia National Laboratory	S, GW		
Kansas City Plant	S, GW, Se	Se	S, GW, Se
Rooky Flats Plant	S, GW, SW, Se	SW, Se	GW
Lawrence Liverrnore National Latmratory	S, GW, Se	GW	S, GW
Nevada Test Site	S, GW		
Hanford Plant	S, GW, SW, Se	SW, Se	
Idaho National Engineering Laboratory	S, GW, Se	s	

NOTE: S = soil; GW = groundwater; SW= surface water; Se= sediment. Information on air contamination was not obtained.

SOURCE: Office of Technology Assessment, 1991; based on U.S. Department of Energy 1987-1988 Draft Environmental Survey; interviews with U.S. Environmental Protection Agency regional offices; DOE review letter from R.P. Whitfield to Peter Johnson, June 22, 1990.

Goals of Environmental Restoration

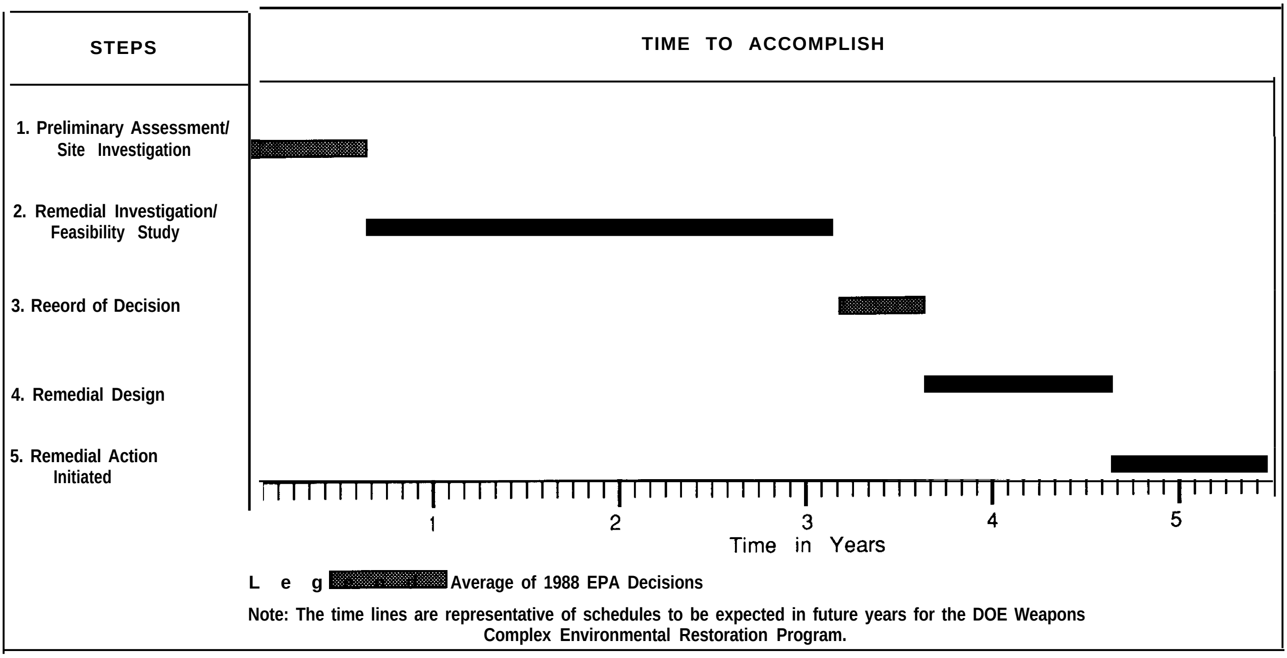
DOE has begun to face the enormous task of environmental restoration at sites within the Weapons Complex. Plans addressing the size, scope, time, and resources required have been developed only recently. The DOE Five-Year Plan describes its goals, strategies, and specific programs for assessment and cleanup of contaminated sites and facilities to meet standards prescribed in Federal and State laws. The first Five-Year Plan was issued in 1989 and covered FY 1991-95 (referred to hereafter as the 1989 Five-Year Plan) (l). The Five-Year Plan issued in 1990 updates the 1989 plan and covers FY 1992-96 (referred to hereafter as the 1990 Five-Year Plan) (4).

In the 1990 Five-Year Plan, DOE states that it is committed to the goal of environmental cleanup at all weapons sites by the year2019 and that the public must be involved in the process (6). According to DOE, "the 30-year goal for environmental restoration is to ensure that risks to the environment and to human health and safety posed by inactive and surplus facilities and sites are either eliminated or reduced to prescribed, safe levels" (7). This goal has been used by DOE in its planning documents for environmental cleanup at sites within the Nuclear Weapons Complex. Although the extent of cleanup has not been determined explicitly for each site, DOE has stated its intent that 'facilities and sites be returned to a condition suitable for unrestricted use. '

[4]DOE defines ''environmental restoration'' to include all ''remedial actions'' and "deCon lamination and decommissioning" at all DOE facilities. Remedial action encompasses: 1) site discovery, preliminaryassessment, and inspection; 2) site characterization, analysis of cleanup alternatives, and selection of a remedy; 3) cleanup and site closure; and 4) site compliance and monitoring. In this study, OTA uses "environmental restoration" to encompass remedial actions at the DOE Weapons Complex but does not include facilities that are not within the complex.

[5]DOE has also stated that ''in certain instances'' in situ stabilization and disposal may be the alternative selected. According to DOE, this will depend on: "l) specific site conditions; 2) the type, nature, extent, and amount of contaminantts present; 3) availability of suitable cleanup technologies; 4) regulatory factors; or 5) other agreed to (with regulators) considerations" (8).

Figure 2-2—Tvpical Schedules for Key Steps in the CERCLA Process From Beginning to End at the ‘DOE-Weapons Complex



SOURCE: Office of Technology Assessment, 1991, with data from recent Superfund experience, 1989.

Regulatory Context of Environmental Restoration

DOE’s environmental restoration activities must be conducted pursuant to applicable environmental laws. The principal environmental laws dictating how the cleanup is to be performed at the weapons sites are the Resource Conservation and Recovery Act, as amended (RCRA), and the Comprehensive Environmental Response, Compensation, and Liability Act, as amended (CERCLA) (also known as Super-fund).[6] Recently, certain provisions of the National Environmental Policy Act,[7] as amended (NEPA), have also played an important role in the CERCLA-based cleanup process. DOE’s environmental restoration efforts are also subject to State laws and regulations, including those set forth under the authority of RCRA and CERCLA (see box 2-A).

DOE nuclear weapons facilities are subject to RCRA requirements, including permits, reporting, and corrective action.[8] Weapons Complex sites must have RCRA permits-or qualify for “interim status” —to operate as treatment, storage, and disposal (TSD) facilities managing hazardous waste. In addition, they must address any release of hazardous material into the environment. Specifically, RCRA requires “corrective action” for the release of hazardous waste from both active and inactive units at a facility that is seeking a RCRA permit.[9] Thus, before issuing a permit for treatment, storage, or disposal of hazardous waste at a weapons facility, the Environmental Protection Agency (EPA) or an

[6] Pub. L. No, 96.510,94 Stat. 2767 (1980) (codified as amended in scattered sections of the I.R.C. and 33,42, and 49 U. S.C.). Throughout this report, any reference to CERCLA should be construed as a reference to the 1980 statute, as amended by the 1986 Superfund Amendments and Reauthorization Act and codified at 42 U. S.C.A. $$9601-11050 (West 1983 and Supp. 1990).

[7] Pub. L. No. 91-190, 83 Stat. 852 (1970) (codified as amended at 42 U. S.C.A. $$4321-47) (West 1983 and Supp. 1990).

[8] See RCRA section 6001; 42 U.S.C.A. §6961 (West 1983).

[9] RCRA Sections 3008(h), 3004(u) (on-site), and 3004(v) (off-site) specify corrective actions. RCRA Section 3004(u), enacted in the Hazardous and Solid Waste Amendments of 1984, prescribes that an Environmental Protection Agency (EPA) or State RCRA permit must require “corrective action for all releases of hazardous waste or constituents from any solid waste management unit [SWMU] at a treatment, storage, or disposal facility seeking a permit. . . regardless of the time at which waste was placed in such units. ” Under this section, EPAmust also promulgate standards requiring corrective action for the release of hazardous waste from SWMUs at any TSD facility seeking a permit.

Box 2-A—Key Laws and Regulations Governing Cleanup at the Nuclear Weapons Complex

RCRA—The Resource Conservation and Recovery Act (RCRA) was enacted in 1976 to address the widespread contamination problem resulting from the disposal of municipal and industrial solid waste. Managed by the U.S. Environmental Protection Agency (EPA) or EPA-authorized States, the RCRA program focuses on reducing the generation of hazardous waste and conserving energy and natural resources. DOE's Nuclear Weapons Complex facilities are subject to RCRA and therefore must apply for an EPA or State permit to treat, store, or dispose of hazardous wastes or radioactive waste mixed with hazardous pollutants. Under the Hazardous and Solid Waste Amendments of 1984 (HWSA), DOE is also required to address and eliminate contaminant releases at or from its RCRA facilities within a schedule specified by EPA. This type of activity, called corrective action, is now being carried out at most weapons sites. Releases from inactive or abandoned sites or from accidental spills are not subject to RCRA, but they may be required to be remedied according to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

CERCLA—The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (also known as Superfund) provides the U.S. Environmental Protection Agency (EPA) with the authority to assess contaminant releases from abandoned waste sites (such as those within the Nuclear Weapons Complex), categorize sites according to their risks, and include them in the National Priorities List if EPA considers their cleanup a national priority. Both radioactive and hazardous contaminants are included under CERCLA authority. Table 2-3 indicates that eight of the Nuclear Weapons Complex sites are currently listed by EPA as requiring cleanup under CERCLA. The Superfund Amendments and Reauthorization Act (SARA) of 1986 authorize EPA to negotiate interagency agreements with other Federal agencies and States and to oversee Federal agency efforts toward developing appropriate remedies.

NEPA—The National Environmental Policy Act (NEPA) of 1970 mandates that all Federal agencies and departments take into consideration the adverse effects that their actions may have on the environment. The Council on Environmental Quality is responsible for developing the guidance for Federal agencies to comply with the act. NEPA requires that agency actions be reviewed early in the planning process and that the process be open to public participation. This review often results in the preparation of an Environmental Assessment or an Environmental Impact Statement (EIS), usually on a specific project. An EIS prepared for an entire program of agency activities is called a Programmatic EIS (PEIS). DOE is currently preparing a PEIS for its Five-Year Plan for waste management and environmental restoration and its modernization plan for the Nuclear Weapons Complex.

SOURCE: Office of Technology Assessment, 1991.

authorized State must require DOE to take such corrective action. If the corrective action cannot be completed before issuance of the permit—which is invariably the case at DOE weapons facilities—the RCRA permit must contain schedules of compliance for the corrective action.

Most of the DOE weapons facilities are operating under interim status.[10] EPA has authority under RCRA to require interim status facilities to take corrective action or other necessary response measures whenever it is determined that there is, or has been, a release of hazardous waste or constituents from a facility.[11] EPA is authorized to issue a corrective action order, which can suspend or revoke the authority to operate an interim status TSD facility, or to seek appropriate relief (including an injunction) from a U.S. district court. RCRA also authorizes EPA to require corrective action at and beyond the facility boundary and to issue civil and criminal actions to those unable to demonstrate compliance.[12] Because of EPA's limitations under RCRA in prosecuting other Federal agencies[13] and

[10]RCRA Section 3005(e) establishes the "interim status" provision for existing TSD facilities, which allows them to continue to operate while going through the final permitting process until a site-specific permit is issued. To obtain interim status, a DOE facility has to submit a brief preliminary application (called a "Part A Application") and comply with interim status requirements for waste management. It must then prepare and file a Part B application for a final permit. 42 U.S.C.A §6925(e) (West Supp. 1990).

[11]See RCRA Sections 3008(h), 3004(u), and 3004(v); 42 U.S.C.A. §§6924(u)-(v), 6928(h) (West Supp. 1990).

[12]See RCRA Section 3004(v); 42 U.S.C.A. §6924(v) (West Supp. 1990).

[13]U.S. Environmental Protection Agency, Office of Solid Waste, Permits and State Programs Division, and the Association of State and Territorial Solid Waste Management Officials, *RCRA Orientation Manual—1990 Edition* (Washington DC: U.S. Government Printing Office, 1990), p. III-90.

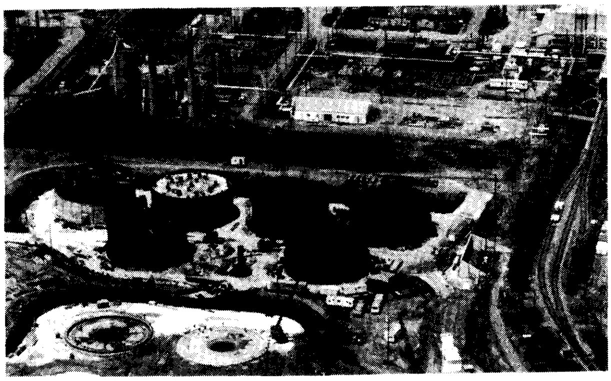


Photo credit: U.S. Department of Energy

Storage tanks for high-level waste under construction at Savannah River from 1980 to 1982.

the 1977 Memorandum of Understanding[14] making the Department of Justice solely responsible for conducting legal proceedings on behalf of EPA, EPA can only issue civil penalties in the form of fines for failure to comply with a corrective action order.

DOE weapons plants are also subject to CERCLA and, in particular, to the special requirements and deadlines for cleanup of Federal facilities contained in CERCLA's Section 120 enacted by Congress in the 1986 Superfund amendments.[15] More than half of the Weapons Complex sites (see table 2-3) have been placed on the National Priorities List (NPL) following application of EPA's Hazard Ranking System. Examples of these include the Idaho National Engineering Laboratory (INEL); the Hanford, Rocky Flats, and Mound Plants; the Feed Materials Production Center (FMPC, also referred to as Fernald); the Savannah River Site; the Oak Ridge Reservation; and Lawrence Livermore National Laboratory (LLNL). Within 6 months of being listed, facilities are mandated under CERCLA to identify both the extent of contamination and appropriate remedial measures and to report the results to EPA for review. This step in the cleanup process is known as the remedial investigation/ feasibility study (RI/FS).[16] EPA has 180 days to approve the RI/FS or ask DOE for additional inforrnation.[17] If approved, DOE officials at these NPL facilities are required to enter an interagency agreement (IAG) with EPA for remedial action.[18]

EPA policy is to have the State join in the IAGs. Thus, these agreements are often signed by three parties: DOE, EPA, and the State in which the facility is located (9). IAGs, which are normally entered into at the RI/FS stage, must include at least a schedule for accomplishing the cleanup, arrangements for operation and maintenance of the site, and a review of the cleanup options considered and the remedy selected.[19] IAGs are enforceable against DOE facilities through citizens' suits; civil penalties may be imposed for failure or refusal of a facility to comply with an IAG.[20] Table 2-4 gives the status of these IAGs as well as other agreements, decrees, and consent orders for each facility.

After completion of the RI/FS, a record of decision (ROD) that outlines proposed remedial alternatives is prepared and made available to the public for input and comment before it is signed.[21] The ultimate remedy selected must ensure compliance with cleanup standards (including State environmental requirements and Federal standards or criteria) that are "applicable" or "relevant and appropriate' under the circumstances (known as ARAR

[14] Memorandum of Understanding on Civil Enforcement Between the Department of Justice and the Environmental Protection Agency—June 13, 1977, [Federal Laws] Environment Reporter (BNA) 41:2401.

[15] Superfund Amendments and Reauthorization Act, Pub. L. No. 99-499, 100 Stat. 1615 (1986) (codified in various sections of tie I.R.C. and 10, 29, 33 and 42 U.S.C.)

[16] 42 U. S.C.A. §9620(e)(1) (West Supp. 1990).

[17] 42 U.S.C.A. $%20(e)(2) (West Supp. 1990).

[18] 42 U. S.C.A. §§9620(e)(2)-(6) (West Supp. 1990).

[19] CERCLA Section 120(e)(4); 42 U. S.C.A. 36920(e)(4) (West Supp. 1990).

[20] CERCLA Section 122(d) 104(b); 42 U. S.C.A. §§9604(b), 9622(d) (West Supp. 1990).

[21] The ROD must contain remedial technologies developed and selected according to CERCLA Section 121 (42 U. S.C.A. §§9621(a)-(f) (West Supp. 1990).

Table 2-3-Environmental Restoration Program Status at the Nuclear Weapons Complex

	Oak Ridge Reservation	Pinellas Plant	Savannah River	Fernald	Mound Plant	Los Alamos	Pantex Plant	Sandia	Kansas City	Rocky Flats	Lawrence Livermore National Laboratory (Main)	Nevada Test Site	Hanford	INEL
National Priorities List. . . .	Yes	No	Yes	Yes	Yes	No	No	No	No	Yes	Yes	No	Yes	Yes
RFA or PA/SI Complete[a]. .	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
RFI or RI work plan submitted	Yes	u	No	Yes	Yes	No	No	No	u	Yes	Yes	?	u	u
CMS or FS complete[c]. . . .	P	No	No	No	No	No	No	No	Yes	P	u	No	u	Yes
Remedial or corrective actions implemented . . .	Limited	No	Limited	Limited	Limited	No	No	No	Limited	Limited	Limited	Limited	No	Limited
Risk-exposure assessment	Limited	No	Limited	Planned	Limited	Limited	No	No	No	Limited	Yes	No	No	Limited
Number of SWMUs identified to date	587	14	313	?	73	603	143	135	35	178	?	?		

NOTE: P = partial; U = underway; X = not under consideration; ? = no information.
[a]RFA = RCRA facility assessment; PA/SI = preliminary assessment/site investigation under CERCLA.
[b]RFI = RCRA facility investigation; RI = remedial investigation under CERCLA.
[c]CMS = corrective measures study under RCRA; FS = feasibility study under CERCLA.
[d]Limited risk-exposure assessment reflects work that does not necessarily meet CERCLA requirements.

SOURCE: Office of Technology Assessment, 1991; based on U.S. Department of Energy 1987-1988 Draft Environmental Survey; interviews with U.S. Environmental Protection Agency and U.S. Department of Energy review letter from R.P. Whitfield to Peter Johnson, June 22, 1990.

requirements[22]).[23] Cleanup is required by CERCLA Section 120(e) to begin no more than 15 months after completion of an RI/FS. EPA regional offices retain discretion over precise remedies to be applied on a site-specific level.

Most Weapons Complex sites are subject to both CERCLA and RCRA. Some sites, which have not been placed on the NPL, operate only under the regulatory jurisdiction of RCRA (i.e., Pantex, Los Alamos, Sandia, Pinellas, Kansas City). A major difference between the CERCLA and RCRA laws is that CERCLA coverage includes both hazardous and radioactive contamination, whereas RCRA and its corrective action provisions cover only hazardous waste and the hazardous portion of mixed waste. At sites subject only to RCRA authority, some radioactive materials and releases of radioactivity to the environment are regulated exclusively by DOE, subject to the Atomic Energy Act.[24] DOE has its own set of internal directives[25] (DOE orders) governing radioactive waste management and the limitations of radionuclide releases to the environment.

Regulation of the current process to characterize contaminated sites and to select and implement adequate remediation falls under the jurisdiction of EPA, the States, or both.[26] Over the past 5 years, DOE has gradually been required to acknowledge that cleanup of the Nuclear Weapons Complex is subject to regulation by EPA (or the States) to the extent that hazardous materials are involved or a site is placed on Superfund's NPL. Until 1984, DOE claimed that it was exempted from regulation under hazardous waste laws such as RCRA because of its Atomic Energy Act authority relating to national security and sovereign immunity from State regulation.[27] A 1984 Tennessee Federal court decision rejected this claim and ordered DOE to comply with all RCRA provisions.[28] It was not until 1987 that DOE clarified that the hazardous portion of mixed waste at its sites is also subject to RCRA.[29]

EPA's Office of Waste Programs Enforcement, within the Office of Solid Waste and Emergency Response, is responsible for ensuring compliance with RCRA and CERCLA requirements. The Federal Facilities Hazardous Waste Compliance Office at EPA headquarters attempts to assist EPA regions to reach and implement CERCLA interagency agreements at NPL sites and to ensure compliance with RCRA (9). EPA believes that most sites can be addressed comprehensively pursuant to an enforceable agreement under CERCLA Section 120.[30] EPA is using the mechanism of the three-party IAG with the State, EPA, and Federal facilities as signatories to resolve jurisdictional overlaps and disputes about which statute to use and whose jurisdiction takes precedence.[31]

Site Characterization Activities

Site characterization is conducted for the purpose of understanding the nature and extent of environmental contamination. It is also important in designing remediation measures and monitoring their effectiveness. The process is lengthy and technically challenging.

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22 42 u. S.C.A. $6921(d) (West Supp. 1990).

23 A recent commentary explains the ARAR concept as follows: "For sites on the NPL. . .[a]ll legally applicable, relevant, and appropriate requirements (ARARs) contained in State environmental laws that are more stringent than Federal ARARs must be applied to remedial actions at Federal sites. . . . [A]lthough EPA has set forth 'objective' criteria for defining ARARs in various agency guidance documents and rules, the ultimate selection of cleanup standards is highly discretionary and involves a determination by EPA of what requirements (including State laws) make sense for remedying the site.. . . In addition, Section 121(i) of CERCLA states that nothing infection 120 (dealing with Federal facilities) shall affect or impair the obligations of a Federal agency to comply with. . .(RCRA)" (10).

24 42 U.S.C. §§2011-2296 (1982 and Supp. IV 1986).

25 Under the authority of Section 161(i)(3) of the Atomic Energy Act [42 U.S.C.A. 2201(i)(3) (1982)], DOE issues internal directives or orders to assure the protection of workers, the general public, and the environment from hazardous and radioactive waste. DOE orders generally consist of broad requirements with limited criteria on how to demonstrate compliance and with considerable authority delegated to field offices.

26 Most States are authorized t. run the RCRA base program, and some have now been granted authority under the Hazardous and Solid Waste Amendments to regulate mixed waste. As of May 10, 1990, the States witb mixed waste authorization relevant to DOE's Nuclear Weapons Complex were Colorado, Idaho, New Mexico, Ohio, South Carolina, Tennessee, Texas, and Washington.

27 42 u. S.C.A. 552201 Q), 2018 (1982).

28 *Legal Environmental Assistance Foundation* v. *Hodel*, 586 F. Supp. 1163 (E.D. Tenn. 1984).

29 Radioactive Waste; Byproduct Material, 52 Fed. Reg. 15938, 15940 (1987) (codifed at 10 CFR §962).

30 The National Priorities List for Uncontrolled Hazardous Waste Sites; Listing Policy for Federal facilities, 54 Fed. Reg. 10520, 10523 (1989).

31 EPA officials have stated that the IAGs satisfy an NPL Federal facility's corrective action responsibilities under RCRA as well as the public participation requirements of both CERCLA and RCRA, with a RCRA permit perhaps later incorporating the IAG as appropriate (9).

Table 2-4-Federal and State Agreements, Decrees, or Consent Orders Relevant to DOE's Nuclear Weapons Complex Facilities

DOE facility	Parties[a]	Consent decree, consent order, or agreements	Date of signing	Goal
Fernald	DOE, EPA	Federal facility agreement (FFA)	July 1986 (being renegotiated)	Assure DOE compliance with CAA,[b] CWA,[b] RCRA, and CERCLA '
	DOE, EPA	Consent agreement	Under negotiation	CERCLA-based deanup of surface and groundwater sources and of waste storage areas
	DOE, State	Consent decree	December 1988	Address compliance with RCRA, CWA, and CERCLA
	DOE, State	Consent decree	December 1988	Enforce compliance with CAA requirements
Hanford	DOE, EPA, State	FFA and consent order (tri-party agreement)	May 1989	Ensure compliance with all environmental regulations and the establishment of an effective cleanup program that integrates NEPA, CERCLA, and RCRA
Idaho National Engineering Lab	DOE, EPA	Consent order and compliance agreement (COCA)	July 1987	Coordinate corrective actions to address contamination at the site
	DOE, State	FFA	May 1990	Oversee DOE'smonitoring and compliance program on air, surface water, and groundwater
	DOE, EPA, State	Interagency agreement (IAG)	Under negotiation	Integrate RCRA/CERCIA investigations and cleanup requirements
Kansas City Plant	DOE, EPA	3008(h) administrative order on consent agreement	June 1989	Address groundwater contamination
Lawrence Livermore National Laboratory	DOE, EPA, State	Federal facility agreement	November 1988	Coordinate cleanup activities of soil and groundwater under CERCIA
Los Alamos National Laboratory	DOE, State	Federal facility agreement	Under negotiation	Ensure DOE compliance with RCRA requirements
Mound Plant	DOE, EPA	Federal facility agreement and consent order	Under negotiation	Coordinate remedial activities required under CERCLA Section 120
	DOE, State	Consent order and compliance agreement	Under negotiation	Ensure DOE compliance with the State's RCRA program
Nevada Test Site	DOE, EPA, State	Interagency agreement	Under negotiation	Combine RCRA and CERCLA investigations and cleanup requirements
	DOE, State	Agreement in principle	Under negotiation	Coordinate current and future corrective actions needed at the site
Oak Ridge Reservation	DOE, EPA	Federal facility compliance agreement (FFCA)	Under negotiation	Coordinate the application of corrective measures at PCB-contaminated areas
	DOE, EPA, State	Tri-party interagency agreement	Under negotiation	Integrate RCRA- and CERCLA-based cleanup activities
	DOE, EPA, State	Memorandum of understanding	1983	Establish ways of mutual cooperation
Rocky Flats Plant	DOE, EPA, State	Federal facility compliance agreement	July 1986	Coordinate RCRA- and CERCIA-based activities
	DOE, State	Mutual cooperation agreement	June 1989	Increase the level of cooperation between DOE and the State and achieve compliance with State regulations
	DOE, EPA, State	Federal facility agreement and consent order	December 1989	Update 1986 FFCA and achieve a more effective integration of RCRA and CERCIA in cleaning up the site
Savannah River Site	DOE, State	Consent order	February 1989	Require DOE to comply with RCRA
	DOE, EPA	Consent order	July 1987	Require DOE to comply with RCRA
	DOE, State	Consent decree	May 1988	Require DOE to comply with RCRA
	DOE, EPA, State	Federal facility agreement	Under negotiation	Combine RCRA and CERCLA investigations and cleanup requirements

[a]Parties listed are DOE (U.S. Department of Energy), EPA (U.S. Environmental Protection Agency), State (the appropriate agency of the State in which the facility is located), and NRDC (Natural Resources Defense Council).

[b]Clean Air Act, 42 U.S.C.A. §§7401-7626 (West 1983 and Supp. 1990); Clean Water Act, 33 U.S.C.A. §§1251-1376 (West 1968 and Supp. 1990).

SOURCES: U.S. Department of Energy, "Envfronmental Restoration and Waste Management: Five Year Plan," DOE/S-0070, 1989; Office of Technology Assessment, 1991.

Photo credit: U.S. Department of Energy

Wood pallets, contaminated from transport of uranium products, await transport on a concrete pad at the Feed Materials Production Center (Fernald) for shipment to Oak Ridge.

DOE's Five-Year Plan for environmental restoration is devoted mainly to describing work to be done pursuant to RCRA or CERCLA. Environmental regulations and guidance promulgated by EPA (or the States) require extensive documentation and review of characterization efforts prior to the submission of detailed plans for cleanup. DOE is currently engaged in following the site characterization process prescribed by applicable environmental regulations. Many project milestones have been established for this work. In most cases, characterization of contamination will continue for 5 or more years, and decisions will then be made on remediation techniques and programs. However, although the process of identifying and characterizing contaminant problems is underway, it is difficult to determine how much has been done and how much remains to be done for the Weapons Complex as a whole.

OTA has collected data on the status of site characterization activities at DOE weapons facilities and has found that, in almost all cases, this work is in the initial site assessment stage (see app. A). All sites are currently performing environmental assessment work under one or more of the following: a RCRA order (issued by a court), a RCRA permit (issued by a State or EPA), or a CERCLA interagency agreement (either between DOE and EPA or among DOE, EPA, and the State). A number of sites have already negotiated (or are in the process of negotiating) interagency agreements within which DOE, EPA, and the States specify terms or conditions for applying current regulations, and set timetables (see table 2-4). The Hanford Federal Facility Agreement and Consent Order (signed in mid- 1989) was the first of these tri-party agreements completed (1 1). This agreement-among DOE, EPA, and the Washington State Department of

Box 2-B—Preliminary Site Status Summary: Radioactive Waste Management Complex (RWMC) at INEL, as of July 1990

Type of Site: Burial site for radioactive (low-level and transuranic) and mixed waste—solids and liquids—from 1952, generally in unlined trenches.

Contamination Problems: Contaminants have migrated into surrounding soil; floods have enhanced migration. Plutonium has been detected in a clay layer about 110 feet beneath the site. Hazardous contaminants have been measured in the groundwater that is about 600 feet beneath the site.

Characterization Status: Special survey programs have been going on since 1987 when an agreement was signed between DOE and EPA. A hazardous waste work plan was issued by DOE in December 1988. This site is one of the reasons INEL was placed on the National Priorities List by EPA in November 1989. Under the CERCLA process, investigations are underway and have been expanded to include radionuclide contamination. Modeling of migration flows is also underway. Much more characterization work is planned through 1995.

Characterization Techniques: Traditional, standard techniques are being used for groundwater and soils sampling and analyses and air monitoring. Computer modeling has been used to simulate migration of contaminants. Other advanced systems are under development.

Remediation Status: No remediation work has been started and none is planned through 1995.

Remediation Techniques: The complex nature of the buried waste is expected to require a combination of remediation techniques. Three major technology demonstration projects are underway for buried waste and contaminated soils at the RWMC. These are in situ vitrification, vacuum vapor extraction, and buried waste retrieval. Other technologies being investigated include soil freezing as a pretreatment for retrieval, plasma furnace for destruction of organics, and solidification of inorganic contaminants into a vitrified waste form, soil washing for removal of transuranic contamination, and bioremediation treatment for destruction of organics and isolation of heavy metals.

Comments: Characterization work is proceeding at a slow pace and is probably limited by funding. Investigation and testing of more conventional stabilization and containment techniques could be pursued more aggressively.

SOURCE: Office of Technology Assessment, with U.S. Department of Energy data and review.

Ecology—covers both RCRA and CERCLA actions and discusses the activities subject to each. It also includes an action plan and milestones for major items of disposal, cleanup, and related paperwork.

Characterization of contamination problems involves three major elements: 1) detecting the presence of contaminants, 2) understanding their movement and changes after entering the environment, and 3) predicting their subsequent transport and fate (i.e., understanding what they are, where they are and in what concentration, how they are changing, and where they are going and how fast). Data requirements depend on the objectives of cleanup, the specific site, and the remedial technologies to be considered. As shown in table 2-3, DOE is just beginning to address the first of many steps in the characterization process—i.e., attempting to determine what releases have occurred and the location, type, and quantity of contaminants.

Current technical approaches to characterization are illustrated by activities at the following locations in three DOE facilities:

1. the Radioactive Waste Management Complex at INEL (see box 2-B),
2. Solid Waste Storage Area 6 at Oak Ridge (see box 2-C), and
3. the Feed Materials Production Center in Fernald, OH (see box 2-D).

All three sites are in the characterization phase; little or no remedial action has been initiated. At each site, only conventional techniques (well drilling, chemical or radioactive analysis of samples, etc.) are currently being used even though DOE is funding research into more advanced technologies (e.g., remote sensors).

Remediation Activities

Because very few contaminated sites in the Weapons Complex have reached the stage at which

Box 2-C—Preliminary Site Status Summary: Solid Waste Storage Area 6 at Oak Ridge National Laboratory, as of July 1990

Type of Site: Below- and above-ground storage of solid radioactive (primarily low-level, but one buried cask of transuranic waste), hazardous, and mixed (including inorganic, organic, and biological) waste, in trenches; silos; above-ground tumulus; unlined, capped auger holes; and landfill.

Contamination Problems: Disintegrating containers and the influx of water into trenches have led to the presence of tritium, cesium-137, and hazardous pollutants in trench leachate and to the migration of contaminants into groundwater (tritium, strontium-90, and hazardous pollutants).

Characterization Status: Standard surveys (under a RCRA facility investigation) have been underway since 1988. Other characterization work is planned.

Characterization Techniques: Characterization of contamination has been conducted by ground survey (walkover, dose rate, and electromagnetic terrain conductivity), gas and soil sampling, sediment sampling, surface and groundwater sampling, data analysis, and modeling.

Remediation Status: In 1976, a bentonite cover was used to seal one trench. However, water has been observed in underlying trenches. A French drain was installed in the trench area to prevent lateral movement of groundwater into it. Interim corrective measures have been undertaken: trenches with RCRA-regulated waste were covered with a high-density polyethylene cap.

Remediation Techniques: These are expected to include capping, surface water control, drainage upgrade; vertical barriers or French drains to lower the groundwater table; and possible groundwater extraction and treatment. Trench grouting and dynamic compaction have been demonstrated on a pilot scale.

Comments: Characterization work has used conventional, rather than advanced, techniques. Remediation technologies are still in the process of being selected.

SOURCE: Office of Technology Assessment, with U.S. Department of Energy data and review.

the amount, type, and extent of contamination have been characterized, little remediation has been proposed or carried out. OTA found that remediation activities have begun at only a few sites and are complete at hardly any. An example of a completed remediation activity is the S-3 Pond project at the Y-12 Plant in Oak Ridge. There the sludge in a series of old radioactive and hazardous waste storage ponds was stabilized through treatment and the addition of rock fill; an engineered cap was then installed. Box 2-E describes the project in more detail.

Several groundwater remecliation projects are underway, all involving 'pump and treat' techniques. Examples of such projects are air stripping organics from a large contaminated aquifer at Savannah River, ultraviolet light and ozonation treatment of a contaminated plume at the Kansas City Plant, ultraviolet light and hydrogen peroxide treatment of contaminants at the Lawrence Livermore National Laboratory, and pumping contaminated groundwater to a wastewater treatment plant at Femald. At other sites (i.e., Rocky Flats), simple collection systems such as French drains have been installed to intercept contaminated water and recycle it to a solar evaporation pond.

As seen from these examples, remediation activities at the weapons sites involve mainly conventional methods such as stabilizing soil or sediments by excavation or by treatment and installation of barriers or caps to prevent leaching. At the S-3 Ponds, investigations of more advanced methods such as in situ vitrification and grouting were carried out, but the techniques were rejected because of uncertain effectiveness, and conventional techniques were used instead. Similarly, in the remediation of contaminated groundwater, recent experience has also favored conventional pump and treat measures because other techniques (e.g., in situ bioremediation) have not been tested or their use is not considered appropriate. However, some newer technologies are being used in the treatment phase, and new technologies are being developed and tested at Savannah River to operate in conjunction with conventional pump and treat systems; these include in situ air stripping with horizontal wells.

Also, in most cases, remediation efforts at the Weapons Complex are considered "interim" in

Box 2-D—Preliminary Site Status Summary: Fernald, as of July 1990

Type of Site: Production facility for purified uranium metals and compounds. Used for storage and disposal of a variety of radioactive (uranium, radium, and thorium) and potentially hazardous chemicals (heavy metals, fluorides, asbestos).

Contamination Problems: Contamination of soil, surface water, sediment, and groundwater. Sources include airborne contamination from stacks, vents, and landfill; wastewater (process and sanitary waste); and leaking storage facilities (radioactive and hazardous chemicals). Potential for air release of radioactive materials stored on-site in silos.

Characterization Status: Ongoing groundwater monitoring; routine environmental monitoring; special studies (1976, 1985-87) commissioned of groundwater, waste pits (radar and electromagnetic terrain conductivity), and surface radioactive contamination. Sitewide remedial investigation/feasibility study underway, including waste characterization (since 1989).

Characterization Techniques: Sampling of soil, surface water and sediment, and groundwater by using DOE and EPA protocols; also groundwater modeling and waste inventory sampling by using EPA protocols.

Remediation Status: Four interim cleanup actions have been initiated: 1) containment of south groundwater contamination plume (above-background uranium concentration in groundwater), 2) pumping and treating perched groundwater beneath the production plant, 3) collection and treatment of stormwater runoff, 4) attenuation of radon emissions from the K-65 silos.

Remediation Techniques: Possible future use of in situ stabilization (vitrification or cementation); removal, treatment, and return or disposal of mixed waste; channel remediation (lining channels, excavating contaminated soil, diverting flow of surface water); groundwater pumping and treatment by using ion exchange, reverse osmosis, or precipitation.

Comments: The facility is well into its characterization program, and remediation technologies are undergoing evaluation. Several EPA Superfund Innovative Technology Evaluation programs might be effective in removing metals and mixed waste, including organic contaminants, from soil, pits, sediment, and groundwater.

SOURCE: Office of Technology Assessment, with U.S. Department of Energy data and review.

nature-i. e., containment measures to slow the migration and avoid further spread of' contaminants or to remove some contaminants, rather than to achieve permanent cleanup. Any ‘permanent” cleanup actions have usually involved removing contaminated materials from a site and either storing them in containers or shipping them to another site. Such removals have occurred at Oak Ridge, Fernald, Rocky Flats, and the Mound Plant. Most of the shipments have been to the Nevada Test Site.

Throughout the Weapons Complex, DOE is faced with an enormous number of site remediation problems. Choices of effective and predictable cleanup techniques are extremely limited, however, because only a few approaches have been tested. Even conventional techniques are not always predictable when applied to specific sites. Widespread problems such as groundwater contamination are particularly intractable, as shown in box 2-F. DOE has advocated more testing of containment technologies, as well as research into approaches that have the potential to destroy some contaminants in place.

Technology development is part of the Five-Yew Plan and is considered vital to ensure that future cleanup actions effectively meet DOE's long-term goals.

Evaluation of Present Efforts

Meeting Stated Goals

DOE's stated goal of environmental cleanup by the year 2019 represents a formidable challenge, and currently available information does not clearly demonstrate that it can be attained. Although it may be desirable for DOE to set a completion date on which to focus its activities, three major barriers stand in the way of achieving this goal: 1) decisions on cleanup levels and standards that can clarify DOE goals have not yet been established; 2) personnel qualified to conduct characterization and remediation at DOE sites are scarce; and 3) technologies for addressing some of DOE's more perplexing environmental problems are not currently available.

Box 2-E—Preliminary Site Status Summary: S-3 Ponds at Y-12 Plant, Oak Ridge Reservation, as of July 1990

Type of Site: Storage ponds for liquid radioactive (uranium and transuranic) and mixed (heavy metal, organic, and nitrate) waste.

Contamination Problems: Surface and groundwater contamination with heavy metals, volatile organics, and nitrates.

Characterization Status: Characterization completed.

Characterization Techniques: Conventional surface and groundwater monitoring.

Remediation Status: A RCRA final closure is completed and awaiting certification.

Remediation Techniques: 1) neutralization (1983-86) and denitrification of pond contents (1983-84); 2) effluent treatment and release (1983-86); 3) stabilization of sludge, rock fill, and engineered capping.

Comments: Denitrification as conducted here was precedent setting because of its use in open air and at high nitrate concentration. Effluent, after treatment, more than satisfied both EPA and State (Tennessee) requirements. The sludge was stabilized with only rock and soil fill (rather than by in situ vitrification or grouting) because of the desire to "get on" with remediation; these other technologies are still in the developmental stage. The area has been covered with asphalt for a parking facility. Groundwater will continue to be monitored to determine how effective these measures were and to determine whether future treatment is needed.

SOURCE: Office of Technology Assessment, with U.S. Department of Energy data and review.

The 1989 Five-Year Plan states that DOE will "contain known contamination at inactive sites and vigorously assess the uncertain nature and extent of contamination at other sites to enable realistic planning, scheduling and budgeting for cleanup" (12). During this start-up period for environmental restoration of the Weapons Complex, the unpredictable pace and quality of site characterization and the uncertainty of funding may hinder the attainment of even these short-term goals.

Given the potentially high cost of environmental restoration, the availability of funds over the entire 30-year cleanup is likely to be an issue. DOE agreements with EPA and the States contain various environmental restoration plans and milestones; the other signatories undoubtedly expect DOE to obtain the funding necessary to meet those commitments. However, the budgetary process does not ensure that this funding will be available; other entities beyond DOE's purview have responsibilities in this area as well. An important issue in this regard is whether and how interagency agreement provisions can be enforced if appropriated funds are insufficient to meet the milestones and schedules specified in the agreements.

Although DOE has set a 30-year cleanup goal, it has not prepared a long-range planning document with cost estimates to meet that goal. The absence of a budgeted plan can make the attainment of any goals difficult to achieve. Not since 1988, when DOE prepared a "needs assessment" report that attempted to describe environmental restoration requirements over a 20-year period, has this long-range view been addressed (13). Over 20 years, some projects could be planned to completion. The current DOE approach was initiated with the 1989 Five-Year Plan, which does not project beyond its limited time frame. Within that period, no DOE projects can be planned to completion.

DOE cites the uncertainties associated with environmental contamination problems at the Weapons Complex as justification for its use of a short-term planning horizon. Long-range planning and the estimation of total cost to completion will remain difficult until the sites have been characterized fully. Also, the levels of cleanup that will be technically feasible, required under applicable statutes and regulations (some of which are yet to be promulgated), or deemed acceptable to the regulators and protective of public health and the environment are not yet clear. Many of these uncertainties can be resolved only through experience. Other long-term projects with high degrees of uncertainty have been known to experience significant cost overruns and delays.

Box 2-F-Contaminated Groundwiater Can Be Difficult To Clean Up

Groundwater can become conaminated from numerous sources. At the Nuclear Weapons Complex, sources include accidents and spills; intentional introduction of waste into the ground (cribs, surface impoundments, underground injection wells, landfills); and failure of containment methods (underground storage tanks).

Groundwater contamination is very site-specific in terms of the contaminants present and their behavior. Groundwater contamination is such a difficult problem to characterize and cleanup because the environment is not uniform. In genenral, the less uniform the environment (such as fractured limestone at Oak Ridge or the presence of clay lenses at Savannah River), the more difficult it is to characterize contamination problems and clean them up. Some contaminants will be easier to find and clean Up than others. For example, those contaminants that move with water are easier to find than those that do not.

Contaminants at the Weapons Complex include radionuclides, heavy metals, nitrates, and organic contaminants (see table 2-1). Often these are present as complex mixtures that affect the mobility and fate of individual contaminants in the subsurface. Contaminants also behave in different ways, depending on the characteristics of a site. As contaminants move through the ground to an aquifer, many processes occur that affect the amount or concentration of the contamination by the time it reaches a receptor of corlcem such as a well or surface water. The processes may also affect the performance of remediation techniques. Many of these processes, however, are not well understood.

Some contaminants adsorb onto soil particles in the unsaturated zone or onto the aquifer media, thereby slowing their movement and possibly preventing groundwater contamination. Contaminants may also form or adsorb onto colloidal particles, which allows them to move with, or faster than, the average groundwater flow. Flow can result from an apparently unrelated force, such as the flow of water and contaminants due to a thermal or electrical gradient instead of the expected hydraulic gradient. Chemical reactions and biotransformation may occur, possibly changing the toxicity or mobility of contaminants. Some contaminants dissolve and move with the water; some are in the gas phase; others are nonaqueous phase liquids; some are more dense than water and may move in a direction different from groundwater others may be less dense than water and float on top of it.

Contaminants that dissolve in water can often be extracted from groundwater and cleaned up with pump and treat techniques. This is the most commonly used procedure to clean up contaminated groundwater. Pump and treat can successfully remove great quantities of contaminants; however, the approach often takes much longer than originally planned to reduce contaminants to desired levels. Pumping can often bean effective way to prevent the spread of groundwater contamination and even reduce the size of a contaminated plume, but in some cases it may not be possible to restore aquifers by pump and treat methods. EPA recognizes that, with current technologies, complete groundwater restoration may not be practicable in some circumstances, such as highly contaminated zones near the source of contamination that remain contaminated at levels preventing beneficial use. Imng-term containment, natural attenuation, wellhead treatment or alternate water supply, and institutional controls to restrict water use may be necessary rather than attempting to restore an aquifer to health-based standards.

Because contaminated groundwater is so difficult to clean up, it is especially important to prevent contamination from occurring in the first place and to prevent it from spreading further once it has occurred.

SOURCE: **Office of Technology Assessment, 1991.**

Site Characterization

Characterization— the process of locating, identifying, and evaluating huge quantities of radioactive and hazardous wastes that have migrated through the subsurface-is technically complex, costly, and loaded with uncertainty. It currently involves drilling hundreds of weIls, collecting and analyzing samples, modeling contarninant migration, and other activities. Characterization is a difficult task that requires a high level of expertise to implement properly. The quality of' characterization can be harmed by poor planning, inappropriate methods, or incorrect field and laboratory procedures. Even the best approaches may yield highly uncertain results about fate and transport. This uncertainty is a particular problem for certain types of contaminants found at DOE weapons sites and for certain hydrogeologic environments.

As an example, although groundwater contamination may be identified from a few samples, understanding the concentration, extent, and movement of that contamination requires much more extensive

Photo credit: Martin Marietta Energy Systems

S-3 Liquid Waste Holding Ponds at the Oak Ridge Y-12 Plant. The photo on the left shows the pond before remedial action was taken. More than 10 million gallons of liquid waste were treated from the four 1-acre ponds. Sediment in the empty pond basins was stabilized with 60,000 tons of gravel, followed by a covering of 15,000 cubic yards of clay and additional layers of sand and topsoil. The ponds have been paved and are being used as a parking lot as shown by the photo on the right of the S 3 Ponds afterpaviing.

sampling; even then, only partial information will be gathered (see app. B). In addition, great technical uncertainty is inherent in predicting the fate and transport of contaminants. In many instances, characterization work has been underway for several years but has not produced sufficient data to determine the risks of contamination reaching human receptors (see ch. 3). Throughout the characterization process, therefore, DOE'S efforts must involve careful assessment of risks and must be subject to long-term monitoring to ensure that urgent problems are identified and receive immediate remedial attention.

Although sufficient characterization must be accomplished before intelligent cleanup decisions can be made, it is wasteful and sometimes risky to insist on characterizing every situation completely before any cleanup is begun. Achieving a balance between sufficient understanding and cleanup action requires the collective judgment of professionals from many disciplines. As characterization proceeds, however, it is becoming evident that people qualified to conduct and oversee characterization are kicking both at DOE sites and at Federal, regional, or State regulatory agencies. This problem may further lengthen the characterization process, lead to delays in commencing remediatition, and result in new problems in the future. DOE has recognized the need for qualified personnel and must now focus adequate attention on building this cadre of professionals.

Site Remediation

Few remediation techniques are available to DOE for cleanup of many contamination problems at the weapons sites (e.g., groundwater, buried waste, pits, ponds, lagoons, soil, sediments). Those available are limited mainly to capping and stabilizing soil (e.g., at the old settlement ponds at Oak Ridge or Hanford); pumping and treating groundwater (e.g., at LLNL, Savannah River, or Kansas City); and excavating and storing mixed waste (e.g., at Oak Ridge and Rocky Flats). These techniques are used because they have been tested enough to receive regulatory approval. Regulatory approval implies that the consequences of their use are known, but much more work is required to test and prove the effectiveness of these techniques at the Weapons Complex.

OTA has examined the prospects and limitations of various approaches to environmental restoration of some the problem areas found at the Weapons Complex (see app. B). For example, groundwater remediation, in many instances, may prevent the spread of contamination but does not completely remove contaminants from the environment. Pump and treat systems have been tested at Savannah River, LLNL, Kansas City, and elsewhere for the control of organic chemicals in groundwater. These types of contamination may be contained in the future but they probably cannot be eliminated completely. Although newer treatment technologies such as bioremediation are promising, they have not been proved and also have limitations regarding either the extent of cleanup possible or the time required. In light of these limitations in cleanup capabilities over most of the next 30 years, DOE should develop plans for continuous monitoring of groundwater contamination over long periods to ascertain the effectiveness of centainment by available technologies.

For contaminated soil or buried waste, it is not clear whether removal and destruction of some centaminants on-site (e.g., through incineration) or removal and disposal elsewhere offer greater benefits. Some disadvantages of the removal option include worker health risks and the likelihood of increased air emissions when incineration is used. A possible disadvantage of the in situ approach is partial destruction of the toxic elements (in the case of mixed waste). If the disadvantages of waste removal are fairly significant, the alternative of leaving waste or contamination in place and stabilizing it may be the most prudent approach. However, DOE has not analyzed these options carefully enough in specific cases and has not evaluated possible alternatives. The cases requiring evaluation are many and varied and could require different solutions.

What "cleanup" really means may not become evident to the public until actual decisions on remediation techniques are made. In many instances, certain waste and contamination now present at DOE weapons sites—for one reason or another, and in some form or another-will probably remain there considerably beyond the year 2019. Certain situations throughout the Weapons Complex are particularly troublesome, and no reasonable technical solutions are currently available. Among these are centaminated soil at Hanford (from old crib discharges),[32] plutonium-contaminated soil at Rocky Flats, buried transuranic waste at INEL, high-level waste injected into the subsurface at Oak Ridge, uranium-contaminated soil at Fernald, and the single-shell tanks at Hanford. For example, the situation with respect to these single-shell tanks should be carefully assessed to determine the risk to workers and the community from excess radiation exposure. If the waste is to be removed and relocated, this risk should be compared with the risk of alternative solutions.

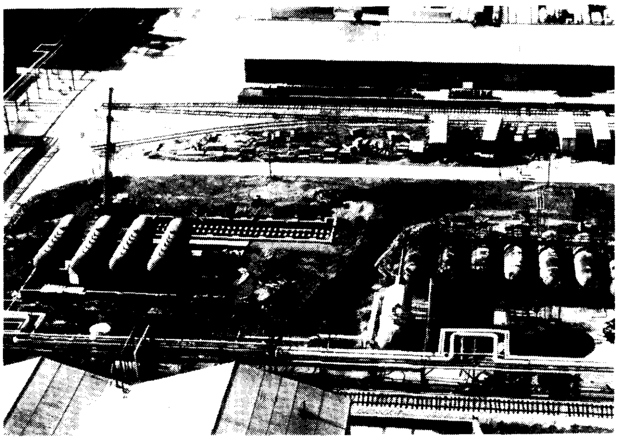

Photo credit: U.S. Department of Energy

Hazardous chemicals used in various Fernald processes are stored in a centralized tank farm, which contains original equipment installed in the 1950s. A comprehensive safety review, completed in 1985, recommended both short- and long-term improvements in storage. All near-term improvements are now complete.

The Nation must begin to define the extent of cleanup that is possible and practical, to identify the decisions that must be made about long-term stabilization and monitoring, and to initiate a process that will specify scientifically sound and publicly acceptable cleanup standards. Considerable confusion and ambiguity surround the cleanup standards that DOE will be required to meet. Box 2-G illustrates three situations contributing to this confusion: 1) radiation protection guidance is outdated; 2) CERCLA cleanup standards are at least 5 years from being finalized; and 3) no maximum concentration level standards have been set for radon or uranium in drinking water. These problems and others should receive high priority.

DOE is now emphasizing the development of new technologies that may be more effective, be less costly, and go farther toward actual destruction of some contaminants (14). New technologies may offer benefits for treating certain types of waste or contamination in place (in situ), but they generally require much more testing and evaluation than are currently planned. In addition, many of these technologies, especially those using biological processes, work very slowly and their progress is difficult to monitor. Thus, they probably cannot be applied to weapons sites until determinations are made about required or acceptable levels of cleanup

[32]Cribs are shallow trenches dug in the ground and used to receive overflow from the old high-level radioactive waste tanks.

Box 2-G—Examples of Cleanup Standards Needing Attention

Radiation Protection Standards

The existing Federal guidance for protection of the public against radiation is outdated, and the development of new guidance is uncertain.

In developing regulations to protect the general public against radiation, EPA adopted the Federal guidance developed by the now-defunct Federal Radiation Council and approved by President Eisenhower in 1960.[1] With the exception of the radiation protection standards issued by EPA in 1979 to control radionuclide emissions from nuclear power plants, relatively little has been done in this area under the authority of the Atomic Energy Act. As a consequence of this deficiency, Federal agencies (e.g., DOE and the Nuclear Regulatory Commission) promulgate agencywide orders requiring compliance with radiation limits they believe will protect the public. Most of these standards, however, are derived from permissible radiation levels for occupational exposure. In an effort to update the Federal guidance for public protection, EPA has formed an interagency group called "the Residuals Project" to make suggestions for updating the guidance within a few years. It is uncertain when and whether EPA would revise their standards to reflect: 1) recent findings by the National Research Council's Committee on Biological Effects of Ionizing Radiations[2] (BEIR V report) that the risks of low-level ionizing radiation are two to three times more serious than it previously anticipated and 2) the draft recommendation by the International Commission on Radiological Protection that the current radiation limit for workers be reduced by 60 percent.

Site Cleanup Standards

CERCLA requires EPA to develop cleanup standards for radioactively contaminated sites; however, cleanup standards are at least 5 years away from being finalized.

EPA is planning to develop standards for the cleanup of radioactively contaminated sites. This task will be conducted by Residuals Project members after completion of their work on radiation protection. Standards will address radioactive contamination not covered by high-level, low-level, or media-specific regulations. EPA expects to promulgate its final cleanup standards in 5 to 10 years. These will be needed for much of the large-scale cleanup contemplated at the Nuclear Weapons Complex.

Drinking Water Standards

Current primary drinking water standards do not provide maximum concentation levels (MCLs) for radon or uranium contamination. EPA is attempting to address this need; however, no appropriate standards for protection of drinking water from these radionuclides are expected to be proposed before 1992.

Section 1412 of the Safe Drinking Water Act[3] (SDWA) requires EPA to issue primary standards to control the amounts of radionuclides in public drinking water systems. As opposed to the "radiation dosage" approach (i.e., allowed dose to the maximally exposed individual) used by the Office of Radiation Programs for developing radiation protection standards, the Office of Water uses the "population dose" concept (i.e., MCLs) to develop drinking water standards. The primary objective of the MCLs currently enforced is to prevent the contamination of groundwater sources by manmade radiation, particularly radium-226, radium-228, and gross alpha particle activity.

At present, the drinking water quality standards are being revised. The most relevant options being considered by the Office of Water are: 1) modifying the current standard to include separate MCLs for radium-226 and radium-228, 2) proposing MCLs for radon and uranium, 3) using the current gross alpha particle activity standard for monitoring purposes, and 4) replacing the concentration levels for radionuclides with a single limit for all radionuclides.

Uncertainties associated with their occurrence, toxicity, and exposure routes have prevented EPA from promulgating maximum concentration levels for radon and uranium. EPA expects to issue its revised standards in early 1992.

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[1]Federal Radiation Council, Radiation Protection Guidance for Federal agencies, 25 Fed. Reg. 4402 (1960).

[2]National Research Council, Committee on the Biological Effects of Ionizing Radiations, *Health Effects of Exposure to Low Levels of Ionizing Radiation—BEIR V* (Washington, DC: National Academy Press, 1990).

[3]42 U.S.C.A. § 300g-1 (West 1982, and Supp. 1983-1989).

SOURCE: Office of Technology Assessment and footnotes 1, 2, and 3.

Box 2-H—Types of Waste

High-Level Waste (HLW): The highly radioactive waste material that results from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid waste derived from the liquid that contains a combination of transuranic waste and fission products in concentrations requiring permanent isolation.

Transuranic (TRU) Waste: Without regard to source or form, waste that is contaminated with alpha-emitting transuranium nuclides with half-lives longer than 20 years and concentrations higher than 100 nanocuries per gram at the time of assay.

Low-Level Waste (LLW): Waste that contains radioactivity and is not classified as high-level waste, transuranic waste, spent nuclear fuel, or byproduct material. Test specimens of fissionable material irradiated for research and development only, and not for the production of power or plutonium, may be classified as low-level waste, provided the concentration of transuranics is lower than 100 nanocuries per gram.

Hazardous Waste: Waste that is designated hazardous under RCRA and EPA regulations.

Mixed Waste: Waste containing both radioactive and hazardous components as defined by the Atomic Energy Act and the Resource Conservation and Recovery Act, respectively.

SOURCE: U.S. Department of Energy Order No. 5820.2A.

over extended periods. In the past, only a few remediation technologies received sufficient long-term developmental attention and funding to bring them to the point at which they could be applied to actual cleanup projects.

If benefits are to be achieved from new technologies, future DOE technological development programs will have to focus more carefully on major remediation needs and will require a consistent long-term coremitment of resources. Yet, although the promise of new techniques for remediation is real, technological research is only part of what is required to develop them. An entire program must be implemented that will develop, test, and implement these techniques, as well as obtain regulatory and public approval for their use.

WASTE MANAGEMENT

Status

Overview

Environmental problems at the Nuclear Weapons Complex today are a direct result of poor waste management practices over the past 40 years. The challenge now facing DOE is how to design and build a waste management system that will prevent future contamination from radioactive and hazardous materials. Waste management has been given attention in recent years by DOE, and major funds (about $1.5 billion in FY 1991) are now directed toward waste management projects throughout the Weapons Complex.[33] DOE has acknowledged, however, that much more needs to be done especially in minimizing future waste generation, building treatment systems to create more secure forms of waste, and creating better and safer long-term storage and disposal facilities.

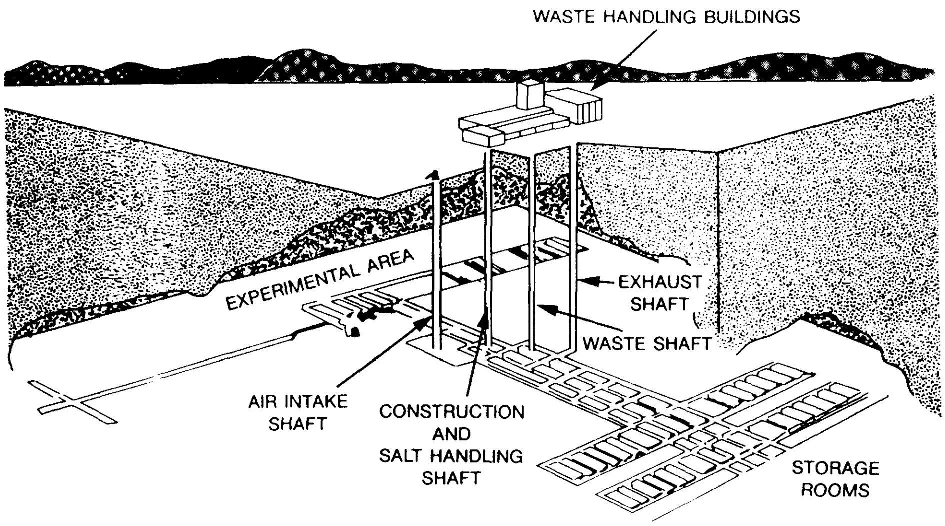
In the 1990 Five-Year Plan, almost two-thirds of current and future funding is devoted to waste operations.[34] This funding initiative reflects the fact that, although major waste management facilities are now under construction, most DOE waste is still stored at all sites under temporary, sometimes marginal, conditions. Making the transition from temporary storage to safer, more permanent conditions will require major investments.

Since the 1970s, DOE has organized its waste management programs by type of waste and thus has had separate programs for the storage and disposal of high-level waste (HLW), transuranic (TRU) waste, and low-level waste (LLW) (see box 2-H). In addition, DOE is required to manage hazardous

[33]In this assessment, OTA has focused on the evaluation of high-level and transuranic waste management at the Weapons Complex because these forms pose the most risk, they are unique to DOE, and the bulk of current and future resources will be devoted to them. For a discussion of low-level and mixed waste primarily in the commercial sector, see the 1989 OTA report "Partnerships Under Pressure: Managing Commercial Low-Level Radioactive Waste" (15).

[34]Unlike environmental restoration, a relatively new concept at the DOE Weapons Complex, waste management has been a traditional function for a long time. It has always been necessary, as part of weapons production, to control and dispose of generated waste products.

Figure 2-3—The Waste Isolation Pilot Plant: Its Capacity, Estimated Operational Cost, and Estimated Lifetime



Total waste capacity:	6 million cubic feet
Current accumulated waste volume:	2.12 million cubic feet
Construction cost to date:	$700 million
Estimated cost for 25-year operation:	$2.5 billion
Estimated total time to fill the WIPP repository:	20 - 30 years

SOURCE: Office of Technology Assessment and U.S. Department of Energy.

waste and mixed waste in accordance with EPA and State regulations. The 1990 Five-Year Plan discusses DOE programs for managing the waste at the Weapons Complex and reflects the recent reorganization of DOE waste management activities. Programs for treating, storing, and disposing of the weapons waste are now the province of the Office of Waste Operations, one of three subdivisions of the Office of Environmental Restoration and Waste Management.

According to current DOE plans, most of the high-level and transuranic waste now stored at various weapons sites would be shipped off-site for disposal to two repositories-one for each type of waste. Congress has mandated that a site at Yucca Mountain, NV, be evaluated for potential use as a deep geologic repository for both commercial spent fuel and high-level waste from the weapons plants. High-level 'waste would be placed there-if and when the site proved suitable (16). In 1980, Congress authorized the Waste Isolation Pilot Plant (WIPP) near Carlsbad, NM, as a research and development facility to demonstrate the safe disposal of radioactive waste from U.S. defense activities and programs.[35] DOE now plans to conduct tests at this facility (see figure 2-3) and, if it is deemed suitable, to dispose of retrievable stored and yet-to-be-generated TRU waste from the weapons sites there (16).

Most high-level waste at the weapons sites is currently stored in liquid or semiliquid form in underground tanks (see box 2-I).[36] The next step in DOE's plan for HLW management is to separate a "low-level" fraction, solidify the remainder (pri-

[35] U.S. Department of Energy National Security and Military Application of Nuclear Energy Act of 1980, Pub. L. No. 96-164, $213(a), 93 Stat. 1265 (codified as amended at 42 U.S.C. §7271 (1983).

[36] At Savannah River and Hanford the liquid, acidic, high-level waste from reprocessing is neutralized (a consequence Of the decision to use carbon steel rather than stainless steel tanks for 'interim' storage), which complicates later waste treatment because sludge and salt cake are formed in the tanks.

Box 2-I—Description of High-Level Waste Tanks

Savannah River

There are 51 large concrete reinforced steel tanks located in two separate "tank farms" at the Savannah River Site. The tanks are of four different designs. Type I and II tanks are closed steel cylinders. Each tank sits inside a 5 foot-high secondary steel "pan" enclosed by a reinforced concrete support structure and topped by a thick concrete roof. There are twelve 750,000-gallon type I tanks and four 1,030,000-gallon type II tanks. Type III tanks are of similar design, with the pan forming a secondary barrier under and around the primary tank at full height. Twenty-seven type III tanks have been built to date, each with a 1.3-million-gallon capacity. Types I, II, and III tanks also have waste cooling capacity. Type IV tanks are older, uncooled, single-wall tanks used for storage of waste that does not require auxiliary cooling. There are 12 type IV tanks, each capable of holding 1.3 million gallons.

None of the type III tanks has developed any leaks; to date, five type I tanks have leaked detectable amounts of waste into the secondary steel pan; all four type II tanks have leaked significant amounts. (Waste from one tank (16H) overflowed its secondary pan on one occasion.) One type IV tank (20) developed leaks in the steel liner, and the waste has been removed from that tank.

SOURCE: U.S. Department of Energy, "Savannah River Waste Management Operations Program Plan—FY1989," DOE/SR-WM-89-1, December 1988.

Hanford

There are 177 tanks located in 18 "tank farms" at the Hanford Reservation. The Hanford tanks are of five different designs. There are 149 type I through IV tanks; each is a reinforced concrete cylinder lined with a single layer of carbon steel. The 28 newer type V tanks are built with secondary carbon steel barriers in what is known as the "tank-within-a-tank" design. The lined cylinders are then capped by concrete roofs and covered under 1.8 to 2.7 meters (5.9 to 8.8 feet) of soil and gravel.

The capacities of the tanks range from 210 to 4,300 cubic meters (55,476 to 1.137 million gallons) distributed as follows:

Type	Numbers built	Capacity in cubic meters	(gallons)
I	16	210	(55,476)
II	60	2,000	(528,344)
III	48	2,800	(739,682)
IV	25	3,800	(1.004 million)
V	4	3,800	(1.004 million)
V	24	4,300	(1.137 million)

None of the newer type V tanks has been known to leak. However, DOE officials have identified definite or possible leaks in 66 of the 149 type I through IV tanks since 1959, with the estimated leakage volume currently ranging between 670,000 and 900,000 gallons. Unlike Savannah River, where tank leakage can be determined by the presence of liquid in the secondary pans, leaks in the single-shell tanks at Hanford are detected by monitoring liquid levels in the tanks and levels of radiation in the dry wells near the tanks. Because DOE cannot measure liquid levels in many of the older tanks, detection and estimation of the amount of leakage depend mostly on dry well monitoring.

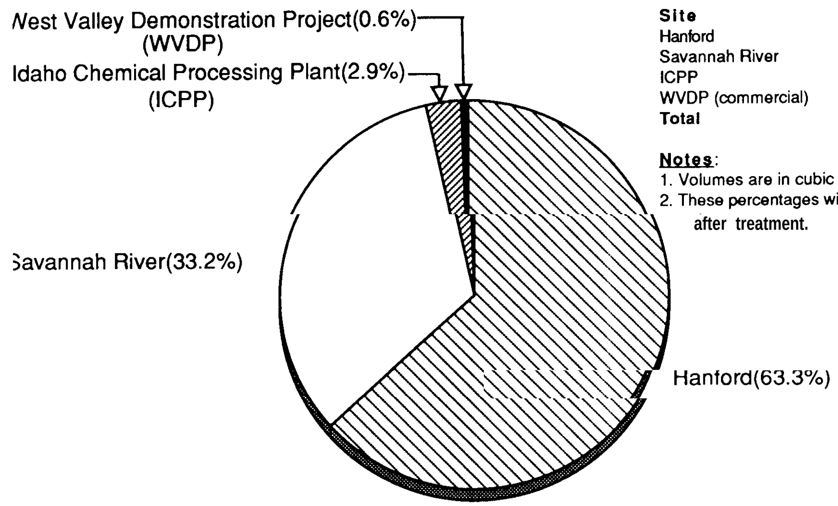
SOURCES: U.S. Department of Energy, "Disposal of Hanford Defense High-Level, Transuranic and Tank Wastes," DOE/EIS -0113, vol. 2, December 1987; U.S. General Accounting Office, "DOE's Management of Single-Shell Tanks at Hanford, Washington," GAO/RECD-89-157, July 1989.

marily by turning it into a glasslike form through vitrification),[37] and then dispose of the vitrified waste in the Federal geologic repository at Yucca Mountain. This plan applies directly to the sites at Savannah River and Hanford where most of the high-level waste is now stored as liquid, sludge, or slurry in underground tanks.[38] After separation, the low-level fraction of this waste will be mixed with

[37]Vitrification at Savannah River and Hanford involves mixing the waste with borosilicate glass material and melting the mixture at high temperature so that it solidifies into a glasslike solid.

[38]At INEL, high-level waste is now stored in dry, granular form ("calcine"), and treatment options to prepare this form for repository disposal are being studied.

Figure 2-4-Total Volume of High-Level Waste Through 1988



Site	Volume
Hanford	244,000
Savannah River	128,000
ICPP	11,000
WVDP (commercial)	2,130
Total	385,000

Notes:
1. Volumes are in cubic meters.
2. These percentages will change after treatment.

SOURCE: U.S. Department of Energy, "Integrated Data Base for 1989," DOE/RW-0006, November 1989.

volume than the sludge) would be processed for disposal as low-level waste.[44] Over the past several years, many concerns have been raised about the leakage of high-level tank waste and possible explosions within tanks. DOE and its contractors have recently been evaluating hydrogen gas generation in both the older single-shell tanks and the newer double-shell tanks at Hanford, which could conceivably reach ignitable or even explosive concentrations. DOE is also studying methods to reduce the likelihood of such occurrences (16).

At Idaho, the high-level waste (about 3 percent of the total volume and 6 percent of the radioactivity within the Weapons Complex) has been handled differently from the other two sites. For the last 25 years, instead of neutralizing the waste so that carbon steel storage tanks could be used as at Hanford and Savannah River, INEL has been converting liquid high-level waste into a white powdery solid material known as "calcine" and storing it in underground stainless steel bins inside concrete vaults. At some future date the calcine will be immobilized (by a method as yet undetermined) and eventually placed in a repository. Prior to calcining, the acidic liquid waste is stored in stainless steel underground tanks at the Idaho Chemical Processing Plant (ICPP). These tanks, however, have been judged incapable of meeting all environmental regulations and DOE orders. Thus, five of the eleven 300,000-gallon-capacity (underground) storage tanks are expected to be replaced by four new stainless steel tanks by 1997. Figure 2-6 shows existing and planned HLW management facilities at each of the DOE sites.

DOE plans to dispose of high-level waste within the Weapons Complex in a deep geologic repository. Because of Congressional action, the only site being examined at present for an HLW repository is at Yucca Mountain in Nevada. If a repository is built there, it will not be able to accept waste until the second decade of the 21st century, at the earliest (16). The repository, which would accept commercial spent fuel as well as high-level weapons waste, would have to be licensed by the NRC. The facility would also have to comply with applicable EPA environmental standards for disposal of spent fuel

[44]The 149 single-shell buried tanks containing high-level waste are not included in this plan, and no final plan has been adopted for these tanks. For additional information, see reference 16.

cement, solidified, and disposed of in large concrete vaults at Hanford and Savannah River. These near-surface or above-surface vaults at each site will contain the waste in a form believed by DOE to be sufficiently immobile to meet requirements for safe disposal. The vaults will cover large areas and require long-term monitoring. DOE's plan for transuranic waste is to transport it by truck to WIPP from the various sites at which it is stored in 55-gallon drums.

In addition to the above, much low-level radioactive waste and hazardous waste is generated at every DOE facility as a result of daily operations. In general, low-level radioactive waste is disposed of in shallow trenches at each site (Savannah River, INEL, Oak Ridge, Hanford, Los Alamos, Nevada Test Site) or shipped off-site (from Pinellas Plant, Mound Plant, Fernald) for burial. At some sites, improved disposal practices for low-level waste are in use with controlled drainage and monitoring. At most sites, nonradioactive hazardous waste is shipped to a commercial treatment and disposal facility.

Regulatory Context of Waste Management

DOE's waste management programs at the Weapons Complex are subject to several Federal laws, including the Atomic Energy Act, as amended (AEA),[39] and RCRA. These laws, as well as regulations and DOE orders, define categories of waste (e.g., HLW and hazardous waste). The laws also assign responsibility over these wastes to various Federal agencies. DOE has authority over the storage and treatment of HLW on site (including the proposed vitrification of HLW and interim storage of the resulting glass logs), and the management of TRU waste at weapons sites.

Much of the radioactive waste on DOE sites is mixed with waste defined by RCRA as hazardous waste, and thus is subject to regulation by EPA or the States under RCRA. Historically, DOE did not have a separate program for mixed waste because it managed this waste under AEA authority only with regard to its radioactive constituents. Until the mid-1980's, DOE maintained that the AEA exempted this waste from regulation under RCRA. Following a Federal court decision rejecting DOE's position regarding RCRA hazardous waste at the Y-12 Plant,[a] DOE eventually issued an interpretative ruling confinning and clarifying that RCRA applies to the hazardous component of mixed Waste.[41] DOE has issued several internal orders governing the management of radioactive and mixed waste at the weapons sites.[42]

Storage, Treatment, and Disposal of High-Level Waste

High-level waste is stored at three weapons sites: Savannah River and Hanford (which together have more than 96 percent by volume of the HLW in the Weapons Complex and 92 percent of the radioactivity (17)) and Idaho.[43] Figures 2-4 and 2-5 illustrate the amounts of high-level waste at each site.

High-level waste stored in underground tanks (see box 2-I) at Savannah River (about 34 million gallons of waste) is awaiting vitrification at the newly constructed Defense Waste Processing Facility (DWPF), which is planned to begin operating with radioactive materials in 1992 or 1993. A waste storage building has been constructed on-site to store 2,300 canisters of the vitrified HLW "glass logs" (approximately 5 years of DWPF production). DOE hopes eventually to ship these to the Yucca Mountain repository. DOE intends to manage the radioactive salt solution fraction from the HLW vitrification process as low-level waste, and to treat and process it in the newly constructed Saltstone Manufacturing and Waste Facility. That facility began treating some low-level waste in 1990. The waste will be disposed of on-site in above-ground concrete vaults (16).

At Hanford, DOE intends to vitrify the "high-activity fraction" (mostly in the form of sludge) of the 20 million gallons of high-level radioactive waste now stored on-site in double-shell tanks, in a facility whose construction has not yet begun but that is planned to be operational in 1999 (the Hanford Waste Vitrification Project). Liquid from the pretreatment process (which has a much larger

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39Atomic Energy Act, 42 U.S.C. §§201 1-2296 (1982 and Supp. IV 1986).

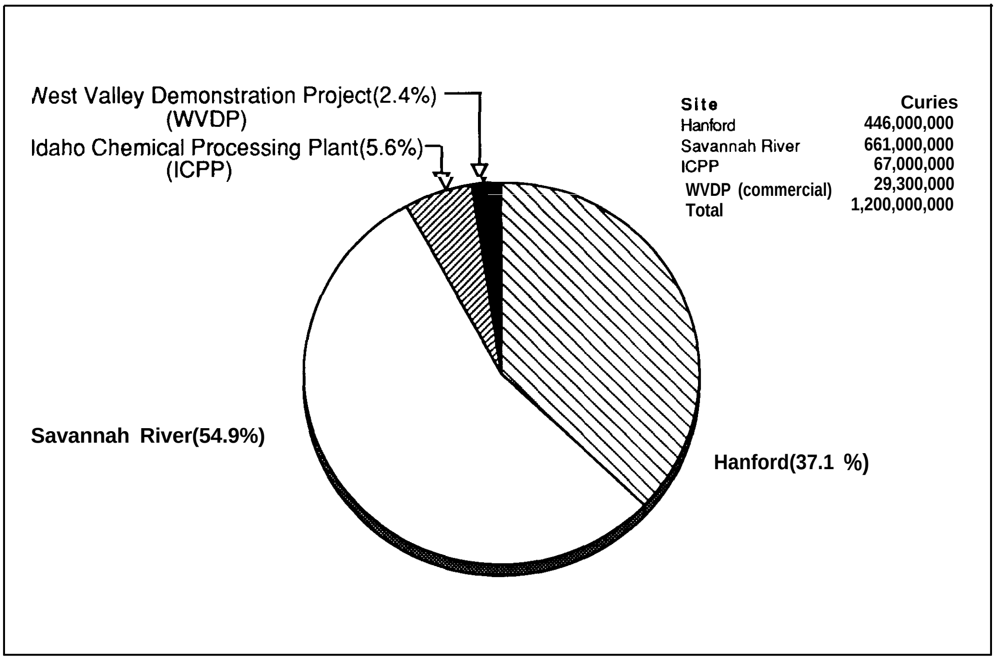
40*Legal* En,i,,nm,nt,l Assistance *Foundation* v. *Hodel*, 586 F.Supp. 1163 (E.D. Tenn. 1984).

41Radioactive Wrote; Byproduct Material, 52 Fed. Reg.15937 (1987).

42E.g., DOE Orders 5820.2A (Radioactive Waste Management) and 5400.3 (Hazardous and Radioactive Mixed Waste Program).

43A fourth location at West Valley, NY, although not a weapons site, also has high-level waste that falls within the purview of DOE and is being treated in a fashion similar to Savannah River and Hanford.

Figure 2-5-Total Radioactivity of High-Level Waste Through 1988



SOURCE: U.S. Department of Energy, "Integrated Data Base for 1989," DOHRW-0006, November 1989.

and defense high-level waste.[45] The standards are not expected to be reissued until late 1990 and may not be adopted until 1992. Because essentially all high-level waste is mixed waste, RCRA regulations would also apply.

Storage, Treatment, and Disposal of Transuranic Waste

Prior to 1970, tmnsumnic waste was disposed of in the same manner as low-level waste---by shallow land burial; since 1970, however, it has been retrievable stored (mostly in 55-gallon metal drums placed on concrete or asphalt pads) at several sites including Idaho (61 percent, the largest volume), Oak Ridge (which has most of the TRU waste that must be remotely handled because of its high radioactivity), Hanford, Rocky Flats, Los Alamos, and Savannah River. A portion of the stored TRU mixed waste is in containers that are reaching their design lifetime of 20 years (16). Table 2-5 shows the estimated dates when the storage capacity for TRU mixed waste will be exceeded at individual weapons sites.

Mixed transuranic waste constitutes a large portion of retrievable stored TRU waste at the Weapons Complex sites. Mixed waste contains both a hazardous waste component subject to RCRA and a radioactive waste component regulated under AEA. Mixed transuranic waste is thus subject to the 1984 amendments to RCRA-the Hazardous and Solid Waste Amendments (HSWA)-which prohibit land disposal of hazardous waste that does not meet treatment standards established by EPA,[46] unless EPA grants a "no-migration" variance to a waste, a national capacity variance for 2 years beyond the statutory deadline, or a case-by-case extension.[47]

In January 1990, DOE provided EPA with its "National Report on Prohibited Waste and Treatment Options" (18); this included data showing that DOE lacks treatment capacity for mixed waste. After reviewing this and other data sources, EPA found that a capacity shortfall of treatment technologies for "Mixed RCRA/Radioactive Wastes" exists on the national level.[48] In recognition of this lack of treatment capacity, EPA granted a 2-year national

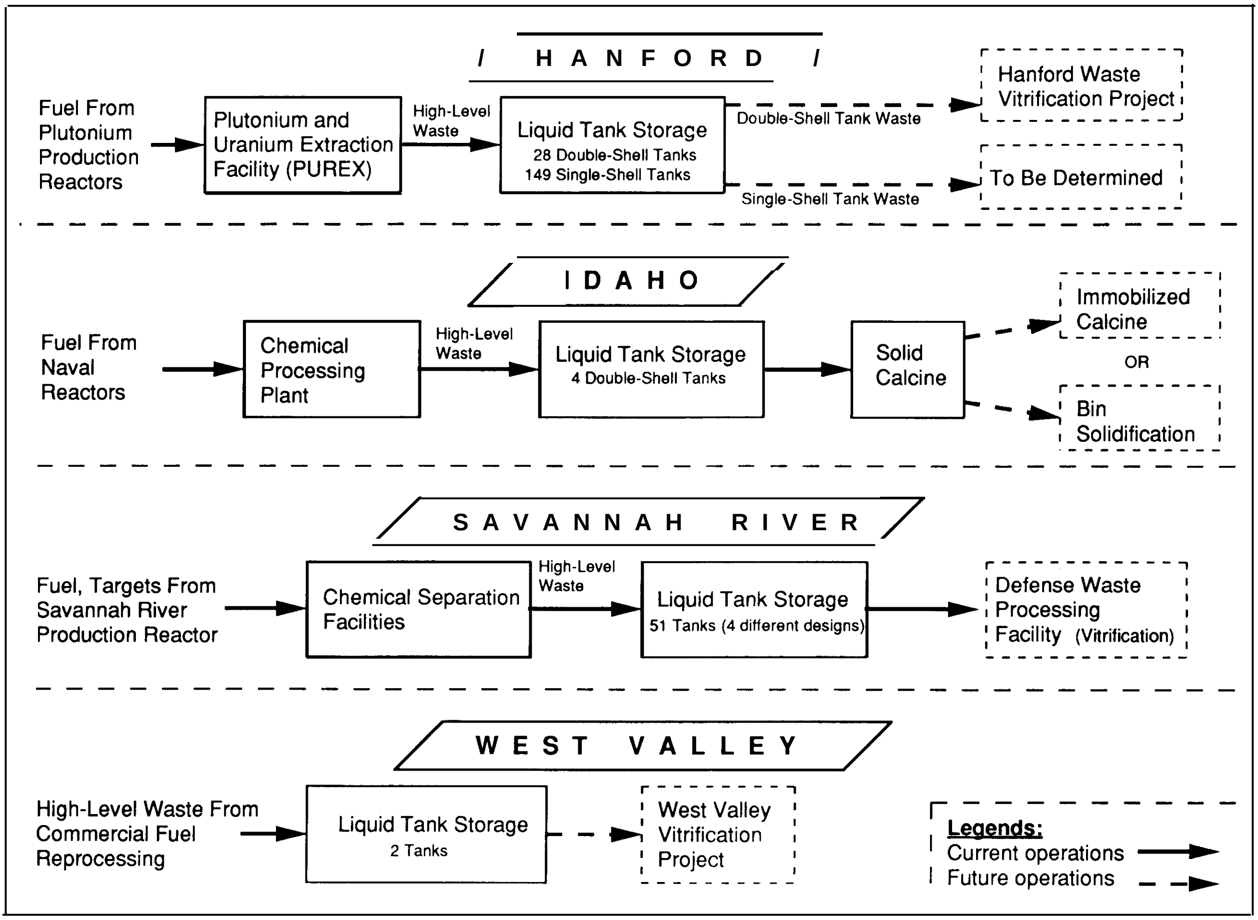
[45] EPA standards for future disposal of HLW and TRU waste, which were promulgated in 1985 (40 CFR 191, Subpart B), were vacated and remanded to EPA for further proceedings by the U.S. Court of Appeals for the First District (*NRDC* v. *USEPA, No. 85-1915 [26* ERC 1233] (lst Cir. 1987)).

[46] 42 U.S.C.A. $6924(m)(l) (West Supp. 1990).

[47] 42 U. S.C.A. §§6924(d)(1), (e)(l), (g)(5), (h)(2), and (@(3) (West Supp. 1990).

[48] Land Disposal Restrictions for Third Third Scheduled Wastes, 55 Fed. Reg. 22520, 22645(1990).

Figure 2-6-High-Level Waste at DOE Facilities



SOURCE: Office of Technology Assessment, 1991; based on DOE data, 1990.

capacity variance from the May 8, 1990 effective date of the Land Disposal Restrictions.

In addition to prohibiting land disposal of hazardous waste, HSWA prohibits storage of land-disposal-restricted waste unless "such storage is solely. . .to facilitate proper recovery, treatment, and disposal.'"[49] Thus, mixed transuranic waste is subject to the land-disposal-restricted waste storage prohibitions promulgated by EPA.[50] Acknowledging the current shortage of treatment or disposal capacity (and citing an OTA report (15)), EPA announced on June 1, 1990, its intent to issue a policy on the mixed waste storage issue.[51]

Most transuranic waste (including mixed TRU waste now stored at weapons sites) is to be assayed and certified[52] for what DOE hopes will be eventual shipment to WIPP. Between 1992 and 1999, DOE plans to begin operating six new facilities to process, treat, and certify certain transuranic waste prior to shipment to WIPP. The technologies to be used will

@42 u. S.C.A. $6924(j) (West Supp. 1990).

50 Prohibitions on Storage of Restricted Waste, 40 CFR $268.50 (1989).

51 Land Disposal Restrictions for Third Third Scheduled Wastes, 55 Fed. Reg. 22520,22673 (1990).

52 Prior t. disposal at WIPP, TRU waste packages must meet waste acceptance criteria. A Waste Acceptance Criteria Certification Committee, with representatives from EPA, the State of New Mexico, and DOE established criteria to be used to certify that TRU waste is in an acceptable form for placement at WIPP. Criteria for contact-handled TRU waste and remote-handled TRU waste were established in 1980. The waste must also correspond to the definition of TRU waste, which currently excludes TRU-contaminated materials with alpha radioactivity lower than 100 nanocuries per gram.

Table 2-&Waste Groups, Applicable RCRA Program Authority, and Storage Availability for Radioactive Mixed Waste (RMW) Regulated Under the Land Disposal Restrictions, by DOE Nuclear Weapons Complex Facility

Nuclear Weapons Complex site	Class of radioactive waste mixed with the hazardous waste stream	RCRA RMW program authority: Responsible agency	RCRA RMW program authority: Facility's RCRA permit status	Type of storage and availability: Primary form of storage	Type of storage and availability: Date capacity will be reached
Fernald	LLW	EPA	Interim status	Drums	October 1990
Hanford	LLW, HLW, TRU[a]	State (since Nov. 23, 1987)	Interim status	Containers; single- and double-shell tanks	Indefinitely?
INEL	LLW, HLW, TRU[a]	EPA	Interim status	Underground tanks and steel bins; concrete vaults	1993 (if additional construction is approved)
Kansas City	LLW	EPA	Interim status	Containers	Adequate fortheforeseeable future
LLNL	LLW	EPA	Interim status	Containers; portable tanks	Adequate fortheforeseeable future
Mound Plant	LLW	EPA	Interim status	Containers	Mid-1990
Nevada Test Site	TRU[a]	EPA	Interim status	Drums; containers	
Oak Ridge	LLW	State (since Aug. 11, 1987)	Interim status	Containers	Mid-1990
Oak Ridge Y-1 2 Plant	LLW	State (since Aug. 11, 1987)	Interim status for some units, final permit for others	Tanks; waste piles; drums	1998 for some waste
Pantex Plant	LLW	EPA	Interim status	Drums	Adequate fortheforeseeable future
Rocky Flats	TRU, LLW	State/EPA[b]	Interim status	Drums; tanks; containers	Mid-1990 for TRU waste and late-1990 for solvents
Sandia laboratory	TRU, LLW[a]	EPA	Interim status	Containers	?
Savannah River Site	HLW, TRU, LLW	State (since Sept. 13, 1987)	Interim status	Underground tanks and containers	Adequatefortheforeseeable future

[a]Additional waste characterization is necessary not only to confirm the presence of these radioactive waste streams but also to eliminate any uncertainty that this waste is to be regulated under Land Disposal Restrictions.

[b]Although the State of Colorado has the authority to regulate mixed radioactive waste, authority to enforce the Land Disposal Restrictions of RCRA still remains with EPA.

SOURCE: U.S. Department of Energy, "National Report on Prohibited Wastes and Treatment Options—As Required by Rocky Flats Plant Federal Facilities Compliance Agreement Dated September 19, 1989," Jan. 16, 1990.

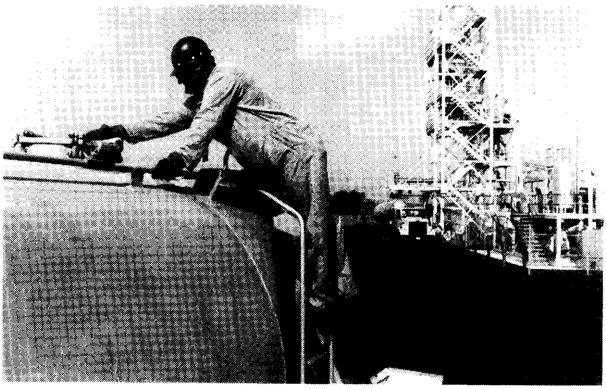


Photo credit: U.S. Department of Energy

Checking seal on tank truck after unloading at the grout facility at Hanford.

include shredding, incineration, compaction, and immobilization in grout. The only newly constructed TRU mixed waste incineration facility (at INEL) has encountered technical problems and may not begin operating for some time. DOE has not decided how to deal with the portion of transuranic waste that is not certifiable (16).

Transuranic waste (including mixed TRU waste) from Rocky Flats, Mound Plant, and other weapons sites was shipped to Idaho until September 1989, when the Governor closed State borders to additional TRU waste. DOE's plans call for transportation of transuranic waste to WIPP when it opens, with waste from Rocky Flats and INEL among the earliest shipments. The waste will have to be transported over long distances in a fleet of trucks, each carrying three shipping containers (which were granted a Certificate of Compliance by the NRC in August 1989); each container would, in turn, hold 14 waste drums (see figure 2-7). It will take 20 to 30 years for weapons site or yet-to-be-generated waste to be disposed of at WIPP. Waste would remain on-site until its turn to be sent to WIPP.

DOE plans to dispose of all transuranic waste (including TRU mixed waste) now retievably stored in the Weapons Complex at WIPP, a geologic repository excavated from salt formations 2,150 feet underground near Carlsbad, NM. Construction of a substantial portion of WIPP was completed in 1989. According to DOE, WIPP has the capacity to handle newly generated as well as presently stored transuranic waste. DOE's current program for managing stored transuranic waste contemplates the construction of six new facilities at various sites (19) during 1992-1999 for processing, treating, and certifying transuranic waste prior to shipment to WIPP.[53] The full extent and nature of treatment, however, have not been specified.

DOE's plan for disposing of retrievable stored transuranic waste depends on the availability of WIPP as the disposal facility. However, the opening of WIPP for preliminary tests was delayed from the initially projected date of October 19, 1988, and more recently projected opening dates have also not been met. Before making a decision to store transuranic waste at WIPP on a permanent basis, DOE plans to conduct tests for about 5 years, in accordance with its plan for the WIPP Test Phase (20). After experimental emplacement in WIPP of a limited number of TRU-filled bins, tests would be conducted to evaluate the potent@ problem of gas generation in the waste package (26). Alcove tests would also be performed to examine the interaction between waste and the surrounding salt medium.

Secretary of Energy James D. Watkins announced his decision in June 1990 that WIPP was ready to proceed with the test phase.[54] In addition, DOE's No-Migration Variance Petition under RCRA was approved by EPA in November 1990.[55] Before WIPP can be actuated, however, the land on which WIPP is located must be withdrawn from the jurisdiction of the Department of the Interior. Legislation to accomplish this was proposed by the Administration in 1990 but was not passed.

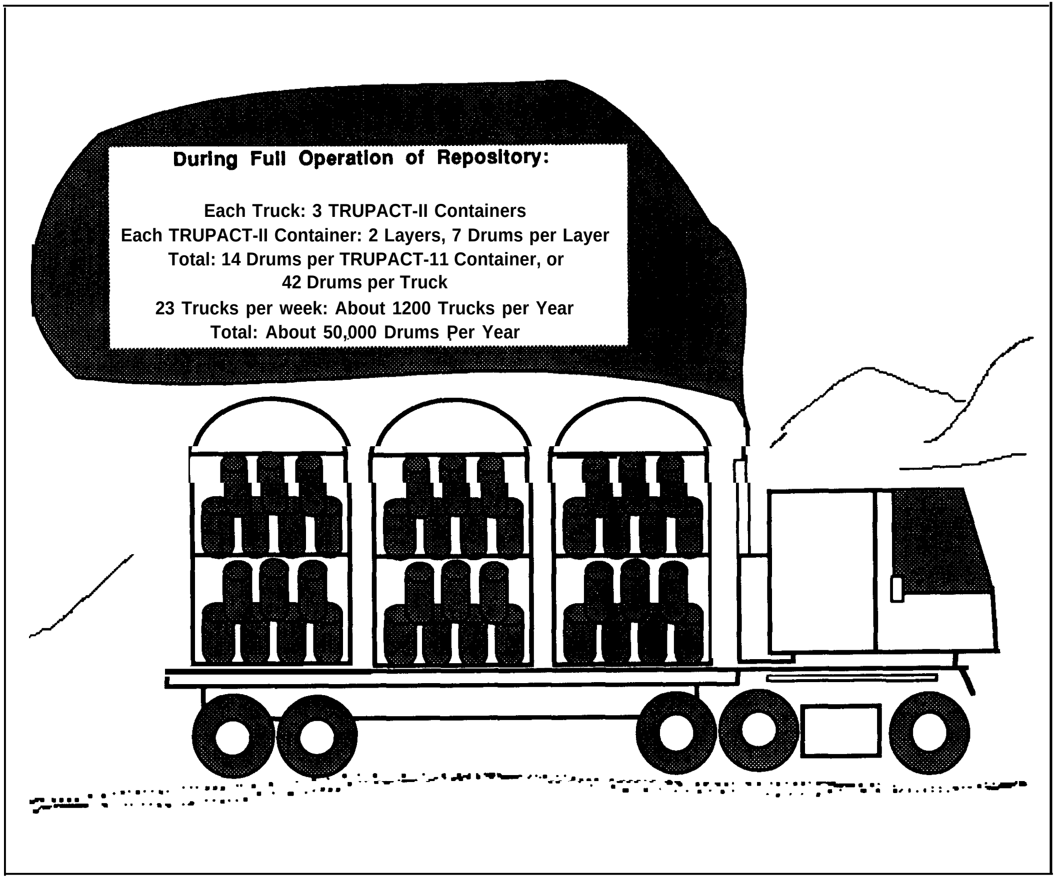
The proposed legislation also called for DOE to comply with EPA standards for disposal of transuranic waste and for EPA to establish such standards within specified time frames. Only after completing the test phase would DOE be able to declare whether the facility is suitable for the disposal of transuranic waste. If suitable, DOE would then have to operate WIPP in accordance with new environmental standards for the disposal of transuranic waste to be promulgated by EPA.

[53] Sites are INEL, Savannah River, Hanford, and Oak Ridge.

[54] Record of Decision, Waste Isolation Pilot Plant(WIPP), 55 Fed. Reg. 25689 (1990).

[55] Conditional No-Migration Determination for the Department of Energy Waste Isolation Pilot Plant (WIPP), 55 Fed. Reg. 47700 (1990).

Figure 2-7—Bringing Trucks of TRU Waste Drums to WIPP



SOURCE: Office of Technology Assessment, 1991.

Storage, Treatment, and Disposal of Mixed Waste

Most of the radioactively contaminated hazardous waste, also known as "mixed waste,' at DOE weapons facilities results from the production of defense and research materials and from recycling or reprocessing spent fuels and obsolete weapons. DOE facilities were generally not designed for on-site treatment and disposal of mixed waste. The management of mixed waste has traditionally been based on storing it at the generating facility until long-term radioactive waste disposal facilities become available. Waste stored at the Weapons Complex has increased substantially in recent years. In 1988 DOE reported a projected increase of more than 11 percent in on-site storage of transuranic waste compared with the 1986 total (21).

At the same time, DOE's available on-site waste storage capacity has diminished rapidly, and some of the capacity needed for mixed waste is currently being utilized to manage radioactive waste as well as RCRA-restricted hazardous waste (22).[56] Fernald, Mound Plant, Oak Ridge National Laboratory, and Rocky Flats (for certain waste) are on the verge of running out of capacity for storing mixed waste. Storage capacity at eight other Nuclear Weapons Complex facilities is expected to be reached by the mid-1990's.

Several regulatory and technical issues are associated with present and future mixed waste management at the complex. Mixed waste must be managed in compliance with specific treatment and disposal requirements established under RCRA's Land Dis-

[56] Leo P. Duffy, Director, DOE's office of Environmental Restoration and Waste Management, testimony before the House Armed Services committee, Mar. 15, 1990, p. 12.

posal Restrictions (LDRs). (Mixed waste placed in storage before the LDR effective dates, however, is not subject to RCRA, unless it is moved from its current place of storage (23).) Interagency agreements among DOE, EPA, and the States are being used to address the mixed waste issue at some sites. For example, because storage of radioactive materials contaminated with LDR waste "may be construed to violate RCRA regulations, in particular the Land Disposal Restricted Waste storage prohibitions. . ." (24), the State of Colorado and EPA signed a Federal Facility Agreement and Consent Order with DOE on September 19, 1989, in which DOE committed itself to comply with RCRA and State regulations. The agreement has also led to assessment of storage problems at other weapons facilities.

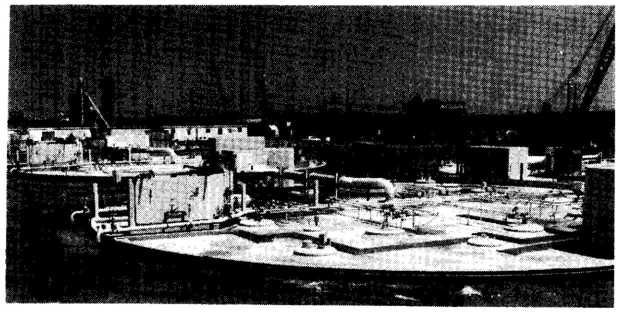


Photo credit: U.S. Department of Energy

Completed underground storage tanks for high-level waste at Savannah River. Design provides for stress relief and access to tank and annulus to measure tank liquid levels, temperature and pressure, allow inspection of tank walls, and collect samples.

Evaluation

High-Level and Transuranic Waste

DOE's strategy for ultimate disposal of high-level and transuranic waste is predicated on placement of the waste, after treatment, in deep geologic repositories. OTA finds that, in some instances, DOE has not paid sufficient attention to options that could be exercised if delays in repository openings persist. For high-level waste, if vitrification works the way its developers anticipate, treatment should create a more stable, secure waste form than exists with liquid tank storage--one that can be safely stored on-site or in a monitored retrievable storage facility for hundreds of years, given adequate institutional controls, independent oversight, and public support. However, current plans for transuranic waste treatment and storage are not adequate in the face of repository delays.

Most DOE plans for dealing with high-level and transuranic waste at the weapons facilities assume that a deep geologic repository will be available for disposal of each type of waste at some specified time in the future. Until very recently—in fact, just prior to preparation of the 1989 Five-Year Plan-DOE's disposal strategy for HLW and TRU waste was based on the assumption that a repository for high-level waste would be available by the year 2003, and a research and development facility for disposal of transuranic waste by 1988, followed soon after by an operational repository. DOE's projections have changed significantly, but its planning with regard to interim storage has not kept pace with the changing scenarios of geologic repository availability. DOE has recently focused more attention on the interim storage that will be required until the high-level waste and spent fuel repository is opened, which has now been delayed at least 7 years until 2010 (5). The interim storage period continues to grow as both repositories continue to be delayed.

For example, DOE currently assumes that the earliest possible time at which an HLW repository at Yucca Mountain could be available for shipment of defense high-level waste is the year 2015. Given that situation, any vitrified high-level waste must remain on-site longer than originally anticipated. The public has not been explicitly notified of the possible on-site storage of vitrified high-level waste for the next two to five decades, and DOE has not focused adequate attention on the waste testing and monitoring that may be required. DOE has, however, noted that "interim storage after conversion will be required until the repository is opened" (25). Yet it has not analyzed all the impacts of longer storage or detailed plans for possibly further delays in the availability of a high-level waste repository. Additional delays of more than 5 years could mean that Savannah River and Hanford (and perhaps even INEL) would have to provide longer and more extensive interim storage than originally planned.

DOE's strategy for vitrifying high-level waste, although costly, appears to be an important step in the right direction. It is not clear, however, whether the time frame for vitrification is such that liquid high-level waste will be immobilized soon enough to avoid potential problems with waste tanks. Because of the importance of vitrification, independent technical oversight of its development and greater regulatory oversight of the waste form may be required.

Delays in opening WFP have already necessitated some longer interim storage of transuranic waste than initially planned. WIPP maybe available for testing stored transuranic waste disposal in 1991. If the test phase is followed by a prompt positive decision to open WIPP and no further delays occur, the earliest date for disposal of waste at WIPP on an operational basis is 1995. In the meantime, stored transuranic waste intended for WIPP must remain where it is or be transferred to some other site for storage until WIPP opens. DOE has recognized this problem and suggested a number of alternatives, including transferring some of the waste to privately operated storage facilities.

Under current DOE plans, transuranic waste destined for WIPP will be given minimal treatment. Fifty-five-gallon drums are loosely packed with contaminated clothing, paper, metal scraps, and other items. The drums were designed to last for 20 years, and some are already this old. The transuranic waste is generally not immobilized within the drums. Additional treatment and storage options must be considered now if this tmnsuranic waste is to be managed safely. Furthermore, much of the transuranic waste is mixed waste whose treatment requires complex facilities yet to be built. Treatment standards for this waste have been developed by EPA, but DOE does not have to demonstrate compliance immediately because of EPA's 2-year capacity variance.

DOE's strategy of minimal treatment of the transuranic waste form prior to disposal at WIPP, although less costly than other options, is problematic for two reasons. First, there is the question of whether the waste form will be able to meet EPA disposal standards fortransuranic waste under human intrusion scenarios. Second, interim storage of TRU waste would appear to be precluded for more than the short-term (i.e., 20 years), given the current storage of loose waste in drums.

There appears to be only one site-Rocky Flats—for which DOE has begun to plan alternative storage approaches for transuranic waste. However, at least one of those approaches—storing Rocky Flats waste at other DOE sites—has been opposed by the Governors of affected States. The other two approaches---commercialization of disposal and use of

Photo credit: U.S. Department of Energy

Low-level waste in compacted drums being packed into steel boxes for off-site shipping from Fernald.

Defense Department sites—will raise regulatory, political, and other questions. Furthermore, there is little in the 1990 Five-Year Plan to indicate how DOE will deal with the implications of this longer interim storage at the six principal sites other than Rocky Flats, where transuranic waste is now stored (26).

In addition, considerable confusion surrounds the applicable standards for DOE's radioactive waste management program. Box 2-J illustrates the slow pace and complexity of radiation standard development. Attention to adequate standards and competent oversight are necessary to assure the public that it is being protected while waste is managed at DOE sites.

Mixed Waste

DOE's problems are also complicated by the regulatory implications of its actions or lack of action regarding mixed waste. Mixed waste (particularly mixed transuranic waste) is difficult for the weapons sites to manage because regulatory limits on storage capacity do not exist. The time for which mixed waste can be stored on-site is generally limited by law, or regulations. In early 1990, DOE published a report on prohibited wastes and treat-

Box 2-J—Radiation Protection Standards in Limbo

EPA can promulgate generally applicable environmental radiation protection standards for low-level and high-level waste management facilities but has no enforcement authority.

As a result of Reorganization Plan No. 3 of 1970,[1] the Atomic Energy Act of 1954,[2] the Low-Level Radioactive Waste Policy Act of 1980,[3] and the Nuclear Waste Policy Act of 1982,[4] EPA was given the authority to promulgate generally applicable environmental standards for the management, storage, and disposal of low-level and high-level radioactive waste. The goal of these standards is to establish exposure radiation limits to ensure the protection of individuals and the general public. Compliance by DOE with EPA standards, however, need only be demonstrated at the facility boundary because the authority to implement and enforce these standards at sites themselves resides in DOE. According to some EPA officials, this anomaly must be corrected so that public health and environmental safety are ensured.

EPA standards to protect the public and the environment against radiation from DOE's low-level radioactive waste management and disposal activities are still being developed.

Under the authority of the Atomic Energy Act, EPA proposed a radiation protection limit to any member of the public from all pathways of 25 millirem per year, from low-level waste disposal sites and a limit of 4 millirem per year for the protection of groundwater sources. The latter requirement has drawn considerable criticism, especially from the Nuclear Regulatory Commission, which considers it too stringent in comparison with its own limit of 10 millirem per year from groundwater.

EPA sent the proposed standards to the Office of Management and Budget (OMB) for approval. OMB has returned the proposed standards to EPA for further modification, particularly of the groundwater portion of the regulations. Approval of final regulations is not expected before 1991. In the interim, no specific Federal regulatory standards exist to protect the public from DOE's low-level radioactive waste. Commercial low-level waste management facilities, however, continue to be regulated by NRC.

EPA radiation protection standards for high-level radioactive and transuranic waste disposal are still being developed.

In September 1985, EPA proposed standards to control the management and disposal of high-level radioactive waste.[5] Immediately after their promulgation, the standards were challenged in court by several States and environmental groups. As part of the legal proceedings, in 1987 the court reinstated the section (40 CFR 191 Subpart A) that deals with the management and storage of high-level waste. Subpart B, however, was remanded back to EPA for modification and is still being changed to satisfy the court's requirements. Issuance of final Part B requirements may be further delayed if OMB does not approve them in a timely fashion.

[1]Reorganization Plan No. 3 of 1970, 35 Fed. Reg. 15623 (1972).

[2]42 U.S.C. Sections 2011-2296 (1982 and Supp. IV 1986).

[3]42 U.S.C. Sections 2021b-2021d (1982).

[4]42 U.S.C. Sections 10,101-10,226 (1982).

[5]Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High Level and Transuranic Radioactive Wastes, 50 Fed. Reg. 38066 (1985).

SOURCE: Office of Technology Assessment and footnotes 1, 2, 3, 4, and 5.

ment options. Table 2-5 summarizes the status of each DOE facility's permit and storage capacity.

Because of its past reluctance to acknowledge that certain laws and regulations (particularly RCRA) apply to weapons sites, DOE did not initiate programs to comply with those requirements until relatively recently. DOE is now having difficulty integrating the regulatory requirements governing mixed waste with its management of stored waste. While regulations allow for variances to be granted,[57] DOE has acted to obtain the variances and exceptions permitted under these regulations (e.g., the no-migration petition submitted in connection with WIPP and the delisting petitions filed by Oak Ridge). DOE should be considering alternatives (e.g. treating the waste or changing its form) in the

[57]For example, the 2-year national capacity variance from the Land Disposal Restrictions granted by EPA in May 1990.

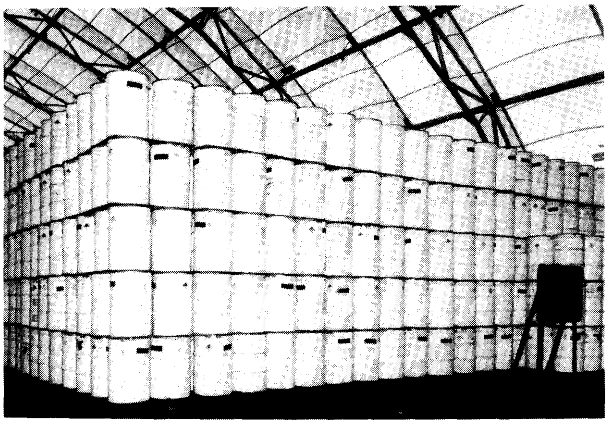


Photo credit: U.S. Department of Energy

Waste awaiting shipment to WIPP from INEL Radioactive Waste Management Complex.

event that some of its requested petitions are not granted.

In addition, in addressing the regulatory and technical issues raised by mixed waste, it may be prudent to consider regulations that more adequately address improvements in storage to reduce risks to human health and the environment-and to ensure that EPA's universal treatment technology standards do not preclude research into technological alternatives with greater potential to address the varied nature of DOE's mixed waste.

Photo credit: U.S. Department of Energy

Radiation monitoring at Hanford.

ESTIMATING COSTS

status

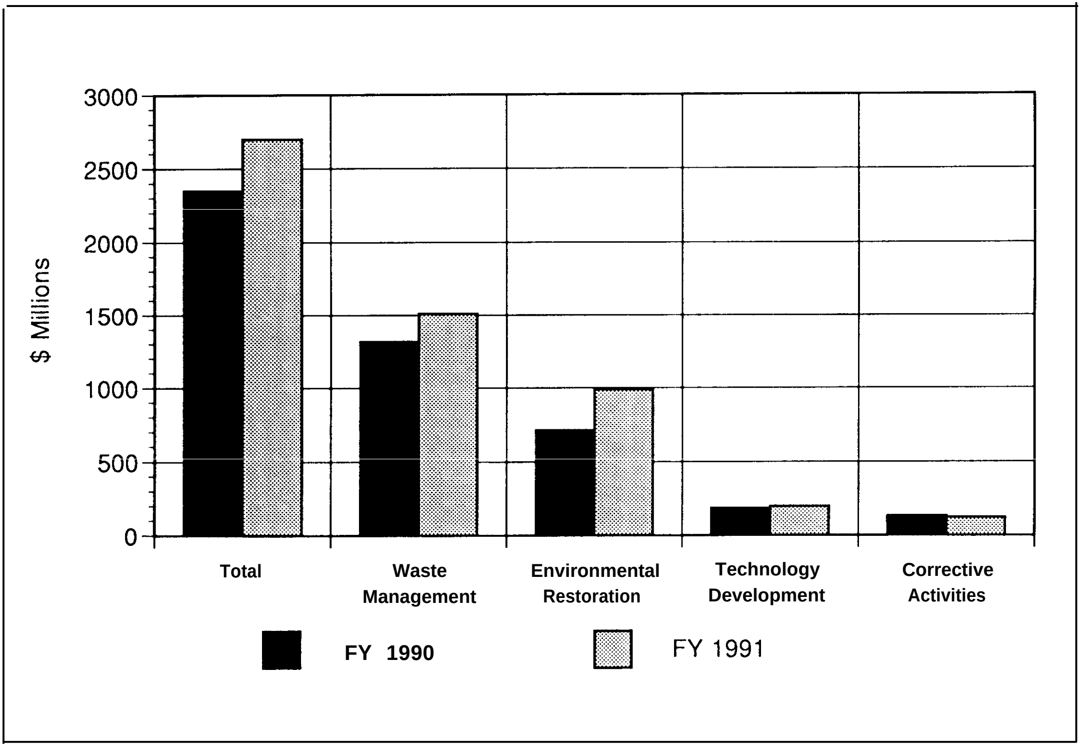
Over the past 2 years, DOE has provided a variety of cost estimates for waste management and environmental cleanup at the Weapons Complex (1,4,13). Other agencies and organizations have reviewed these estimates and offered their own analyses and interpretations (27,28). Only DOE has made site-specific estimates of the cost of accomplishing work under these programs, and very few of the projected cost estimates are reliable. Other analyses have used DOE estimates and applied different assumptions about what should be included, what should be given priority, or how costs should be accounted.

The most recent DOE cost estimates can be found in the 1990 Five-Year Plan in which DOE presents budget costs for FY 1990 and 1991 and planning estimates for the following 5 years (FY 1992-96). This plan covers only those activities that may be accomplished during that time. As described elsewhere in this report, work planned for the next 5 years is devoted primarily to characterizing contaminated environments, stabilizing some inactive sites at which standard techniques can be applied, and continuing to manage the large quantity of waste within each site. These latest estimates exceed the estimates contained in the 1989 Five-Year Plan by a substantial amount (see figure 2-8).[58]

The only attempt by DOE in recent years to estimate a total cost for completion of its cleanup program was published in a 1988 report (13). That estimate, which was hastily made when data were even more unreliable than today, is the only compre-

[58] Funding requests for the President's budget are lower than the costs estimated in the 1990 Five-Year Plan. DOE has stated that the levels of funding implied by the latest cost estimates "cannot now be managed responsibly and effectively, given the inadequacy of the DOE, contractor, industry and regulatory infrastructure" (29).

Figure 2-8-DOE Budget for Environmental Restoration and Waste Management



SOURCE: U.S. Department of Energy, "Environmental Restoration and Waste Management: Five Year Plan, Fiscal Years 1992-1998," DOE/S-0078P, June 1990.

hensive baseline for understanding the magnitude (in terms of dollars) of the future DOE cleanup program at the weapons sites. That 1988 estimate put the 20-year cleanup cost at $71 billion to $111 billion. By comparison, estimates made for all environmental activities in the 1989 and 1990 Five-Year Plans for 1989 through 1996, only 8 years, amount to almost $40 billion. The uncertainties associated with even these near-term estimates cast further doubt on long-term estimates. Subsequent reviews of available cost data have not attempted to make independent detailed estimates of total cost to completion. One General Accounting Office (GAO) study in 1988 suggested that total costs could be between $115 billion and $155 billion, including modernization, but it did not substantiate this in detail (28). The 1990 Congressional Budget Office report on Federal facility environmental cleanup costs merely summarized the estimates made by DOE (30). A 1990 GAO study stated that 'according to DOE's estimates, the total cost of modernization and responding to environmental problems of the Weapons Complex could range from $125 billion to $155 billion"[59] (31).

Since 1988, DOE has not published an estimate of costs for the entire cleanup program. The reason given for its reluctance to do so is the existence of too many unknowns-especially the nature and extent of all contamin ation problems and the types of remediation that would lead to acceptable results.

Evaluation

OTA has reviewed relevant cost data prepared by DOE and analyzed by others. OTA has also investigated the quality and completeness of DOE cost estimates for some of the most recent and active cleanup projects at a number of Weapons Complex sites (see app. C). OTA's analyses have led to conclusions in three general areas: 1) the magnitude of total program costs for environmental restoration and waste management, 2) the division of costs into

[59]This estimate includes $50 billion for modernization, $35 billion to $65 billion for environmental cleanup, $15 billion for decontamination and decommissioning, and $25 billion for waste management, through 2010.

various categories, and 3) the quality of cleanup cost projections for environmental restoration.

Overall Costs

At present no data are available on which to base a reasonable estimate of cost-to-completion of the DOE weapons waste cleanup program. The only attempt at such an estimate (in 1988) was too hastily made to yield accurate results (13). Even though an overall cost estimate is difticult, a much more methodical effort to estimate the most significant costs over the next few years would be extremely beneficial to policymakers and to the Nation as a whole. Such an effort could focus on the different levels of certainty associated with various cost estimates and include explicit consideration of alternative solutions for the most difficult remediation problems. The cost estimates at different levels of certainty could then be compared with the progress made toward characterizing the sites to help determine the rate of progress toward meeting overall cleanup goals in the short term.

More data about environmental problems and solutions are available today than in 1988, and much information about contaminated sites should be coming in over the next several years. An overall cost estimate can be more realistically made when the bulk of characterization work has been completed. Even though specific approaches and their costs will have to be studied and updated continuously, a total cost accounting at that time would be more meaningful and would alert policymakers to the direction of the program as it develops toward its long-term goals.

Cost Categories

DOE's current cost estimates contained in the 1990 Five-Year Plan are generally divided into four major categories: 1) waste management, 2) environmental restoration, 3) technological development, and 4) corrective activities.[60] Figure 2-9 shows the division of the current FY 1991 budget into these four categories through 1996. DOE has allocated about 90 percent of the funds for waste management and environmental restoration, with about twice as much for the former as for the latter. Over the 7 years covered in the plan, these two categories are expected to grow from 86 to 93 percent of the budget. The remainder is allocated to corrective activities (from 6 to 2 percent) and technological development (from 8 to 5 percent).

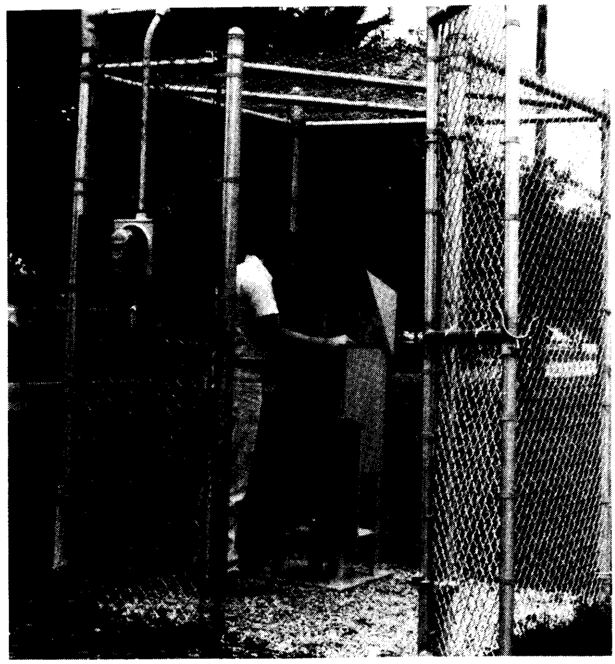


Photo credit: U.S. Department of Energy

Air monitoring station at an elementary school near Fernald collects data on airborne emissions of particulate, radionudides, and uranium.

A major factor influencing the dominant cost allocation to waste management in the Five-Year Plan is the number of large, new, and costly technologies being implemented over this time (16). In addition, serious problems with storage and treatment of certain waste must be resolved. It is therefore understandable that waste management is given high priority in the budget plan. This heavy emphasis on one category, however, will require continued scrutiny as environmental restoration decisions begin to be made a few years hence and more funds are required. If waste continues to be generated, it may be more prudent to allocate resources to solve existing contamination problems frost and then to focus on *minimizing* future waste generation.

Reliability of Environmental Restoration Costs

Although the DOE Five-Year Plan is a good approach to planning budget allocations in the near term, most of the current environmental restoration

[60] A fifth category, transportation, contains relatively small amounts of funds and is omitted from this discussion.

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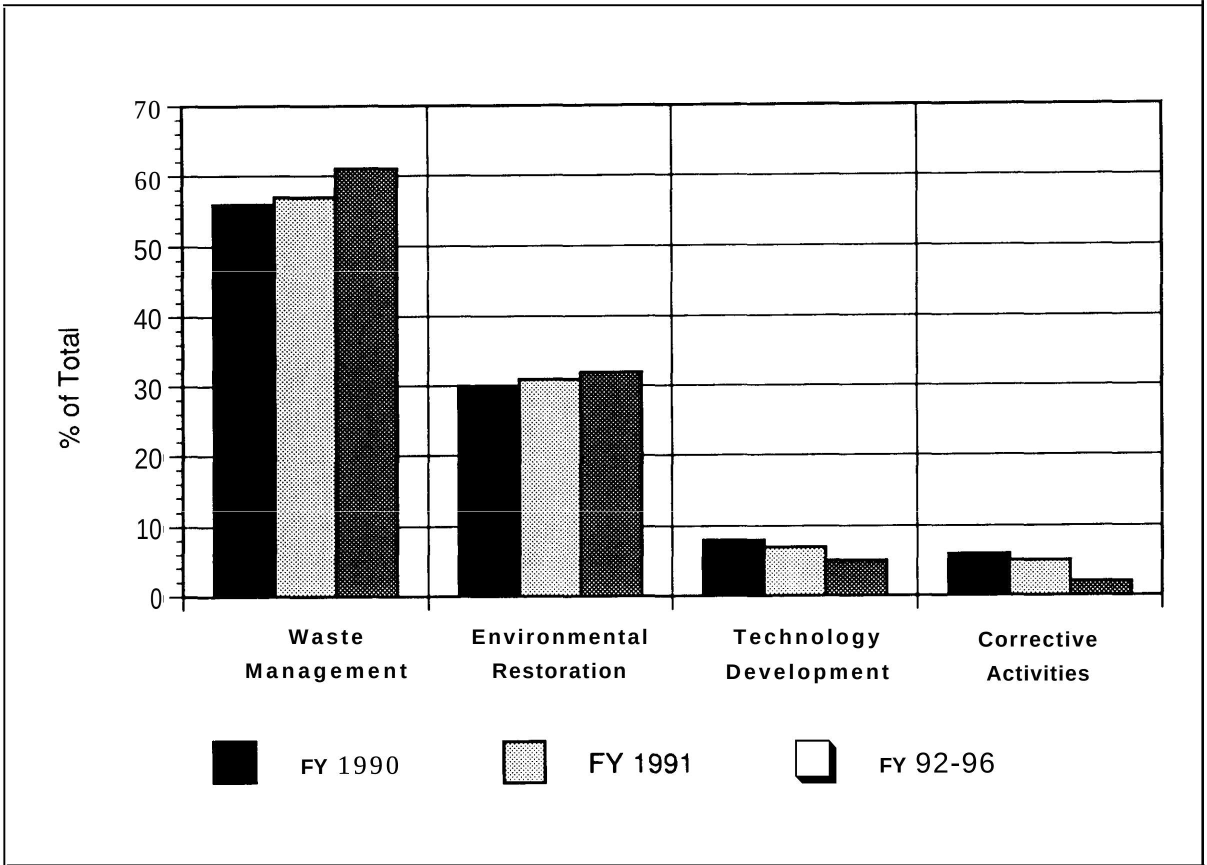
Figure 2-9-Cost Categories for Waste Management and Environmental Restoration Program



SOURCE: U.S. Department oi Energy, "Environmental Restoration and Waste Management: Five Year Plan, Fiscal Years 1992-1998," DOEK3-0078P, .June 1990.

costs are for studies and assessments to characterize the problem, not for remediation activities. OTA analysis indicates that recent estimates of the cost of cleanup projects are unreliable in many areas and are inconsistent throughout the Weapons Complex. To evaluate estimated and actual costs involved in remedial activities, OTA investigated the costs of all remediation projects that DOE was willing and able to provide (see app. C). The sample was from nine weapons facilities at which some remediation is either complete or underway. It included ground-water pumping and monitoring, pond stabilization and closure, centaminated soil removal, and a grouting demonstration project.

OTA analyses of these case studies show that the costs for similar activities, both estimated and actual, vary significantly from facility to facility and even from site to site in one facility (see table 2-6). Because data are extremely limited and so few projects have been completed, it is dificult to draw any conclusions about this variation. Variations may be due to legitimate technical differences at each facility or to accounting differences. The implications are, however, that a close accounting must be made of the costs of remedial actions to improve DOE's ability to estimate costs accurately and verify instances in which cost savings maybe attributed to better technology, improved management, or variations in cleanup standards. At present, no data are available to support the claim that technological development will reduce cleanup costs by any significant amount. Although certain technological approaches hold promise in this area, much more work must be done to evaluate where cost savings might result and where cost increase would be the outcome (both cost savings and cost increase have been documented in past studies; see app. C).

Table 2-6-Some Typical Ranges of Costs for Environmental Restoration Projects

Type of project	Cost ranges from OTA ease studies
Installation of groundwater monitoring well (per foot)	$150 (Pinellas) -$417 (Hanford)
Annual sample analysis (per well)	$1,333 (LLNL) -$20,500 (INEL)
Excavation of soil and sludge (per cubic yard)	$8 (Savannah River) -$260 (Oak Ridge)
Off-site soil disposal (per ton)	$110 (Pinellas) -$146 (Kansas City)
Installation of groundwater recovery well (per foot)	$159 (Savannah River) -$400 (LLNL)
Capinstallation (persquare foot)	$5 (Oak Ridge) -$8 (oak Ridge)

SOURCE: App. C.

It is evident from OTA's analysis that these DOE cost estimates are inconsistent and difficult to compare. In some cases, for example, costs were overestimated (for Savannah River's mixed waste facility); in others, estimated accurately (the Savannah River Groundwater Remediation Project).[61] Because data are extremely limited and so few remedial actions have been completed, it is difficult to draw any conclusions from this variability. Variation between estimated and actual cost depends heavily on the project stage in which the estimate was made, as well as on the complexity of the problem. In addition, DOE project engineers have indicated that they were given too little time to accurately estimate environmental remediation costs in the preparation of both Five-Year Plans. Steps are being taken by both DOE and its prime contractors to understand and address these inconsistencies.

DOE has begun to analyze cost uncertainties associated with environmental restoration projects, and its study shows that as a project becomes more defined, estimates become more accurate (i.e., better assessment provides better cost estimates, up to a point). According to this analysis, a cost increase of more than 25 percent is not uncommon for environmental restoration projects because of the complexity of the waste, the variability of the sites, and the level of sophistication of the technology used. This information is being used to help DOE cost estimators on environmental restoration projects, along with a cost estimating handbook developed by DOE (32). These tools were not used to estimate the costs for the 1990 Five-Year Plan, however.

Also, in the limited cost information available to OTA on environmental restoration projects, no consistent relationship is apparent between estimated and actual costs. Cost overruns appear to be due primarily to the lack of detailed characterization of the contamination, especially with respect to volume, or to unforeseen circumstances such as unusually high rainfall or new information uncovered in the characterization process. Based on EPA Superfund experience, cost overruns as high as 100 percent for remedial action are not unusual (see app. C).

Closer attention to details may help in estimating future costs, but even with the best information, the cost of environmental remediation will be subject to large uncertainties. Thus, a close **accounting of the costs** of remedial actions is necessary to assess the efficiency or effectiveness of DOE's Environmental Restoration program. Such careful accounting of costs appears to have been lacking in the early years of Superfund (and may still continue), making it extremely dificult to determine the success of that program. Careful attention to unit costs could be most valuable in helping DOE to avoid such problems, if initiated early in the program.

Better estimates can be expected as more information becomes available. The use of estimating tools being developed by DOE, along with more information, could help improve cost estimates (see app. C). However, the process of estimation should be consistent throughout the Weapons Complex, and engineers should be given adequate time and resources to make such estimates.

[61] It should be noted that although cost estimates for the groundwater project at Savannah River accurately reflect actual expenditures for the plant equipment installed, the design was insufficient, additional equipment was required, and much less than the planned quantity of contaminants was removed (see app. B).

SETTING PRIORITIES

Status

As with most federally funded programs, priorities for funding environmental restoration and waste management activities at the Weapons Complex are set through the annual budget process. Apart from that process, DOE has attempted to establish a more rigorous system to guide its own decisions regarding environmental restoration and waste management activities, both to support its budget request and to allocate appropriated funds. Thus far, these attempts have been directed primarily at DOE's relatively new internal 5-year plarming process, rather than the annual budget cycle.

In the 1990 Five-Year Plan (33), a DOE-wide, four-level priority system is set forth for allocating funds to environmental restoration and waste management activities. The categories encompass the following types of activities:

1. those necessary to prevent near-term adverse impacts on workers, the public, or the environment, including containment to prevent the spread of contamination and waste management activities to maintain safe conditions (also included in this category is the continuation of ongoing activities that, if terminated, could have significant negative effects);
2. those necessary to meet the terms of agreements between DOE and local, State, or Federal agencies;
3. all other activities required to reduce risks, promote compliance, reduce public concern, and maintain DOE missions; and
4. activities with no pressing time constraints, such as decontamination or decommissioning.

In practice, most activities fall into priority 1 or 2. Because priority 2 includes milestone; set by all the interagency agreements that have been signed, it would be difficult for DOE not to assign these activities top priority.

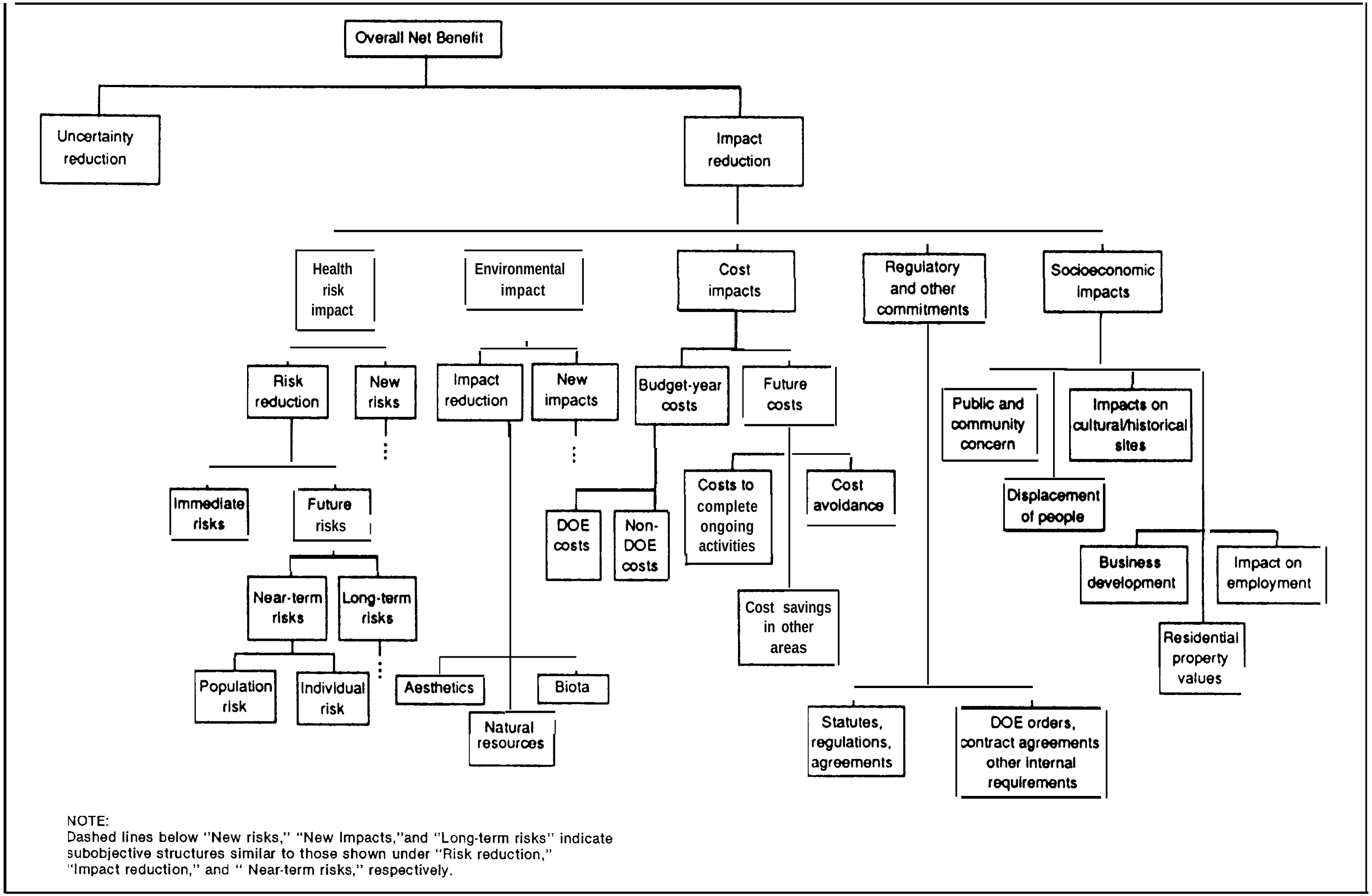
At the field level, each weapons facility is setting its own priorities for environmental restoration work, based on regulatory orders and agreements, as well as on that facility's understanding of urgent problems or needs. Thus, facilities that have negotiated and executed agreements with EPA or the States setting specific timetables for action have essentially already established many priorities for those sites. Some facilities (e.g., Hanford and Rocky Flats) have entered into very detailed agreements with specific schedules, whereas others have not begun to make such detailed commitments. Funding for these site-specific priorities, however, depends on the overall DOE budget allocation, and it is not clear how DOE will seek to modify existing agreements if adequate funding is not available in the future.

At the same time, DOE headquarters has been developing a separate "risk-based" priority system to help DOE "make budget decisions about how much funding to request for cleanup activities and how to allocate the funds that are made available" (34). This system will replace a similar, earlier one (the Program Optimization System) developed in response to congressional requests and will be applied initially only to environmental restoration activities. If the system proves useful and acceptable, DOE plans to extend the same general approach to waste management operations and to research and development. According to DOE, the "precise relationship of the steps in the priority system to the Five-Year Plan and the overall budget process is still evolving' (35). DOE has stated its intent to develop this method, which it contends is a "rigorous, risk-based prioritization methodology for application starting in FY 1992" (34).

The new priority system operation involves four phases. In the first phase-activity prioritization—the full range of activities that require funding at each facility for the budget year are to be identified as if full funding were available. The activities are then evaluated and assigned priority based on their ability to reduce uncertainty about the problems and consequences in five categories: health risk, environmental impact, cost impact, regulatory or other commitments, and socioeconomic impact. Figure 2-10 illustrates these categories. This phase is conducted primarily by DOE field offices.

In the second phase, also conducted by field offices, possible budget constraints are considered through the selection of sets of activities from the prioritized list to fit maximum, intermediate, or minimum budget levels. Then, in the third phase, the costs and benefits of each activity package (i.e., the sets of budget-yea activities focusing on a facility's problems) are determined. To accomplish this, field offices estimate the cost of each activity package and then assign a score for each of the five objectives

Figure 2-10-Proposed (Fundamental) Criteria for a Formal DOE Priority System Organized in a Hierarchy



SOURCE: U.S. Department of Energy, Office of Environmental Restoration, "A Preliminary Conceptual Design of a Formal Priority System for Environmental Restoration," CDR Rev. 7 (Working Draft), May 1990.

used in the first phase, based on the package's ability to reduce impacts in these categories. After each activity package cost is estimated and the categories are scored, they are reviewed and, if necessary, revised by panels composed of representatives from all field offices and from headquarters.

Once the costs and "scores" of activity packages have been reviewed by the panel, a "multiattribute utility analysis" is applied to extract a single indicator of overall benefits for each package, along with an estimate of total package cost. The overall indicator of benefits is an aggregate of the objective scores resulting from this analysis, based on headquarters value judgments.

In the final phase, alternative budget levels are generated by using the estimated total costs and the indicators of package benefits. This phase is performed entirely by DOE headquarters using the formal priority system computer model. The multiattribute utility analysis model compares the costs and benefits of all the activity packages and calculates funding levels by evaluating different options for allocation of funds among field offices. The computer model also identifies the activity packages that can achieve or exceed regulatory and other objectives (those packages that offer the greatest benefits) at each funding level.

A different and largely unrelated effort by DOE's Environmental Safety and Health organization-the Environmental Survey[62]-attempted to develop a ranking system for environmental problems at DOE facilities. The system used multimedia transport models to project the potential for release of centaminants into the environment, the movement of contaminants through the environment to humans, and the risks to humans. The results of that survey are now being used as input to DOE's new quantitative priority system.

Evaluation

DOE's various priority systems have certain fundamental flaws and have yet to prove themselves useful in decisionmaking. The priority scheme used in the 1990 Five-Year Plan groups activities into four very broad categories. Most DOE activities fall into some portion of the first two categories (primarily, ongoing activities and compliance with interagency agreements). However, the scheme provides little or no guidance for ranking activities within those major categories (or indeed any category). In apparent recognition of this problem, DOE states that it is considering several different approaches to the priority system such as breaking down categories into sublevels.[63]

A different limitation pertains to priority 2—"those activities required to meet the terms of agreements (in place or in negotiation) between DOE and local, State and Federal agencies. " As noted in the 1990 plan, these agreements "represent legal commitments to complete activities on the schedules agreed to by DOE." If and when all the sites have entered into such agreements, the problem of funding all commitments simultaneously, along with other priority activities, will undoubtedly arise.

Federal regulators, the States, and many environmental organizations do not necessarily view these obligations as appropriate subjects for a priority system; rather, they believe that all commitments must be met and all regulations complied with. At the DOE Stakeholders' Forum[64] held in April 1990, several participants from environmental organizations were concerned that DOE was not requesting sufficient funds to meet all its commitments.[65]

In the 1990 Five-Year Plan (37), DOE's description of its new quantitative priority system and computer model states that reducing "health risk impact is of primary importance' and that "public health risk reduction and environmental protection'

62The Environmental Survey was initiated to identify and prioritize existing environmental problems and risks at all DOE defense production sites. It was later expanded to include nondefense production sites. Preliminary results from defense sites were summarized in the "Environmental Survey Preliminary Summary Report of the Defense Production Facilities," released in September 1988. The final report is due in 1991.

63One other alternative discussed in the Five-Year Plan is "to develop a ranking based on direct heal@ environmental, and regulatory risk'' (36).

@DOE invited several dozen people reflecting a range of interests in the DOE Weapons Complex cleanup to a meeting called a ''Stakeholders Forum'' to review and discuss DOE's ''Predecisional Draft" of the 1990 Five-Year Plan. Participants in the 2-day forum (held at Airlie House, VA, in April 1990) were mainly from affected States, Indian Nations, Government agencies, and environmental, labor, and industry groups.

65Although DOE has moved all "corrective activities" to priority 1, these relate primarily to bringing ongoing wastemanagement operations into compliance with environmental laws. Compliance with regulations under RCRA and CERCLA governing environmental restoration activities is still presumably covered under priority 2 by agreements. It is not clear that all such requirements are covered by agreements, however; those that are not will likely fall into priority 3.

Photo credit: Martin Marietta Energy Systems

Sediment samples are regularly taken in bodies of water impacted by the operations at Oak Ridge.

are "two factors of primary concern' in evaluating the utility of activities or projects (38). Yet, at present, the greatest uncertainty concerns the variables that should be given highest priority in these systems—reducing health and environmental risks. (See ch. 3 and app. D).

A major problem with any priority-setting scheme for cleanup is that credible data for most of the key parameters needed to evaluate proposed activities and assign priorities have not yet been obtained. It is not clear how DOE intends to address the uncertainties that now dominate the system's criteria, or what efforts will be made to develop a database for some critical factors such as specific information on each centaminated site within a facility, health and environmental risks from those sites, and lack of accurate cost estimates.

The priority systems could perhaps be used to identify categories of information that must be gathered in comection with key ranking factors (e.g., health or environmental impact) and to record any progress made in filling those data gaps over time. In fact, at this stage of the cleanup process, these may be the most useful applications of this type of system.

The methodology and model used in DOE's Environmental Survey (MEPAS-Multimedia Environmental Pollutant Assessment System), for example, has been criticized by the Natural Resources Defense Council (NRDC) on a number of grounds, including its failure to consider multiple contaminants or to identify the "most exposed individual, " as well as the lack of public involvement in its development.[66] The results of that MEPAS-based

[66] D. Reicher and J. Werner, Natural Resources Defense Council, testimony before the Senate Armed Service Committee, Subcommittee On Strategic Forces and Nuclear Deference, Apr. 7, 1989.

survey are among the only data available on site-specific risks from weapons plants, and the system did not begin to evaluate public health risks. The survey is nonetheless being used as input to the quantitative priority system being developed for application to DOE's environmental restoration (ER) budget. DOE recognizes the limitations of the Environmental Survey, which it describes as having "developed baseline information for some, but not all, of the problems covered by the ER program" (38).

Public involvement in the development and application of any DOE priority system is essential for its acceptance. The new quantitative priority system for environmental restoration activities may be too complex to obtain broad and meaningful public involvement. It is not yet clear whether effective public involvement will be achieved at each of the critical phases of this system, including those conducted by the field offices and finalized at DOE headquarters.

PUBLIC INVOLVEMENT

status

The foreword to the 1990 Five-Year Plan states that "through openness and cooperation, DOE hopes to make its environmental program more responsive to public concern' (39). In the 1989 Five-Year Plan (2), DOE outlined its public involvement efforts, which were directed primarily toward obtaining review and comments in connection with the plan. During development of the 1989 plan and after its publication, DOE invited input from the State and Tribal Government Working Group, which included representatives chosen by the Governors of 10 States, leaders of 2 Indian Nations, and representatives from the National Governors' Association, the National Association of Attorneys General, and the National Conference of State Legislators.

Recently, DOE has expanded the external review process to include several more States, another Indian Nation, and participants from a wider cross section of the public, including unions, industry associations, public interest groups, and environmental groups. In addition, as promised in the 1989 plan, a *Federal Register* notice invited public comment on the published plan.[67] DOE's responses to the comments are included in an appendix to the 1990 Five-Year Plan. In addition, DOE received input to that plan at the Stakeholders Forum held in April 1990. A "predecisional draft" was reviewed at this forum, which was attended by representatives from national environmental organizations, industrial and labor organizations, State governments, one Indian tribe, DOE, and other Federal agencies.

In response to a comment on the 1989 Five-Year Plan inquiring how State, tribal, and public participation will be implemented (and, specifically, what DOE means by public participation-whether groups will participate in the preparation of Activity Data Sheets submitted by the facilities, whether public hearings will be held, etc.), DOE noted that the "commitment to participation by States, Tribes, and the public is 'new culture' for DOE"; thus, details for accomplishing this will continue to evolve (40). DOE also noted that public hearings on the Five-Year Plan were not anticipated, but it specified other avenues for public participation: "Availability of plans for public comment, notice of intent to prepare environmental impact statements, and public scoping meetings are announced in the *Federal Register.* Public meetings near DOE facilities are advertised in area newspapers." DOE also stated that "defining public participation is difficult because the intent is to be inclusive, rather than exclusive, but limits to time, effort and budget must be recognized" (40).

The 1989 Five-Year Plan also called for public involvement in DOE's implementation of the plan at the operations office level. It states that affected parties should participate in the development and review of site-specific implementation plans. The 1990 plan does not indicate that this has come to pass. Although it acknowledges public involvement in the development of national plans (the Five-Year Plans and the Applied Research, Development, Demonstration, Testing, and Evaluation Plan (RDDT&E) (1,2,4)), it mentions local involvement only as something that is yet to come: "Beginning with this Plan, DOE will extend formal involvement to local communities near its facilities and sites. The mechanism for expanded public participation will be public participation plans for DOE's major installations, to be specified by Operations Offices in their

[67]Solicitation of Cements from the General Public on the Environmental Restoration and Waste Management Five-Year Plan, 54 Fed. Reg. 36372 (1989).

Site-Specific Plan'' (41). DOE anticipates more public involvement in the site-specific plans in the future (42).

The National Environmental Policy Act[68] and other environmental laws require public involvement in determining the scope and commenting on the analysis of weapons facility waste management and environmental restoration projects and alternatives. Pursuant to those requirements, the public has been invited to comment on certain environmental analyses prepared by DOE operations offices on specific waste management and environmental restoration projects. Several environmental organizations, led by the Natural Resources Defense Council, sued DOE, contending that it should be required to prepare a Programmatic EIS (PEIS) on weapons production, waste management, and environmental restoration at the Weapons Complex as a whole. In January 1990, Secretary James D. Watkins announced that DOE will prepare a PEIS for the Five-Year Plan (and a separate one on modernization of weapons production facilities) and will hold public meetings to obtain comments on the scope and content of that EIS (43). The series of 23 public scoping meetings began in December 1990 and is scheduled to continue in 1991 (44).

A final area in which DOE proposes to involve the public is the development of a priority system for the Weapons Complex. This system, described above, will serve as a replacement for the Program Optimization System—DOE's first quantitative priority-setting effort for environmental restoration. According to the 1990 Five-Year Plan, ''since last October, the External Review Group . . . has participated in the design of a rigorous, risk-based methodology for prioritizing remedial activities'' (45). Representatives from several States, Indian Nations, EPA, the Natural Resources Defense Council, and the Environmental Defense Fund are currently participating in the ERG.

Originally, six ERG meetings were planned between August 1989 and July 1990. Two were actually held during that period. After the second, members of the DOE-invited group stated their opposition to the current process because it limited, rather than encouraged, public involvement. DOE has since revised its approach and decided to hold

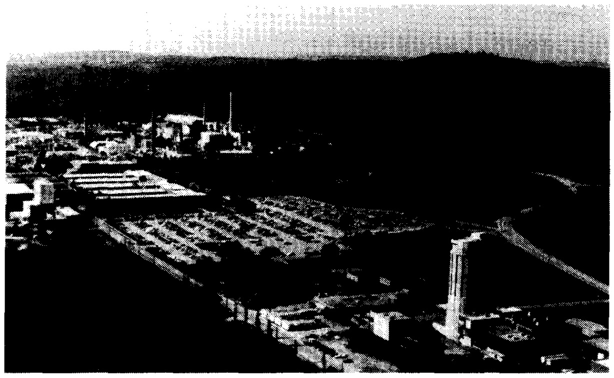


Photo credit: Martin Marietta Energy Systems

Aerial view of the Oak Ridge National Laboratory.

future meetings around a more developed concept while, at the same time, applying that concept to its budget process (46). A third meeting was held in September 1990, and members again expressed their frustration with the limited opportunity for input (47). These events or developments indicate that DOE appears to be having difficulty in effectively utilizing public input in this process.

At some DOE weapons facilities, advisory groups and committees that include representatives of community and environmental groups have been established. One such group is the FMPC Environmental Safety and Health Advisory Committee at Fernald. Committee members are appointed by the president of Westinghouse Materials Company of Ohio, the contractor at Fernald, and include scientific experts as well as representatives of the general public. According to the group's charter, its purpose is to provide ''independent assessment, evaluation and advice to the operating management relative to health and environmental issues, programs and policies.''[69]

There is also an advisory committee at Oak Ridge. In addition, DOE's Oak Ridge Operations Office is expanding its public involvement effort through its Environmental Restoration and Waste Management Office. That Office is responsible for developing and submitting to EPA a Community Relations Program Plan, based on EPA regulations and discussions with representatives from Oak Ridge and nearby communities. An implementation plan is also being developed, which is intended to provide opportunities for

[68] See supra note 6.

[69] FMPC Environmental Safety and Health Advisory Committee Charter, 1989.

public input, inform the public of planned and ongoing activities, and to focus and resolve conflict.

The implementation plan's objectives are being met through printed materials; DOE Oak Ridge officials are also preparing a newsletter that is being put in circulation through local newspapers. An "information resource center" has been set up in Oak Ridge to house documents relating to the Oak Ridge Reservation site activities as well as to Superfund, as required by EPA regulations. Future public meetings, workshops, and a speaker's bureau are also planned.[70]

Evaluation

Historically, the public has had great difficulty in obtaining information from DOE about environmental and health issues at the Weapons Complex. Many have been frustrated in their efforts to express concerns about these issues to DOE or to obtain satisfactory responses from DOE addressing those concerns. Recent DOE efforts outlined above have attempted to change this situation.

Throughout this study, OTA discussed public involvement issues with national and local public interest and environmental groups concerned with Weapons Complex cleanup. Many of these groups emphasized the need for additional and more aggressive efforts by DOE to involve the public in cleanup decisions. In addition, to obtain some impressions of how DOE's recent efforts are viewed by those actively involved with these issues—particularly at the community level-OTA staff had telephone interviews with 14 people from 10 citizen and environmental groups involved with cleanup issues at 8 sites across the Weapons Complex.[71] Through these interviews, OTA learned that all those interviewed were familiar with DOE hearings and comment periods. In general, representatives of most groups believe that certain individuals in DOE or with its contractors do make an effort to communicate more openly with the public. All were skeptical, however, about the existence of "a new culture, especially at the local level, and all expressed the view that, on the whole, DOE is still not actively seeking public involvement except in a few very specific instances. The problems outlined below contribute to this skepticism.

An issue cited in the conversations as fundamental to public involvement is public access to information. Conversations revealed continuing frustration over the difficulty of obtaining useful information from DOE. For example, no one gave a mainly positive response to the question, "Are you getting the information you need from DOE?" More than half of those interviewed emphasized the need to request desired information repeatedly. Most had experienced some level of success in making requests under the Freedom of Information Act,[72] but no one considered this a perfect, or even very satisfactory, way to obtain information. Representatives from four groups said that a noticeably longer time was required to obtain even routine environmental reports than before Admiral Watkins became Secretary of Energy, apparently because DOE headquarters wants to review information put out by field offices before making it available to the public.

Furthermore, although some public meetings or hearings held by DOE concerning individual sites were said to have gone well, every person interviewed expressed dissatisfaction with the way most meetings were conducted. Common complaints were as follows: the notification process is poor; meetings me held too late in the processes that they are supposed to inform; and information is presented so as to "intimidate' rather than inform the attending public. According to many, it is difficult, if not impossible, for people to track consideration of their comments. (In contrast, one person cited the Advisory Committee on Nuclear Facilities Safety, also known as the Ahearne Committee, as a group that sees its mission as involving the public and whose conclusions have clearly reflected public comments.[73])

70See "Environment Update, A Report from the Department of Energy on Environmental Restoration (ER) Activities at the Oak Ridge Reservation,'' Issue One, Oak Ridge, TN, September 1990.

71Interviews were held in July 1990 with representatives of the Concerned Citizens for Nuclear Safety; Energy Research Foundation; Fernald Residents for Environment, Safety, and Health; Greenpeace Action-Southeastern; Greenpeace USA; Hanford Education Action League (HEAL); Heart of America Northwest; Nuclear Safety Campaign, Snake River Alliance; and Tri-Wiley Citizens Against a Radioactive Environment (CARES). The sites with which these groups are directly concerned are Fernald, Hanford, INEL, LLNL, Los Alamos, Rocky Flats, Savannah River, and WIPP.

72Pub. L. No. 89-554, 80 Stat. 378 (1966) (codified as amended at 5 U.S.C. 552).

73Jason Salzman, Greenpeace USA, telephone conversation, July 13, 1990.

Representatives of two groups objected specifically to "workshops' at which DOE does essentially all the talking.[74] According to one, public attendance at these workshops is being used by DOE to "rationalize a level of community involvement that doesn't exist."[75] Another person cited the Stakeholders Forum to discuss the predecisional draft of the 1990 Five-Year Plan as a meeting that went well. However, he was not wholly satisfied, because, in his opinion, the meeting occurred too late to make any real difference in the plan.[76]

OTA's findings on the basis of these conversations are that DOE and the persons interviewed have very different perceptions of public involvement. Although DOE's recent efforts to involve the public are generally viewed as a step in the right direction, these efforts have yet to produce effective public involvement.

PLANS TO ENHANCE THE TECHNOLOGICAL BASE

Research and Development

General

DOE intends to develop and utilize new technologies in its environmental restoration and waste management efforts. The motivation for doing so is twofold: first, in many instances, technologies to accomplish certain cleanup and waste management tasks are either nonexistent or ineffective; second, implementation of new technologies is said to be able to significantly reduce future expenditures, especially with in situ treatment. These and other factors led DOE to state that "to successfully achieve its 30-year cleanup goal and to do this with the lowest possible cost, DOE must create and rapidly field new technologies concordant with all applicable regulations" (48).

The 1990 Five-Year Plan also calls for technological development spending related to site cleanup and waste management to increase from about $200 million in FY 1991 to *$360* million by FY 1994-96. This represents 5 to 8 percent of the total cleanup budget projected for these years (8 percent currently, decreasing to 5 percent in 1995 and 1996). A new national program has been created for research and development; the organizational fiamework for such a program emerged in 1990 in the form of the new DOE Office of Technology Development (OTD). This program builds on past DOE research and development efforts including the Hazardous Waste Remedial Action Program (HAZRAP).[77]

DOE states in the 1990 Five-Year Plan that major research initiatives will focus on: 1) waste minimization, 2) improved waste operations to prevent the need for future site cleanup, and 3) environmental restoration to remedy past contamination. In addition, DOE intends to support major initiatives in education, training, and technology transfer. The 5-year budget allocates about 39 percent of technology funding for environmental restoration, 23 percent for waste operations, 10 percent for education, 13 percent for technical support, and 15 percent for program support (administration). Through this technological development program, DOE plans to make new, improved, and innovative technologies available for the most difficult environmental restoration and waste management problems.

OTD is addressing all major areas related to environmental restoration but is focusing particularly on new technologies for site characterization and monitoring because most current DOE activities are at this stage. In addition, DOE believes that new technologies could improve traditional well monitoring or laboratory sample analysis techniques that are costly and time consuming. DOE is cooperating with other agencies (e.g., EPA and the Department of Defense) in this effort, as well.[78]

The 1990 DOE plan proposes to increase funding; foster greater cooperation among national laboratories; implement a process for identifying the best technologies; develop a rigorous, consensus-based prioritization methodology for research and devel-

[74] Marylia Kelley, Tri-Valley CARES, telephone conversation, July 9, 1990; Jim Thomas, Hanford Environmental Action League, telephone conversation, July 6, 1990.

[75] Marylia Kelley, Tri-Valley CARES, telephone conversation July 9.1990.

[76] Tim Connor, Energy Research Foundation telephone conversation, July 9, 1990.

[77] HAZRAP consists of the Hazardous Chemical Waste Research and Development Program and the Technology Demonstration Program. With funding from DOE headquarters, the objective of these programs is to promote and expedite technological research, development, and demonstration relevant to RCRA, CERCLA, and SARA.

[78] Thomas Anderson, Physical Scientist, Office of Technology Development, DOE, letter to Peter Johnson, OTA, July 16, 1990.

opment activities, with public participation; promote specific technologies for specific purposes; and implement new educational initiatives. DOE intends to support new university consortia and degrees relevant to its needs, as well as proposals encouraging students to specialize in vital areas. These actions in education respond to DOE's concern about a shortage of skilled personnel in areas required for cleanup.

The new Office of Technology Development is one of three separately funded entities in the Office of Environmental Restoration and Waste Management, created to provide a closer link between needs and research projects. During 1990, substantial efforts were devoted to putting these new organizations in place, holding meetings, or starting educational initiatives. DOE claims that its program of technological development will help achieve its 30-year cleanup goal at the lowest cost. DOE has made only rough estimates of the benefits (in the form of decreased costs, risks, and time required for completion) that may result from aggressive technological development. However, it claims that such benefits will be substantial and that without such a program, exorbitant costs, probable delays, and unnecessary exposure of workers and the public to chemical or radiological hazards will result. DOE expects a major return from its investment of about $1 billion in technological development over the next 5 years (49).

Selecting Projects

DOE has established a process within OTD to select the most promising technologies for developmental support.[79] For example, the In Situ Remediation Committee, consisting of DOE contractor technical personnel, will review the large number (about 1,000) of proposals received by DOE from field offices and prepare a report recommending specific technologies for funding. In the course of its evaluations, the committee will develop a checklist of criteria to be used in evaluating proposals. DOE's Office of Environmental Restoration will participate in a "validation' meeting to provide input on specific environmental restoration needs. Also, the contractor committee will assist the DOE program manager for in situ remediation.

DOE has also emphasized cooperation among field offices on technical projects. Although technological development has been reorganized and budget increases have been projected, work on disposal and remediation technologies has been underway at DOE for some time (e.g., in situ vitrification). There does, however, appear to be movement toward closer cooperation among personnel in field offices working on similar technical projects, as well as in defining projects that involve more than one field office (e.g., the integrated demonstration of directional drilling with air injection at the Savannah River Site). Finally, DOE seems to be looking toward more cooperation with both the private sector and other Government agencies in technological development, including EPA's Superfund Innovative Technology Evaluation (SITE) program.

Cleanup Technologies: State of the Art

With a few notable exceptions, the state of the art in nuclear and hazardous waste management and cleanup is primitive. The exceptions, such as the Defense Waste Processing Facility for vitrification of high-level waste at Savannah River, tend to be technologies that DOE has taken a long time and spent a great deal of money to develop (16). In environmental restoration, DOE has adopted a similar approach with respect to in situ vitrification, in which it has invested about $15 million and a decade of developmental work so that today the technology can begin to be field-tested for immobilization of certain contaminated soil sites (see box 2-K). Another recently developed technique that DOE has begun to test at sites such as Savannah River and INEL is vapor vacuum extraction. This commercially developed technique entails pumping and suctioning shallow underground wells to extract volatile organic contaminants from the soil.

Evaluation

Although many problems at the weapons sites are still in need of solutions, practically all new ideas in cleanup technology are in the very early stages of development. DOE should plan for a long-range commitment of time and money to the development of new technologies if it is to bring them to the stage at which they can be applied at weapons plants. A well-thought-out strategy is required for bringing the most promising technologies into the field.

7'9'IMs process was discussed with DOE officials at an OTA Workshop on Remediation Techniques, May 8, 1990.

Box 2-K—Development of In Situ Vitrification (ISV) Technology

Types of Technology: Thermal treatment of near-surface soils, sludge, and other contaminated materials in place by using electrodes that heat up to 2,000 ° Celsius, thus melting the material and later solidifying it into a glasslike form. A hood with filters is used to capture the off-gasses. The process is reported to destroy organics and immobilize certain metals and radionuclides.

Developmental Highlights: Development began at DOE in 1981, based on electric melter technology for high-level waste. Initial work was performed at Battelle's Pacific Northwest Laboratory at Hanford. Thirty-six laboratory, engineering, and pilot tests were conducted from 1981 to 1986. A patent was issued to DOE in 1983 for the process, and DOE later granted the rights to Battelle. Several large-scale tests were run through 1988 when Battelle created a separate company (Geosafe, Inc.) to commercialize the technology.

Funding: DOE has invested about $15 million on ISV development to date. Current (FY 1990) funding is about $4 million.

Status: In 1990 a full-scale demonstration test was conducted on a mixed radioactive and hazardous waste site at Hanford; the results are being analyzed. Other DOE sites have run smaller-scale tests on inert material. Geosafe intends to use the technology for a commercial application at a Superfund site in 1990 or 1991. The technology still has a number of limitations (melt depth and dimensions, water table instability, collection of effluents) and requires further development to make it more widely applicable.

Application: This technology appears to be suitable for remediation work at certain sites where contaminated near-surface soils or burried waste can be treated in-place. Determination of applicability would include considerations of waste types, amount of moisture present, cost of electricty, ability to contain off-gasses, and dimensions of contamination.

Lessons Learned: Technology that has a variety of applications to critical DOE remediation work and that can benefit from related developmental efforts has a good chance of success if it receives substantial, consistent support over a long time period. That support would include a competent work force as well as funding. A successful developmental process must also allow for creativity, flexibility, and learning from problems encountered.

SOURCE: Office of Technology Assessment, with information developed at May 8, 1990, Technology Workshop.

As part of DOE's technological development program, it will be important to identify the greatest needs and the areas in which new technology can make a difference. The first step should be to identify cleanup needs and to determine those that are most urgent and serious. In this step, information about health effects should be factored in as it becomes available. For example, among the problems that DOE has already identified as particularly intractable are the following (see apps. A, B, C and ref.16:

- groundwater centarnination at almost all sites,
- plutonium in soil (e.g., at Rocky Flats and Mound Plant),
- silos containing uranium processing residues at Fernald,
- single-shell tanks containing high-level waste at Hanford, and
- buried transuranic waste at INEL.

After determining those problems most in need of solution, DOE could identfy the technologies that are most likely to address key needs and investigate the alternatives that can be developed for each key problem, together with the relative costs and benefits of these alternatives. This identification of needs, followed by an analysis of alternative technological approaches, should be a continuous process that feeds in new characterization data as well as information on health and environmental effects as they become available.

If DOE is going to develop advanced technical solutions, however, it will have to be realistic about the effort, time, and funds required. Many projects could require at least the level of effort devoted to in situ vitrification over the past 10 years. Considerable effort must be given to the demonstration, testing, and evaluation phases of technology development. If a new technology does not perform as expected under particular field-test conditions, the results should not necessarily be viewed as a failure. Rather, early problems can provide opportunities to improve a technology and develop appropriate applications.

In some instances, however, not enough is known to solve a problem—e.g., groundwater remediation.

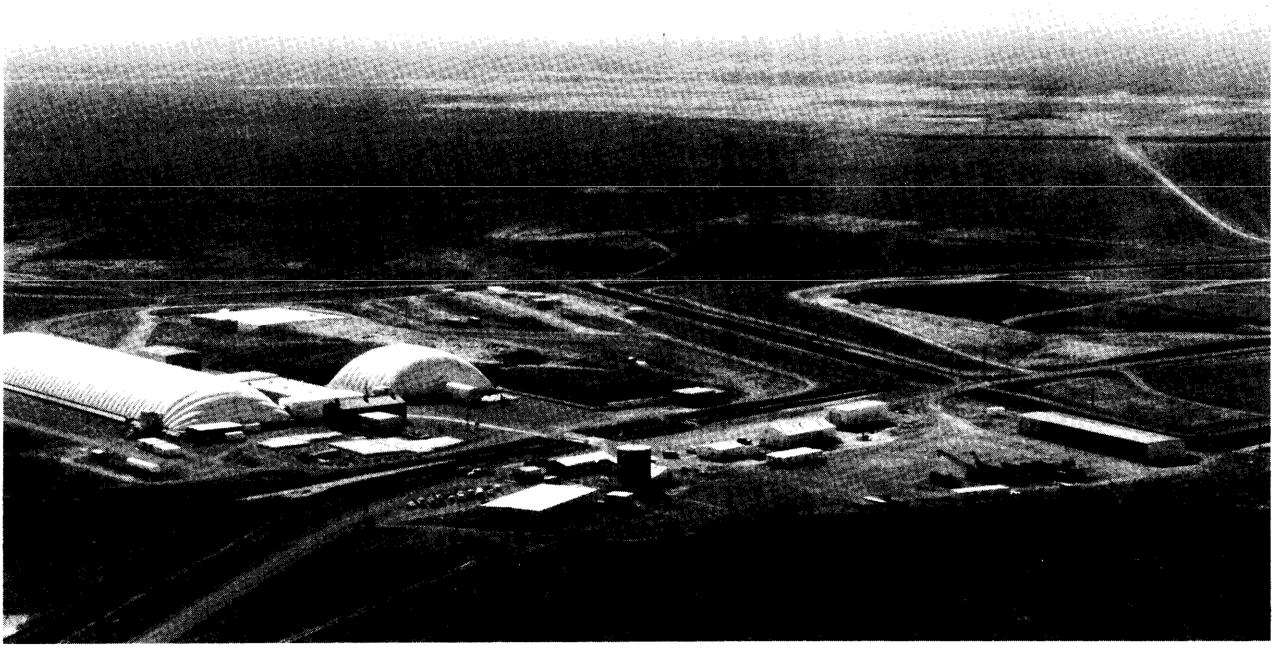


Photo credit: U.S. Department of Energy

Radioactive Waste Management Complex where a number of new technologies will be tested at INEL.

The best approach in this case maybe not to spend a great deal of money attempting to develop new approaches, but rather to contain and monitor centarnination, to apply state-of-the-art technology at each place groundwater centamination is found, and to learn about the successes, failures, and appropriate applications of this technology. In some cases, it may not be feasible to clean up an aquifer but instead to rely on point-of-use treatment.

Although investing in technology is never a sure thing, a program that is too diverse and scattered among research projects may not bean effective way to solve the problems existing at weapons plants. What is needed is a process that will devote adequate sums of money and concentrated efforts to focused technological development, rather than spending a little money for many items on a long "wish list."

DOE has taken the necessary first step by establishing a headquarters organization devoted entirely to technological development. That organization can conduct the analyses required. First, however, it must overcome a problem inherent in DOE's current 5-year planning approach-i. e., taking the amount of money expected to be available for 5 years and estimating the projects that can come out of that amount, rather than determing what really needs to be done to solve key problems and what can be accomplished toward that objective during the 5-year period.

The OTA workshop held in May 1990 focused on: 1) defining the status of existing and forthcoming remediation technologies that may be applied to DOE's environmental restoration program and 2) understanding the benefits and limitations that can be expected from their use.

Participants noted that although much work has been devoted to research, development, and testing ofremediation technologies, few real "breakthroughs" have occurred over the last 10 years either within DOE or in the private sector. (The only significant ones noted by participants were in situ vitritication and vapor vacuum extraction.) The reasons listed below were cited as possible contributors to what was viewed as an overall lack of major progress:

- *Insufficient Numbers of Trained Personnel*— Good management of remediation efforts requires individuals with multidisciplinary aca-

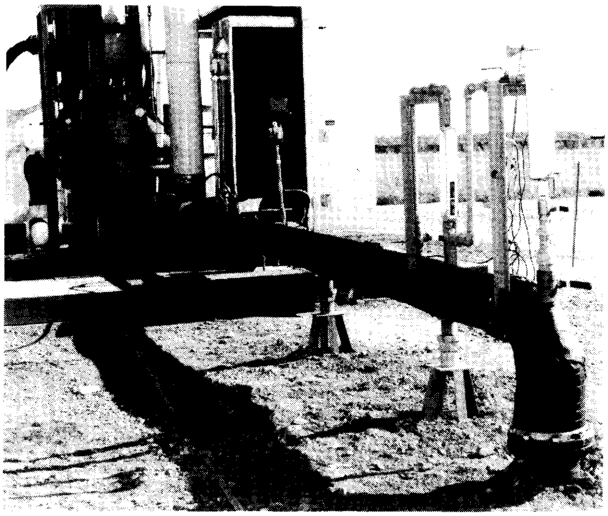


Photo credit: U.S. Department of Energy

Vapor vacuum extraction demonstration at INELto remove hazardous organic vapors including carbon tetrachloride from below the Radioactive Waste Management Area.

demic and professional backgrounds. Better communication among disciplines is also needed. Expanded support for academic and training programs is essential.

- *Lack of Feedback From Characterization and Remediation to Research—A* key requirement is a connection between research and characterization or remediation efforts. Initial remediation efforts should be subject to postmortems to assess their effectiveness and provide guidance for further research; site characterization should also be reviewed systematically.
- *Lack of Prioritiescorrelative Levels of Funding—* Very few developmental efforts have received consistent, substantial support focused on clear goals. There is a need to set priorities for the development of new technologies (i.e., to identify those with the most promising potential solutions for problems at hand), so as to allow the most effective allocation of funds.
- *Tendency To Seek "Quick Fixes'' -It* is generally beneficial to consider the use of interim remedies to gain time for the development of more effective solutions, rather than to proceed with expedient—but often inadequate— solutions. Most remediation problems are very complex and require the application of a wide range of skills over a long period.

DOE has indicated that it favors in situ remediation technologies as a means of reducing the cost of environmental restoration. There is a general sense within DOE that in situ technologies could lead to savings, particularly because removal and treatment technologies usually involve handling and processing large quantities of material (50). However, in situ technologies in general require substantial development before they can be applied widely to cleanup problems. Biological and chemical in situ techniques involve introducing agents into soil or groundwater so that they come in contact with contaminants and react with them; these techniques, however, do not affect radionuclides. Other techniques such as in situ vitrification serve to immobilize and contain the pollutants (including radionuclides) in place. Because knowledge of the location, concentration, and movement of contaminants is difficult to obtain, the effectiveness of in situ techniques is doubly difficult to assess. For example, bioremediation has progressed farthest as a system to treat contamination in surface bioreactors, rather than underground where there is great uncertainty about its effectiveness. Substantial research and characterization will be necessary to reduce this uncertainty (see app. B).

Education

There seems to be general agreement that the number of individuals and the level of expertise required for DOE's cleanup efforts are inadequate. A shortage of necessary skills exists at all levels. Human resource availability and skills in weapons production do not necessarily translate into availability and skills for environmental restoration.

In the 1990 Five-Year Plan, DOE points out that environmental restoration and waste management activities require a relatively high level of expertise and that skilled professionals are in short supply. Furthermore, the competition for critical skills is likely to intensify among DOE, EPA, State agencies, and private contractors.

DOE intends to implement new and expanded educational support programs focused on helping meet its critical personnel requirements for the future. Initial steps include pilot programs for DOE and university partnerships, as well as fellowship or scholarship programs to draw students into environmental careers. DOE's plan calls for an expansion of innovative outreach programs to minorities and to the educationally disadvantaged (4).

Two pilot DOE-university partnerships have been established, one involving three universities in New Mexico and the other involving four universities and colleges in South Carolina. In New Mexico, a Waste Management Education Research Center was established to offer master's degrees in several engineering fields, with emphasis on environmental restoration and waste management. In South Carolina, in addition to curriculum modifications the partnership will emphasize applied research closely connected with environmental restoration and waste management issues at the Savannah River Site.

DOE's budget in the 1990 Five-Year Plan for education and outreach is about $21 million in FY 1991, increasing to $37 million by FY 1994. Clearly, an educational initiative is needed that, given consistent support, should significantly enhance the pool of talented professionals available to resolve future environmental problems. Most experts agree that human resources are as critical as financial resources in solving contamination and waste problems at the Weapons Complex. It would also be wise to monitor the DOE educational program for some later analysis of its accomplishments. Although DOE has emphasized support for educational initiatives, it has not specifically analyzed its needs for a future environmental work force, in terms of either numbers, a timetable to meet cleanup goals, or a breakdown of the required disciplines.

Reducing Future Waste

DOE has emphasized the role of waste minimization in several of its planning documents for defense waste management and environmental restoration. For example, in the 1989 Five-Year Plan, DOE stated that it will focus resources on three major classes of activity, one of which is to ". . continue safe and effective waste management operations but emphasize systematic minimization of waste generation" (51). In the 1989 Draft Applied Research, Development, Demonstration, Testing and Evaluation Plan, DOE stated, "Waste minimization, the reduction in the generation of radioactive, hazardous, and mixed waste *before* treatment, storage, or disposal, is a legal requirement, an ethical responsibility, and often a financial benefit. DOE will make waste minimization a key factor, not only in process and facility modification but also in the procurement of goods and services. The major new modernization goal of minimizing waste generation entails a significant RDDT&E component" (52). Recycling is stated to be another major initiative associated with waste minimization. DOE's stated goal is to achieve a 60 to 80 percent reduction in waste generation (FY 1985 baseline) within 10 years of program initiation by material substitution, process alteration, new production hardware, and recycling. Planned programs include demonstration of minimization methods for plutonium and enriched uranium, hazardous material substitution, and material reclamation from old burial grounds (4).

Preliminary DOE estimates indicate that waste minimization could result in a significant reduction of waste treatment, storage, and disposal costs, as well as a reduction in worker exposure and public risk. According to DOE, waste minimization will affect all present and proposed DOE operations and the agency is now moving to a more formal program from an ad hoc approach in the past (53). A formal cost-benefit analysis of waste minimization is planned during FY 1990-91 by using EPA waste minimization cost-saving methodology (54).

Efforts to develop a focused waste minimization program at DOE are new, having been initiated in early 1989 when DOE established a Waste Reduction Steering Committee (54). This committee has made a series of site visits to review waste generation and packaging operations, to review methods and technologies, to develop methods of reporting, and to develop guidance and requirements. The site visit reports summtie waste reduction activities at these facilities-waste *reduction being* defined in the January 1989 guidance establishing the committee as waste *minimization plus treatment to reduce* either the *volume* or the *toxicity* of waste requiring disposal (55). Four waste reduction workshops have been held during the past 2 years. The committee also hopes to help infuse the waste minimization philosophy into production or modernization planning and decisions.

DOE has drawn several conclusions from the site visit reports:

1. Sites are now very aware of waste minimization concepts and requirements.
2. Many waste minimization projects have been implemented that require little funding and minor technical changes.
3. Many sites have implemented charge-back systems to reward waste minimization efforts. Award fees are also being used to reward contractor waste minimization efforts.

4. High-level and transuranic waste minimization efforts have not been given sufficient attention and emphasis.

DOE lists accomplishments at the visited sites as implementing training programs, performing surveys and audits, achieving substantial source reductions of hazardous waste through substitution and administrative controls, and recycling. Promising areas for future activity include recycling and reuse, administrative controls to segregate wastes and avoid generation of low-level or mixed waste, substitution of nonhazardous for hazardous materials, and process improvements to enhance efficiency or eliminate hazardous waste streams. The last is said to require careful analysis and long lead times (54).

DOE characterizes waste minimization efforts as at a relatively early stage, with staffing and funding a year or two away from full program implementation levels. The design of a hypothetical new plant (e.g., a new plutonium recycling plant at Rocky Flats) incorporating the best methods to minimize waste generation is projected to require a 1-or 2-year effort by a design team (54).

The amount of effort currently devoted to waste minimization is not yet commensurate with the importance DOE attaches to that activity in its principal planning documents. However, if DOE follows through in its stated commitment to waste minimization, a major shift in program emphasis should occur over the next few years.

DOE's waste minimization efforts are less than 2 years old. A comprehensive waste minimization plan is expected to be in place in 1991. A very small staff is currently assigned to waste minimization at DOE headquarters. Organizationally, waste minimization has had relatively low status in the DOE bureaucracy, both in the field and at headquarters. These factors should all change markedly as DOE institutes its new waste management philosophy.

Although OTA has not verified DOE claims for the benefits of waste minimization, the potential for meaningful cost savings and other cleanup advantages is real. This appears to be particularly true in the hazardous waste area, where administrative directives and substitution of nonhazardous materials could have positive effects.

Care should be taken to avoid labeling as waste minimization those actions that are driven primarily by regulatory requirements but do not actually reduce the total amount of waste generated. An example of this is the segregation of hazardous and radioactive components to reduce the amount of mixed waste. Although the latter is currently difficult to store or dispose of because of the EPA land ban and the lack of approved treatment, such segregation does not address the physical reality that a certain amount of hazardous and radioactive material still must be dealt with.

Although some significant reductions in waste generation may be expected from relatively inexpensive measures such as instituting administrative controls on the use of hazardous materials, larger gains are likely to require a substantial increase in resources and commitment if production is maintained and the Weapons Complex is gradually modernized. In particular, the design of new facilities that generate less waste requires a significant increase in both the resources and the personnel devoted to process design and modification.

Getting the production side of DOE to take waste minimization seriously is important if such efforts are to succeed. Waste minimization should be incorporated into the design philosophy for plant modification and new construction. Expanded efforts to create this atmosphere within DOE Defense Programs would yield substantial benefits.

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Chapter 3

Public Health Impacts of Contamination From the Nuclear Weapons Complex

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Chapter 3

Public Health Impacts of Contamination From the Nuclear Weapons Complex

OVERVIEW

People are worried. Some fear that they or their families have or will become sick as a result of living in the path of wastes and effluents released by 40 years of nuclear weapons manufacture (l-8). Others, believing that such fears are unfounded, worry that the alarms raised over contamination at the Nation's Nuclear Weapons Complex will cloud the future of communities located near weapons facilities (9, 10). Many fear that DOE does not understand the human health consequences of contamination (1 1-13); others believe that the whole story of environmental releases from the complex will never be known (14-23).

There is also concern that the quest for action—the desire to "do something' '—will result in billions of dollars spent on senseless projects (24-28) or that attempts to clean up some sites will lead to additional environmental damage or place the health of workers and off-site populations at risk (29-31).

Fears of possible adverse health effects have been stimulated by reports of environmental contamination throughout the Nuclear Weapons Complex and by disclosures of past toxic releases that were hidden from the public for decades (32-40). Congressional debates about Department of Energy (DOE) efforts to plan and execute its environmental cleanup program have also highlighted questions related to possible public health threats (41-43).

In recent years, a series of investigations have documented lapses and inadequacies in DOE environmental health and safety practices (44-55). In August 1990, Secretary of Energy James D. Watkins announced that during the 1940s and 1950s, thousands of children had received significant radiation doses as a result of Hanford operations (56-58). This admission contrasted with previous DOE assurances that no releases posing a threat to human health had ever occurred and increased public skepticism about the accuracy of DOE claims regarding health risks from contamination throughout the Weapons Complex.

Many of the contaminants released to the environment by DOE operations and waste management practices represent a clear danger to human health if people are exposed to sufficient doses of these materials. For example, materials known to be present at the weapons sites include radionuclides such ascesium-134 and 137; strontium-90; americium-241; plutonium-238 and 239; and uranium-234 and 238. All radionuclides are human carcinogens. Weapons contaminants also include large quantities of heavy metals such as lead (a neurotoxin and teratogen), mercury (a neurotoxin), and chromium (a carcinogen). Other chemicals found at the weapons facilities include benzene and other solvents such as toluene and trichloroethylene;[1] chlorinated hydrocarbons such as polycldorinated biphenyls, cyanide, and chelating agents (see table 2-1 in ch. 2). Unfortunately, information about the extent and magnitude of human exposure to Weapons Complex contaminants is limited.

Three conditions must be met for adverse human health effects to result from environmental contamination. First, the contaminants or their metabolizes must be potentially hazardous to biological systems. Second, hazardous contaminants must be able to make contact with people; that is, the potential for human exposure must exist. Third, exposure to contaminants must occur at concentrations and for periods of time sufficient to produce biological effects. In addition, the nature of the hazards posed by specific chemicals, the degree and patterns of exposure that people experience, and the differences in individual susceptibility to toxic injury must all be considered in weighing health risks associated with environmental contamination (60). Determining whether actual harm has occurred as a consequence of toxic releases from weapons sites will depend on specific knowledge of contaminants, exposure routes, and patterns; estimates of dosages; and investigations of health outcomes among exposed

[1] Solvents as a class affect the central nervous system at high doses. In addition to this general effect, individual solvents can exert specific toxic effects. Thus, benzene causes damage to blood producing cells in the bone marrow whereas certain chlorinated hydrocarbons lead to liver damage (59).

Figure 3-l—Health Issues at Toxic Waste Sites and Possible Public Health Responses

What Communities Want to Know	Public Health Responses
1. Are we exposed ?	A, E
II. Are we affected ?	B, D, E, G
III. Did exposure contribute to effect ?	*A,* B, CG, E, H
IV. Will we be affected later?	*A, C,* DEF, H

Key to Public Health Responses

A. Exposure assessment
B, Response assessment
- o Disease cluster investigation
- o Cross-sectional studies

C. Analytical epidemiological study
D. Registries
E. Medical surveillance
F Reference surveys
- o Exposures

G Reference surveys
- o Health effects

H. Risk assessment

SOURCE: D. Wagener and W. Halperin, Presentation at the National Aademy of Sciences conference on "Frontiers in Assessing Human Exposure to Environmental Toxicants," Washington, DC, May 1990.

populations (see figure 3-l). At most sites, these matters remain largely uninvestigated.

As noted in chapter 2, efforts to identify, quantify, and map environmental contamination at the DOE Weapons Complex are in the early stages. Quantitative analyses of the chemical forms, concentrations, and environmental transport pathways of contaminants have not been completed at any site. Nor are the physical and chemical parameters that control centaminant migration through various media understood completely at any site.

Data describing the extent and magnitude of off-site contamination are particularly sparse. Much important information about the type and amount of past environmental releases is not yet available to regulators or to public health officials.[2] New waste sites continue to be discovered at the larger, older, and more complex reservations such as the Hanford Plant, the Oak Ridge Reservation, and the Idaho National Engineering Laboratory.

The mere detection of toxic environmental contamination in air, water, or soil to which people are exposed does not necessarily imply that adverse health effects have occurred or will occur. Reliable information about the amounts of contaminants individuals are exposed to, and the amounts of toxic materials actually absorbed by the body, is especially important in assessing the effects of environmental toxicants. On the other hand, inadequacies in the scientific understanding of environmental toxicology and methodological obstacles faced by environmental health researchers make it difficult to specify with precision what levels of contamination are "safe' or to rule out the possibility of adverse health effects.

The Office of Technology Assessment (OTA) did not conduct detailed analyses of specific contaminants, environmental transport pathways, or human exposure routes at individual weapons sites. Thus, OTA is unable to judge whether or which contamination scenarios throughout the Weapons Complex constitute public health threats. Even if the necessary data for conducting such analyses were available (and they are not), this task would require time and resources beyond the scope of this report.

[2] In 1989, Secretary of Energy James D. Watkins agreed to make public previously classified information on Hanford Plant operations requested by the Technical Steering Panel directing the Hanford Environmental Dose Reconstruction Project (61). It is unclear whether this decision establishes a new DOE precedent ofopenness or is an exception to earlier policies of classifying information on environmental emissions.

Photo credit: U.S. Depafment of Energy

Sludge removal from injection well contaminated with tritium, TCE, and other chemicals at INEL.

Photo credit: Martin Marietta Energy Systems

Workers are protected from possible exposure to contamination during soil sampling operations at Oak Ridge.

OTA investigations did reveal that weapons sites contain large quantities of toxic materials and that enormous expanses of media are contaminated. Contamination includes the relatively straightforward pollution of soil and groundwater by hazardous chemicals found at many non-Federal Superfund sites, as well as extraordinarily complex contamination scenarios involving multiple environmental pathways and toxic substances that are unique to nuclear weapons manufacture (see app. A).

Currently available information about historic air emissions, releases of contaminants to soil and surface water, and environmental transport pathways indicates that human exposure to Weapons Complex contaminants has occurred (62-67) in the past, and that the potential exists for current or future exposure of humans to toxic materials (68-74).

With the exception of the findings of the Hanford Environmental Dose Reconstruction Project (HEDRP) (75), an ongoing study of radioactive releases and possible off-site exposures that occurred four decades ago, and a few reports dealing mostly with estimates of off-site radiation doses resulting from DOE activities (76-80), there is little scientific documentation of the doses of toxic substances that off-site populations have experienced or are now confronting as a consequence of waste management practices and environmental contamination at the weapons facilities. Even the HEDRP results are preliminary.

OTA analyses, based on the limited evidence available, indicate that off-site health effects are an unproven but plausible consequence of Weapons Complex pollution. Given the potential threat to communities that border the complex and the level of concern that already exists in these communities, focused, aggressive investigation into past and potential health impacts at specific weapons sites is warranted.

POSSIBLE MODES OF HEALTH IMPACTS DUE TO WEAPONS COMPLEX CONTAMINATION

There are a number of ways in which the health of off-site populations might be affected, now or in the future, by environmental contamination from the Weapons Complex. Adverse health effects could occur as a consequence of exposure to off-site media that are currently contaminated with toxic substances or liable to become contaminated if measures are not taken to contain the pollution. In addition, historic releases of toxic materials that are no longer health threats might have caused adverse health impacts. Finally, some cleanup activities could present risks to workers or to communities neighboring weapons sites.

1. *Health risks among off-site populations might result from current or future contamination.* Adverse public health impacts may result from contact with air, water, soil, or from ingestion of plants and animals that are currently contaminated with toxic substances or that will become contaminated if measures are not taken to contain pollution.

At some Weapons Complex sites, contaminants are known to have migrated off the weapons reservations (81) (see app. A). Radioactive cesium released from the Oak Ridge Reservation has been found in the sediment of a Tennessee Valley reservoir used for recreation and fishing (82, 83). Local residents have voiced concern about the possible health consequences of swimming and fishing in these waters, but there are no data estimating the amount of toxic exposure that might result from such activities.

At some sites, pollution is migrating in ways that make public contact probable unless action is taken. For example, at the Feed Materials Production Center in Fernald, OH, contaminated groundwater plumes have extended off-site (84) and are migrating toward an important source of dr[redacted]g water, the Great Miami Aquifer (85). At the Savannah River Site in South Carolina, a plume of groundwater contaminated with volatile organic hydrocarbons has traveled to within several hundred yards of the fence line (86); no contaminants have been discovered in the private wells of nearby residents (87).

At some sites, contaminants are known to be ''loose'' in the environment, and their fates are not well-understood. For example, mercury, a known neurotoxin (88), was used in separating lithium isotopes at the Y-12 Plant in Oak Ridge, TN. More than a million pounds of mercury is unaccounted for (89, 90); a large portion of this has been deposited in the sediment of a creek that traverses the city of Oak Ridge and was used as fill for the local civic center (91). Significant amounts continue to escape from plant premises in the form of rainwater runoff (92). A pilot study conducted in 1983 by the Centers for Disease Control failed to find evidence of abnormal mercury levels in people living around Oak Ridge (93) (see p. 84).

In some cases, population growth and development have reduced the distance between areas of on-site contamination and once-remote neighboring communities. Such a pattern is evident at the Rocky Flats Plant outside Denver, CO. The surrounding population numbered 567,000 when the plant was built in 1953; today, 1.4 million people live within 50 miles of Rocky Flats, the majority of them downwind of the plant (94).

For certain persistent hazardous chemicals and long-lived radionuclides that remain toxic for hundreds or thousands of years, potential threats to future generations must be assessed. Waste containment and cleanup strategies must consider the health impacts of possible future scenarios, such as the accidental release of stored waste, human intrusion into sites where waste is buried, or exposure to contaminants that migrate very slowly through the environment.

2. *Adverse health eflects among off-site populations might also resultfrom toxic materials released to the environment years or decades ago* that pose no current exposure risks because they have since decayed, dispersed, or been diluted. The biological effects of such releases may still be felt, however, because there can be a long lag period between exposure to toxic substances and the appearance of disease.

Documents made public in 1986 revealed that hundreds of thousands of curies of radioactivity were released horn the Hanford Reservation during the 1940s and 1950s (95). Recent HERDP analyses of the environrnental transport pathways of one radionuclide, iodine-131, indicate that as many as 13,000 children may have received up to 70 rads of radiation through ingestion of contaminated milk.[3,4] Epidemiological studies are now underway to determine if the doses of radioactive iodine received by people who lived around Hanford as children can be associated with increased risk of thyroid disorders (97). Additional research is planned to investigate

[3]A rad is a radiation unit that describes the absorbed dose, the amount of radiation absorbed by tissue. (Modem terminology measures absorbed dose in grays (Gy): 100 rad = 1 Gy.)

[4]Preliminary dose estimates for the milk pathway show that approximately 13,000 people, the 5 percent of the study population most highly exposed, received between 1 and 70 rads due to iodine-131; the mean dosage was approximately 7 rads (96).

Photo credit: Martin Maritta Energy Systems

Water samples are taken at various depths in bodies of water impacted by the operations at Oak Ridge.

the radiation doses incurred by Native Americans who fished and bathed in the Columbia River, downstream of the release of highly radioactive effluents from Hanford's production reactors (98).

The health consequences of historic emissions could be important in developing health-based cleanup priorities if long-lived radionuclides and hazardous materials are still present in the environment. Also, a true appreciation of past releases and exposure burdens might influence the assessment of current medical conditions in communities located near weapons sites and could lead to medical surveillance programs or other interventions aimed at mitigating the effects of past practices. Understanding the consequences of such releases may also contribute to future waste management practices.

The possible effects of historic emissions are especially important to members of communities that neighbor weapons sites, who fear that they or their children might have been exposed to toxic materials. Questions about historic releases are part of a wide range of health issues that have engaged the attention of both the public and many public health professionals. In some cases, these concerns go beyond matters that bear immediately an the direction and technical aspects of the cleanup.

3. *Finally, cleanup activities could, in some cases, present a potential health threat to workers and the public.* Thousands of workers may be exposed to potentially harmful contamination while cleaning up the Weapons Complex. Collection and analysis of environmental samples, remediation efforts, and the decontamination and decommissioning of buildings are all tasks that might result in workers' receiving significant doses of toxic chemicals or radiation. Extensive health and safety programs, including medical surveillance and long-term followup studies, will be required in some cases to protect workers engaged in cleanup of the weapons sites (99, 100). These issues are the subject of a separate OTA background paper (see box 3-A).

The health risks associated with cleanup activities are not limited to workers engaged in site characterization and remediation. Disturbing large amounts of contaminated soil, for example, could result in resuspension of contaminants in air. Airborne contaminants might then travel beyond the site perimeter to expose the public.

Review of Off-Site Health Studies Related to the Nuclear Weapons Complex

DOE and its predecessor agencies have sponsored research into the health effects of radiation since shortly after the end of World War II, when the Radiation Effects Research Foundation (RERF)[5] was formed to study the health effects of ionizing radiation in atomic bomb survivors and their offspring (101). Over the past two decades, RERF has accounted for more than half of the funds spent on

[5]Data from the Radiation Effects Research Foundation have served as the basis for much of the analysis conducted by the National Research Council's Committee on the Biological Effects of Ionizing Radiation (BEIR). RERF observations of the Japanese survivors of the atomic bomb constitute the largest collection of information about the long-tam effects of acute radiation exposure. The size of the population under study and the relatively long period of observation make this database uniquely valuable. As the study population ages and more data become available, successive BEIR committees have revised their estimates of the cancer risks associated with exposure to low-dose radiation. Five BEIR reports have *now* been published, the most recent in December 1989 (102). (BEIR IV did not analyze the atomic bomb data, but instead addressed the effects of internally deposited radionuclides, chiefly radon, on uranium miners (103).)

Box 3-A—Importance of DOE Worker Data in Assessing Off-Site Health Impacts

Department of Energy (DOE) nuclear weapons production workers are important in the evaluation of potential off-site health impacts resulting from contamination at weapons sites for various reasons. Usually, workers experience occupational exposures to toxic substances that are more intense and more hazardous than exposures resulting from environmental contamination by such substances. This occurs because many jobs necessarily involve direct contact with, or proximity to, toxic materials and also because laws and regulations governing allowable occupational exposure to toxic materials are less stringent than regulations designed to protect the general public.

Health studies of workers therefore might signal the type, extent, or absence of adverse health effects that could be expected among populations experiencing less intense exposures. However, occupational studies do not provide foolproof evidence of the risk of health effects among off-site populations due to environmental contamination. Although workers generally experience higher exposure levels than do off-site populations, they are also generally healthier and hardier than many segments of the general public. Children, the elderly, and people with underlying disease or certain genetic makeup maybe much more vulnerable to the effects of various exposures than are healthy adults. Thus, the lower exposure of populations compared with workers is to some degree offset by variations in individual susceptibility to disease among the general public. Also, exposure to chronic, low doses of environmental toxicants may have biological effects that are not reflected by the consequences of acute, high-dose exposures in the workplace. Nonetheless, information contained in the records of DOE employees and in reports of studies by DOE contractors on segments of the DOE work force maybe very valuable tools in assessing the off-site health impacts of DOE operations.

In addition, there is unique value attached to data that has been accumulated since the start of the Manhattan Project describing the health of the nuclear complex work force. It is the only database that describes the health outcomes for large numbers of people exposed to low levels of radiation over a period of decades. These characteristics make the DOE worker data extremely valuable to researchers investigating the degree of risk associated with exposure to low doses of radiation, an issue that has been controversial and has important policy implications.

epidemiologic studies[6] by DOE's Office of Health and Environmental Research. The remainder of DOE-sponsored epidemiological research has been aimed chiefly at studying the effects of radiation on employees of nuclear weapons facilities (104). Most of this work has been conducted by scientists at DOE national laboratories; some of it has been published in peer-reviewed scientific journals (105).

Very few DOE-sponsored research studies have focused on the potential or actual impacts of various weapons site activities and releases on the health of surrounding communities. Those studies that are available focus on potential radiation effects; OTA is aware of only one study that investigated possible health impacts of toxic chemicals released by DOE operations. This section briefly reviews some of the scientific investigations, site-specific environmental surveys, and annual reports that make up much of the currently available analyses pertaining to off-site health effects due to environmental contamination at the Weapons Complex.

In 1986 a $60-million study to assess the extent of contamination resulted in Environmental Survey preliminary reports (106). These reports were neither comprehensive nor consistent across sites, were limited largely to historical and existing data, and did not utilize standardized quality assurance or quality control procedures (107). However, the Environmental Survey did provide the first qualitative overview of environmental contamination throughout the Weapons Complex.

Each facility in the Weapons Complex prepares an annual environmental monitoring report that includes site-specific monitoring data from routine environmental surveillance activities. Almost all of the data reported pertain to radiological measurements. Calculations of radiation doses received by the off-site population as a consequence of facility operations are also reported. The focus on radiological releases and the inattention to chemical contaminants or to contamination of media such as soil and sediments, the inconsistency of reports from year to

[6]Epidemiology is the study of the distribution and determinants (e.g., causes, risk factors) of disease among human populations. By gathering and analyzing information about the frequency of exposure and illness among groups of people, inferences can be made about the causes of disease, and program for disease prevention and control can be put into practice (see box 3-C)

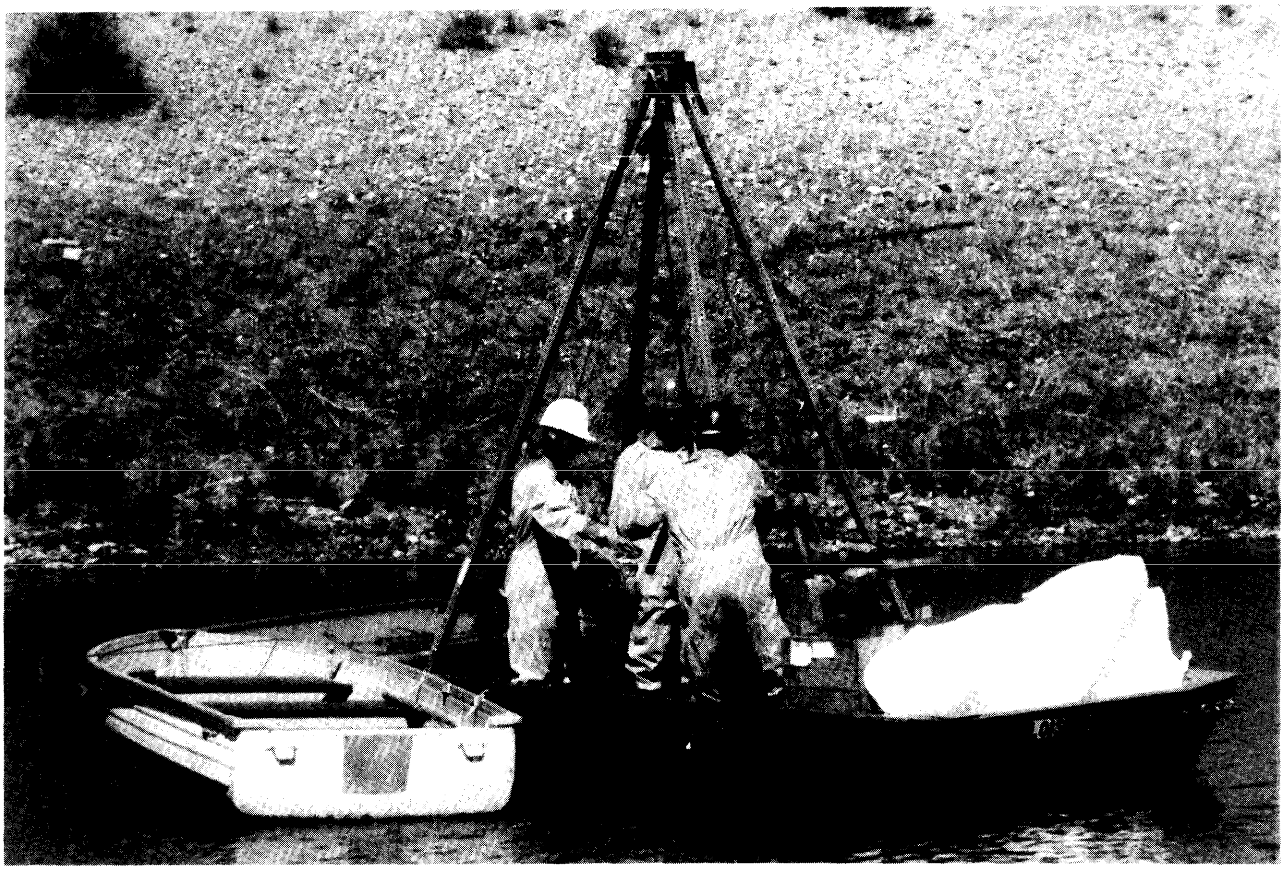

Photo credit: U.S. Depanlnent of Energy

Routine monitoring of warm waste pond at INEL test reactor area.

year at a given site (108) or among sites, the lack of rigorous quality control of data and analyses, and the absence of outside peer review limit the use of these surveys for the purposes of health effects assessment (109, 110). In addition, considerable delay has occurred between the compilation of recent site-specific Environmental Survey reports and their publication. As of mid-1990, most site survey reports for 1988 were still not available to OTA.

Over the past 18 months, a number of critiques of the environmental, health, and safety programs at the Weapons Complex have been published. The Secretary of Energy has directed "Tiger Teams" of DOE managers and contractor employees to perform environmental and occupational health and safety audits at selected DOE sites (111-117). These Tiger Team reports have varied in their approach and manner of documentation but do provide important insights into environmental and occupational health and safety issues, as well as management and organization at selected weapons sites.

As mandated under the Defense Authorization Act of 1988,[7] at DOE's request the National Academy of Sciences convened a Committee to Provide Interim Oversight of the DOE Nuclear Weapons Complex, chaired by Richard Meserve (118). The Meserve Report, published in December 1989, provides an overview of current strengths and deficiencies at the Weapons Complex and calls for remediation strategies based on consistent risk analyses, enhanced on-site safety programs, and substantial improvement in occupational health programs for DOE employees.

OTA has investigated the available published information on public health impacts associated

[7]Defense Authorization Act of 1988, Pub. L. No. 100-180,$3134 (1988).

with contamination from the weapons sites. Only a handful of DOE-sponsored studies have attempted to examie community health impacts of weapons site operations or releases. All were conducted in response to pressure from concerned citizens. One study was a reanalysis of a previous investigation (119, 120) reporting an excess of cancer deaths among people living near the Rocky Flats Plant in Colorado. The later study again found elevated cancer rates in certain census tracts near Denver, but the geographic pattern of excess cancers did not appear to correlate with proximity to Rocky Flats (121, 122).

Another investigation was a 1983 pilot study carried out by the Federal Centers for Disease Control (CDC) on the effects of mercury contamination at the Oak Ridge Reservation (123). This study was requested by the Tennessee Department of Health and Environment (TDHE) because of concern about the potential health effects from human exposure to soil and fish contaminated with mercury released by DOE's Oak Ridge operations. Questionnaires were used to identify individuals who were most likely to have been exposed to contamination. Urine and hair specimens were obtained from a small sample of people with probable high and low exposures: 11 hair samples were obtained from individuals whose questionnaire responses suggested high exposure and were compared with samples taken from 46 individuals with no history of exposure to centamination. Urine samples from 79 people with a history of exposure to contaminated soils were compared with samples from 99 individuals without a history of exposure. Mean mercury levels in hair and urine did not differ significantly between the two groups, nor were mercury concentrations above the levels usually associated with adverse health effects, although such levels have not been well delineated, especially in children (124).

It was concluded that the project did not demonstrate current exposure to mercury contamination. However, the number of persons tested was small. In addition, urine mercury measurements reflect only recent exposure, and the period of greatest mercury releases (1944-1977) was years and even decades prior to the study. The authors noted that their study results supported the fish ban in East Fork Poplar Creek that had been ordered by TDHE and opposed by DOE.

In 1983, Du Pent, then the DOE contractor at the Savannah River Site (SRS), sponsored an epidemiological study of cancer deaths in communities neighboring the plant (125). This cross-sectional study compared cancer death rates in counties surrounding SRS with rates in counties further away and with U.S. cancer mortality rates. No increases were observed in cancer deaths in counties adjoining the plant, nor were any trends detected of increasing death rates with increasing proximity to the plant. This study was spurred in part by public consternation over an earlier Du Pent study that showed an increase in leukemia rates among blue-collar workers at Savannah River (126), as well as an analysis by independent investigators suggesting that high-level waste tanks at SRS pose a substantial threat of explosion and consequent environmental contamination (127).

In 1984, responding to continuing community concern, DOE asked CDC to review and comment on the "feasibility and usefulness of conducting further epidemiologic studies of delayed health effects" around the plant (128). CDC was skeptical about the usefulness of epidemiological studies of off-site health effects from SRS radioactive releases because such studies would involve small populations and low dose rates and thus would have limited statistical power. Public comments at a meeting held to brief the community on CDC findings revealed continuing local concern about the health impacts of SRS operations (129).

The most ambitious and scientifically sophisticated site studies to date are the Hanford Environmental Dose Reconstruction Project (HEDRP) and the associated epidemiological investigation. HEDRP, begun in 1987 at the request of the State of Washington and neighboring Indian tribes, is being conducted by Pacific Northwest Laboratory, a DOE contractor, under the direction of a technical steering panel composed of independent scientists (130). The aim of HEDRP is to use "source terms" (estimates of the amount and type of radioactive materials released to the environment) and computer models of environmental transport pathways to reconstruct a picture of the doses of radionuclides received by individuals who lived near Hanford during the periods of highest plant emissions. The first phase of the study, which was completed in July 1990, reconstructed the air pathway and calculated dose estimates experienced by people living in the 10 counties nearest Hanford as a result of a single

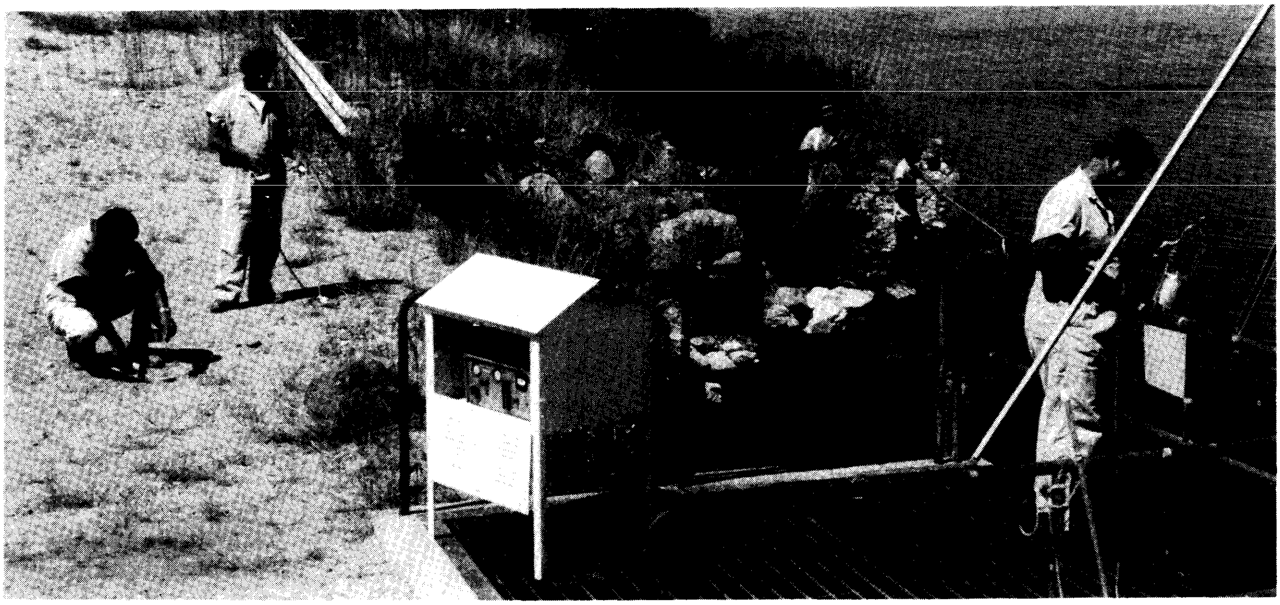

Photo credit: U.S. Department of Energy

Monitoring soil and Columbia River at Hanford.

radionuclide released to the atmosphere between 1944 and 1947. This frost phase of the HEDRP study also considered radiation released to the Columbia River from Hanford between 1964 and 1966, and calculated the radiation doses that would have been incurred by residents whose drinking water came from the river.

Preliminary HEDRP findings indicate that thousands of children born in the Hanford Tri-Cities region (Richland, Kemewick, and Pasco, WA) between 1944 and 1960 may have received significant doses of radioactive iodine (iodine-131) as a result of Hanford releases (131). An associated epidemiological study that will attempt to relate the doses of iodine-131 to thyroid disease among "downwinders" is in the planning stage and will be conducted by independent investigators from the Fred Hutchinson Cancer Center in Seattle in collaboration with CDC scientists (132).

Radiation doses resulting from exposure to contaminated water or fish from the Columbia River were calculated to be much lower than those from air. However, it will be important to consider the habits and lifestyles of Native Americans who used the river during this period, because their relative dependence on and proximity to the river may have resulted in larger doses. Such investigations are planned.

A similar dose reconstruction project to analyze off-site air doses of uranium from the Feed Materials Production Center in Fernald, OH, is also in the plarming stages. Like HEDRP, the Fernald study will be conducted in collaboration with CDC (133).

DOE contractors at the Idaho National Engineering Laboratory (INEL) have devised a dose reconstruction model for some off-site exposures. This model reportedly does not address all historic emissions from INEL (134). The project has been criticized for excluding public participation until recently; even State officials were not informed of the project until asked to comment on prelimirmy results. The project is being reviewed by a panel of independent scientists (135).

Legitimate questions exist regarding the public health impacts of environmental contamination at the Nuclear Weapons Complex. Neither the complexwide Environmental Survey, the Tiger Team analyses, the annual site-specific environmental monitoring reports, nor the few existing epidemiological studies of off-site health effects provide sufficient information to address potential public health impacts due to weapons site pollution. Available studies do not afford a comprehensive survey of centamination present throughout the Weapons Complex; information about toxic chemicals is especially lacking. Nor is reliable information available regarding human exposure routes and dose ranges, other than the very tentative results of mercury assays at Oak Ridge and the preliminary dose estimates generated recently by HEDRP.

DOE'S Current Approach to Off-Site Health Studies

DOE has recognized that its current organizational structure for investigating possible off-site health impacts of the nuclear weapons sites is in need of improvement. In March 1990, Secretary James D. Watkins issued a directive that consolidates DOE's health research within a new Office of Health (136, 137). The reorganization is partially a response to the Secretarial Panel for the Evaluation of Epidemiologic Research Activities (SPEERA) for the U.S. Department of Energy, which recommended that epidemiologic activities scattered throughout DOE be consolidated within a single office (138). According to a DOE draft of the planned reorganization, "community health studies" would be included among the responsibilities of a new Office of Epidemiology and Health Surveillance. This Office, along with the Office of Health Physics and Industrial Hygiene, and the Office of Occupational Medicine, would report through a deputy assistant secretary for health to the Assistant Secretary for environmental health in DOE (139).

The draft of the proposed reorganization does not make clear whether the scope of such "community studies" would include projects beyond those already agreed to by DOE in interagency agreements with individual States. The reorganization plan calls for independent scientists to submit competitive bids on announced Requests for Proposals. However, the draft also states that no "unsolicited proposals' would be funded by the Office of Health (140). How such arrangements would differ from the present practice of arranging for scientists at the DOE national laboratories to conduct the bulk of DOE-funded epidemiological studies is not discussed.

Efforts to increase the competence and scope of environmental health activities within DOE are commendable and necessary. The proposed reorganization foresees the three health offices having a combined total staff of 82 professionals by 1992. Because of the shortage of experts in environmental health fields (141-144), however, it will be difficult to fulfill such staff projections, even if sufficient resources are allocated.

In view of the technical complexities, time, and staff commitments required to investigate the impact of environmental toxicants on communities, it is not clear that DOE will be able to assemble the in-house capacity to carry out such studies. Furthermore, the proposed DOE Office of Epidemiology and Health Surveillance would occupy a relatively low position within the DOE bureaucracy, a status that does not indicate a major new emphasis on health effect investigations within the department.

SPEERA clearly recognized that "[t]here are limits to how well an organization can study itself without facing conflict of interest issues' (145). The proposed reorganization of environmental health programs within DOE may not take appropriate heed of such limits. If epidemiological studies are conducted only when DOE judges such investigations to be necessaty, the proposed reorganization may neither encourage the participation of independent scientists, nor achieve the enhanced credibility envisioned by SPEERA for environmental health programs in DOE.

DOE'S Position on Off-Site Health Impacts

DOE officials have publicly lamented the absence of 'risk-based' priorities in the Weapons Complex cleanup and have contended that the preponderance of cleanup activities will be directed toward satisfying legal requirements, rather than addressing serious risks to the environment or to human health (146,147). DOE's attempts to develop priorities for cleanup activities across all sites are described in chapter 2. The current system gives highest priority to situations that pose, in DOE's terminology, significant "near-term' health risks. DOE asserts, however, that the contamination poses no "near-term" or "immediate" health threats.

DOE's position that Weapons Complex contamination poses "no immediate threat' to public health is asserted in the Five-Year Plan, site-specific Tiger Team reports, and elsewhere (148-150). DOE maintains this position even though it is unable to specify the precise nature and extent of past releases of radioactive and hazardous substances, cannot identify the present whereabouts and concentrations of these materials in the environment, and has only begun to document the presence or absence of human exposure to such materials. Thus, the assertion that contamination represents "no immediate threat" and no "near-term risk" is largely unsubstantiated. It is also somewhat misleading.

"Immediate health effects' or 'near-term risks" are generally understood to be acute effects that occur within hours to days of exposure to high concentrations of toxic chemicals or radiation. By such a measure, smoking tobacco may accurately be said to pose no immediate or near-term risk of lung cancer.

Preliminary data indicate that, with some exceptions, much of the current and future off-site exposure to weapons site contamination involves or will involve relatively low doses of contaminants occurring over long timeframes. Such dosages and exposure patterns would not be expected to produce symptoms of "immediate" poisoning. Rather, the health impacts would be expected to take the form of (151):

- subclinical effects that, alone, would not cause illness but could disturb normal biological functions in a way that might result in disease when combined with other factors;
- increased susceptibility to common illnesses that might be indistinguishable from illness due to "normal" causes (152);
- increased incidence of certain diseases such as cancer that develop and become manifest only years or decades after exposure; and
- genetic defects manifest in subsequent generations, or reproductive dysfunctions, which are often difficult to detect and link to specific toxic exposures.

Efforts to determine whether any such effects have resulted from environmental contamination at DOE weapons sites will require active scientific investigations using sophisticated methodologies, as well as access to records of past releases, entry to the plants themselves, and financial and professional resources. Such efforts have yet to begin at most sites and have not even been contemplated at many locations.

In the absence of evidence indicating "immediate" health effects, DOE is proceeding with plans for environmental characterization and cleanup that are based strictly on regulatory requirements and schedules, some of which are specified in interagency agreements (IAGs). DOE's assumption is that compliance with the law will protect against any possible current or future off-site health impacts of contamination.

Existing regulations and IAGs may prove inappropriate as the exclusive framework for organizing the Nuclear Weapons Complex cleanup, however. Environmental contamination at the Weapons Complex is unprecedented in scope and complexity and is characterized by features that are not addressed or are inadequately addressed by existing regulations. The following section describes those processes and procedures called for by existing laws and regulations that are designed to evaluate the health impacts of environmental contamination, and evaluates their usefulness in providing a health-risk-based scaffolding around which to organize the cleanup of the weapons sites.

THE PUBLIC HEALTH ASSESSMENT PROCESS UNDER FEDERAL AND STATE REGULATIONS

Introduction

A number of specific types of evaluations and procedures are mandated by environmental laws, regulations, and interagency agreements for assessing the possible human health impacts of weapons site centaminants.[8] The formidable technical challenges involved in determiningg whether waste storage facilities or uncontrolled contamination pose health threats are reflected in the complexity of the regulations governing the health assessment processes. The Environmental Protection Agency (EPA), the Agency for Toxic Substances and Disease Registry, the Centers for Disease Control, and State health departments all have roles to play in the health assessment of environmental pollution at the weapons sites. In addition, the regulatory landscape is dynamic; some regulations are in transition, others have never before been applied on the scale required by the DOE cleanup, and negotiations towards health studies agreements are still taking place between some States and DOE. Nonetheless, it is important to understand the components of the health assessment process stipulated by existing regulations because DOE is relying on this process to guide and shape the cleanup.

[8] The regulations are principally those promulgated under the Resource Conservation and Recovery Act, as amended (RCRA), and the Comprehensive Environmental Response, Compensation and Liability Act, as amended (CERCLA or "Superfund"). State laws also apply in some cases. See ch. 2 for discussion of these regulations.

The first set of regulatory fences that guard against adverse ecological or health impacts due to environmental contamination consists of regulations or "standards" that set allowable upper limits for specific chemicals in specific media. For example, EPA Primary Drinking Water Standards permit a maximum level of 0.002 milligram of lead per liter of drinking water.[9]

Environmental standards are derived from toxicological data according to conceptual rules and assumptions formulated principally by EPA. These formulations are designed to take account of gaps and scientific uncertainties in the available data and variations in exposure patterns and individual susceptibility to disease. The basic idea behind chemical-specific standards and guidelines is that noncarcinogens cause toxic effects only if exposure levels exceed a certain "threshold." The threshold for a specific chemical can be identified experimentally and used as the basis for setting regulatory standards and guidelines (153).

Carcinogens are regulated differently (154-156). Carcinogens are treated as though they are capable of causing a finite risk of cancer at any exposure or dose level: there is no threshold below which exposure is considered to be safe. EPA has derived methods for estimating a substance's cancer-causing potency, the quantitative relationship between dose and response (157).

In practice, the EPA cancer potency number, called a slope factor, is multiplied by the amount of exposure to a substance that could be expected under conditions present at a given waste site. The resulting number is an estimate of the upper bound probability of the excess lifetime cancer risk as a result of that exposure. Superfund requires that the calculated individual lifetime risk for excess cancers at a remediated site be no greater than one chance in 10,000 (158). Similarly, media-specific standards governing allowable levels of contamination with carcinogens are designed so that human exposure to such pollution would not produce more than one excess cancer per 10,000 people exposed.

The application of recommended exposure standards and guidelines to real-world situations provides a useful yardstick of some probable potential health impacts. However, legal standards and recommended guidelines are not always well-validated by scientific evidence (159- 161). Approximately 60,000 chemicals are used commercially (162); human data are available on the cancer-causing potential of about 60 substances (163). Animal and in vitro studies of carcinogenicity have been conducted on a somewhat larger number of substances (164). Nonetheless, there is no information about the cancer-causing potential of 75 to 85 percent of all chemicals in commercial use (165).

Even less information is available concerning the nonacute, noncarcinogenic effects of such chemicals. Cancer deaths and acute poisoning are clearly important biological end points, but scientists have become increasingly attentive to other health outcomes, such as the impact of toxins on the neurological, immunological, and reproductive systems (166, 167). A recent OTA report contends that neurotoxicological effects, in particular, have been underemphasized by scientists and regulators (168). Current laws, reflecting the limitations of scientific knowledge, focus almost exclusively on cancer fatalities and acute (i.e., high-dose, short-term exposure) effects.

OTA investigations indicate that, where human contact with environmental contaminants from the weapons sites occurs, it is likely to involve low-dose, chronic exposures or episodic exposures to somewhat higher doses. The biological effects of such exposure patterns are difficult to study, even in laboratory settings, and are poorly understood. It is therefore difficult to craft chemical-specific regulatory standards that effectively guard against the full range of possible health effects and exposure conditions.

Uncertainties in the scientific understanding of the health effects of environmental contamination constitute one reason why compliance with promulgated regulatory standards may be insufficient to ensure the protection of public health. In addition, some regulatory standards take economic benefits, the costs of implementation, and technical feasibility, as well as health considerations, into account and are not intended to designate "safe" levels of exposure (169). Also, different agencies and different regulations within agencies incorporate differing standards of "acceptable risk," which further confuses the meaning of allowable exposures or con-

[9]Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities, 40 CFR §265, App. III (1989).

taminant concentration limits set by chemical- or media-specific standards (170).

Regardless of how a particular standard is determined, it constitutes a sharply defined rule, a regulatory ''line'' that cannot be crossed. EPA does grant waivers from meeting particular standards in some circumstances, but the reasons for not achieving the standard must be compelling.

Within the Superfund program, the chemical-specific, media-specific standards and guidelines set by Federal authorities and by States are collectively known as ARARs (''applicable or relevant and appropriate requirements''). The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) requires that every Superfund site comply with all ARARs, including both Federal and State regulations, in designing remediation goals (171).[10] Thus, the first step in evaluating the health risks from a Superfund site involves comparing contamination levels measured at that site against pertinent standards. However, compliance with all ARARs is still likely to leave many chemicals and situations unaddressed.

For this reason, a second type of approach to environmental health impacts was incorporated into the regulatory framework. This approach involves site-specific investigations and evaluations of releases and waste sites at which health impacts are found or suspected. Site-specific assessments mandated by existing regulations include quantitative risk assessments carried out by DOE and its contractors at Superfund sites and reviewed by EPA, health assessments conducted by the Agency for Toxic Substances and Disease Registry at Superfund sites, and some site-specific health studies negotiated by States as part of IAGs.

There is no clear scientific consensus on how best to study the health effects attributable to environmental contamination. Formidable logistical and methodological obstacles attend all such efforts. Site-specific investigations require that information of many different kinds, usually gathered for purposes other than health assessments (e.g., CERCLA remedial investigations and feasibility studies), be collected, evaluated, and integrated into a composite picture (see box 3-B). Source terms—records or information about the identity and quantity of contaminants that originally entered the environment—

Photo credit: U.S. Department of Energy

Water tank inspection and oleaning at the INEL Radioactive Waste Managerrtent Area.

are often incomplete or unavailable. Exposure measures-reliable ways of identifying who was exposed to the contaminants and in what amounts or pattems-are difficult to obtain. The populations involved are sometimes too small to demonstrate statistically significant differences in health status among exposed v. nonexposed groups (see box 3-C). In some cases, "exposed" groups are diluted by individuals moving into and away from the site under study (see box 3-D). Health outcomes—the biological effects to be investigated-are also problematic. Current limitations on the scientific understanding of toxicology make it difficult to associate specific symptoms, physical findings, or diseases with particular toxic exposures. Here again, small populations impose methodological barriers to reaching clear conclusions.

Partly because site-specific investigations of environmental health effects are so dfficult to design and conduct, this type of public health intervention has not been emphasized in environmental laws. Nonetheless, there is no substitute for site-specific studies in evaluating the health impacts of a particular waste site or environmental release. Only site-specific investigations can provide the environmental characterization data, demographic information, and health outcome measures needed to evalu-

[10] 42 U.S.C.A. §6921(d) (West Supp.1990).

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Box 3-B—Tracing the Toxic Trail From Contaminant Source to Health Effects

Linking an environmental contaminant to a particular human health effect requires tracing a long and complicated trail from the original source of a pollutant to the particular symptom, disease, or other biological end point suffered by an individual or a population. The trail maybe years or even decades old, and documentation of the original source term may not be ideal. The course of a contaminant's progress may literally be underground, where its route and direction cannot be visualized directly, or the pollutant may have been dispersed by winds long ago. Once a chemical or radionuclide is loose in the environment, it can interact with other substances, change chemical form, become diluted, transfer from one medium to another, piggyback on other substances that transport it long distances, or accumulate in geophysical sinks or in plants and animals. Tracking such escape routes, mapping the present whereabouts of the contaminant, and designing measures to contain or eliminate the pollution are the purposes behind the remedial investigation/feasibility study (RI/IX) and facility investigation (RFI) processes of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Resource Conservation and Recovery Act (RCRA), respectively. Virtually every aspect of the cleanup effort thus far has involved efforts to identify, trace, and quantify environmental contamination.

Figure 3-2 traces a contaminant from the source of pollution to the observable health effect. Most of the requirements stipulated by environmental regulations, and all Department of Energy (DOE) cleanup efforts to date, address the top half of the diagram: assessing the path and behavior of contaminants as they move into the environment and become potentially accessible to human contact. Very little effort has been directed toward investigating the *effects* of the contamination on human health or the environment.

Environmental health assessments focus on the bottom half of figure 3-2, that part of the"toxic trail" leading from human exposure to health effect. For health investigators, information describing the types and whereabouts of the contamination is just the beginning of the puzzle. Environmental health assessments attempt to follow the progress of an environmental toxicant from its presentation in the ambient environment at the point of potential human exposure through its absorption into the body and subsequent metabolism. accumulation, or elimination, and to relate these phenomena of molecular biology to observable expressions of dysfunction or to overt disease.

Ultimately, the scientific challenge is to determine as accurately as possible each term in the path that links the source of the contaminant with the particular biological end points or health effects, and to understand the molecular mechanisms that connect them. However, the present state of scientific knowledge regarding the effects of exogenous chemicals on human biology is very limited. Understanding the connections at the molecular level between the terms in figure 3-2 is, at best, a blurred picture and often a black box. Moreover, the nature of the terms in the bottom half of the figure is frequently unknown as well.

Because, in practice, many terms in figure 3-2 are estimates, guesses, or simply unknown, environmental health assessments must be designed and interpreted carefully, lest the many unknowns and the large ranges of uncertainty in individual pieces of the assessment combine to yield ambiguous or even misleading results. Judgments are inevitably integrated into any assessment of environmental health effects, whether the methods used involve large epiderniological studies or the most rigidly codified quantitative risk awessmen~. The scientific credibility of such assessments is enhanced when those judgments are made explicit and research efforts are conducted in an open, unbiased manner.

Analytical Components of Environmental Health Assessments

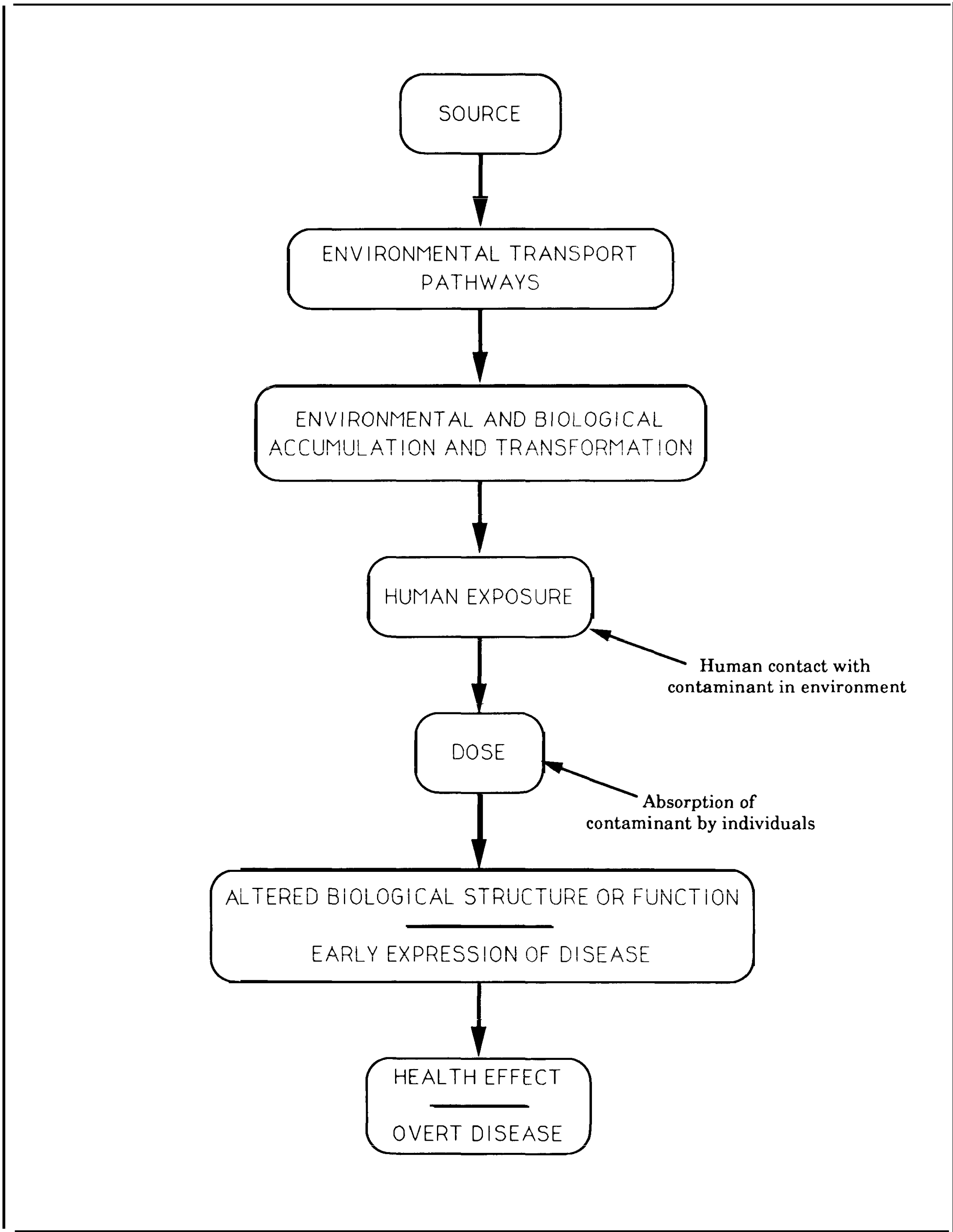
Environmental health assessments must rely on what is known about the toxic effects of a chemical, or similar chemicals, to fill in the blanks and sketch tentative connections 'between exposure and disease. The aim of all analytical methods that seek to understand and predict the linkages between exposure to environmental agents and human health is to devise a legitimate means of relating a given exposure to a given biological effect *without knowing* all the terms in the bottom half of figure 3-2.

All methods of assessing environmental health effects can be thought of as consisting of three key elements:

1. determining exposure and dose,
2. determining health effects, and
3. determining dose-response relationship (a term that quantitatively relates dose and effect).

Different environmental health assessment methodologies are distinguished by the ways in which these terms are derived and utilized. Wrying situations, purposes, and priorities may render some methods more suitable than others in identifying the terms and interpreting their meaning.

Figure 3-2—Tracing the Toxic Trail



SOURCE: Office of Technology Assessment, 1991.

Box 3-C—All About Environmental Epidemiology

Epidemiology is the study of the occurrence and distribution of disease among population.1 Epidemiology rests on the premise that disease does not occur randomly among populations but instead afflicts certain people at certain places and times according to the underlying causes of the illness.[2] By studying these relationships, epidemiologists can achieve important insights into the association between certain exposures or risk factors and the occurrence of disease. Such insights can provide valuable tools in the prevention and control of disease.

Traditionally, epidemiology has focused on diseases of infectious origin such as cholera and Acquired Immune-deficiency Syndrome (AIDS), or on some chronic diseases such as lung cancer and heart disease. Recently, there has been increasing interest in applying epidemiological methods to investigations of disease among populations exposed to environmental toxicants.

Environmental epidemiologic studies consist of several analytical components. For example, groups maybe identified according to their exposure to a certain substance, operation, waste facility, etc. The occurrence of certain health outcomes, such as age-related mortality or cancer incidence among exposed groups, is investigated and compared with the health effects experienced by groups who were not exposed to the substance or process in question. If a positive association is discovered between a certain exposure and a particular health effect, and if the degree of exposure can be quantified, the results of epidemiological studies can be used to derive dose-response relationships, which in turn can be incorporated into quantitative risk analyses.

Epidemiological studies are less constrained by the limits of existing knowledge than are quantitative risk assessments (QRAs). In theory, the association between any exposure and any health effect could be examined by an epidemiological study; it is not necessary for such an exposure-effect linkage to have been previously noted or for dose-response data to be documented in the scientific literature. Thus, for example, the incidence of cancer among people exposed to a certain combination of toxic chemicals can be investigated in the absence of specific toxicological data about the effects of such complex exposure, If a positive association between exposure and effect were detected, laboratory studies could then be focused on the consequences of such exposure. In contrast, quantitative risk assessments could not even consider the possible outcomes of complex exposures unless dose-response data were already available linking the exposure and the health effect in question.

For example, workers exposed to coke oven emissions suffer unusually high rates of lung and genitourinary cancer compared with coworkers of similar characteristics (including smoking status) who are not exposed to these emissions.[3] Coke oven emissions consist of a complex mixture of hydrocarbons and metals, including benzene, cadmium, arsenic, chromium, and beryllium. The toxicology of this stew of substances is imperfectly understood.

A quantitative risk assessment of the hazards of coke oven emissions would attempt to identify the health effects of exposure to each chemical ingredient, assess available dose-response information for each substance, quantify human exposure to each of these component chemicals. and sum the resulting chemical-specific cancer risk estimates.[4] Not only would such a task require considerable effort, but the uncertainties, extrapolations, and data gaps would likely make it very difficult to detect any actual risks-especially because the genitourinary cancers observed in humans are not observed in animal experiments.[5] One advantage of epidemiological studies is their ability to consider the health consequences of exposure to substances or combinations of substances whose toxic effects are not well understood. This may be important in designing health studies pertinent to Weapons Complex contamination, where exposure to combinations of potentially toxic materials and to patterns of exposure that are not easily tested in lab studies are at issue.

Pitfalls of Environmental Epidemiology

The flexibility of epidemiology to focus on the particular toxic exposures and health effects of interest is offset by otiier methodological drawbacks, however. In conducting epidemiological studies, it is necessary to specify

[1] J. Mausner and S. Kramer, *Epidemiology An Introductory Text,* 2d ed. (Philadelphia, PA: W.B. Saunders, 1985), p. 1.

[2] J. Greenhouse, "Commentary on Epidemiological Methods of Environmental Exposure and Specific Disease," *Archives of Environmental Health,* vol. 43, 1988, p. 109.

[3] U.S. Department of Health and Human Services, Public Health Service, National Toxicology Program, *Fifth Annual Report on Carcinogens--Summary,* NTP *89-239* (Rockville, MD: Technical Resources, Inc , 1989), p. 290.

[4] U.S. Environmental protection Agency, Office of Emergency and Remedial Response, *Guidelines for the Health Risk Assessment of Chemical Mixtures,* Sl *Federal Register 33992,* Sept. 24, 1986.

[5] U.S. Department of Health and Human Services, op. cit., supra note 3.

exposure accurately—to identify who is exposed and who is not. If an appreciable number of people who are actually exposed are missed by investigators, or if exposed and nonexposed individuals are incorrectly labeled, the likelihood of detecting any true association between the exposure and the effect decreases.[6 7]

The need to document exposure to environmental toxicants accurately—and quantitatively, if possible—is recognized by the scientific community. This issue was recently addressed at a conference held by the National Academy of Sciences.[8] It is very difficult however to reliably document individual exposure to environmental pollutants. Obtaining information about the degree of individual exposures, or quantitative assessments of exposures over time is especially difficult. The efforts of the Hanford Dose Reconstruction Project have been directed towards creating a computer model that calculates amounts of toxicants released to the environment and attempts to trace such pollutants through various media pathways over time, and ultimately, to construct estimates of individual doses of such toxicants. Such "dose reconstruction" will be the first step of an epidemiologic study of the health effects associated with exposures to radionuclides released from Hanford.

Although dose reconstruction of exposures to radionuclides is technically complicated and invested with much uncertainty, radiologic environmental dose reconstruction is far more advanced than efforts to assess individual exposure to toxic (non-radioactive) chemicals. Much recent research activity has focused on developing biological markers of exposure.[9 10] Also, sophisticated computer models of exposure allow representation of individual "microenvironments" and consider indirect, but potentially significant, exposure routes such as the inhalation of organic solvents volatilized during showering with contaminated water.[11 12]

The difficulty of successfully documenting health outcomes among groups under study also plagues epidemiologists. If the occurrence of health effects over time cannot be tracked with accuracy because a significant portion of the exposed or nonexposed groups are "lost to followup," the chances of detecting any true association between the exposure and the effect decrease. These problems are often encountered when the health effects of interest occur only years or decades after initial exposure. Examples of such long-latency effects include cancers that appear 5 to 20 years after the exposures that caused them, and genetic defects that appear only in subsequent generations.

The detection of adverse health effects resulting from exposure to environmental toxicants is also complicated by individual variation in susceptibility to disease. Genetic factors, age, sex, the presence of underlying diseases, concomitant toxic exposures, and personal habits can all influence the expression of disease in an individual. Although such factors are difficult to identify and document, they can have a significant impact on the expression of overt illness among populations.

Quantitative estimation of the comparative measure of disease among exposed v. unexposed groups involves the use of statistical analyses. Statistical analyses endeavor to determine the likelihood that observed results are simply random events that do not truly indicate a real difference in baseline risk and, also, attempt to delineate (i.e., place "confidence intervals" around) the whole range of results compatible with the observed data. There are many opportunities for debate about which statistical strategies are appropriate for analyzing a given data set. Witness, for example, the long controversy over the risks associated with exposure to low-dose ionizing radiation.

The ability of an epidemiologic study to detect real increases in health effects due to to exposures rests to some degree on the size of the populations studied. Obviously, more data points—more people exposed, more people with

[6]B. Barron, "Effect of Misclassification on Estimates of Relative Risk," *Biometrics*, vol. 2, 1977, pp. 414-418.

[7]B. Gladen and W. Rogan, "Misclassification and the Design of Environmental Studies," *American Journal of Enidemiology*, vol. 109, 1979, pp. 607-616.

[8]National Academy of Science, "Frontiers in Assessing Human Exposure to Environmental Toxicants," Washington, DC, May 15-16, 1990.

[9]Subcommittee on Pulmonary Toxicology, Committee on Biologic Markers, National Research Council, *Biologic Markers in Pulmonary Toxicology* (Washington, DC: National Academy Press, 1989).

[10]Subcommittee on Reproductive and Neurodevelopmental Toxicology, Committee on Biologic Markers, National Research Council, *Biologic Markers in Reproductive Toxicology* (Washington, DC: National Academy Press, 1989).

[11]L. Wallace, E. Pellizzari, T. Hartwell, et al., "The Influence of Personal Activities on Exposure to Volatile Organic Components," *Environmental Research*, vol. 5O, 1989, pp. 37-55.

[12]I. von Lindern, K. Steward, M. von Braun, et al., "Use of a Geographic Information System in Selecting Residential Properties for Remediation at the Bunker Hill NPL Site," *Proceedings of the 10th National Conference on Management of Uncontrolled Hazardous Waste Sites*, Superfund '89, December 1989, pp. 430-435.

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Box 3-C—All About Environmental Epidemiology—Continued

cancers, etc.—enhance the precision of the results and increase the likelihood that they accurately reflect the true situation in the entire population of exposed people. Similarly, more data decrease the chances that observed results are merely some peculiarity of the individuals sampled in the study.

The strength of the true association between the exposure and the health effect under study (i.e., the risk of disease if exposed compared with the risk without exposure) is the next important factor in determining whether an epidemiological study can detect "real" risks. If the risk of disease with exposure is very much greater than the risk of disease without it, large increases (i.e., exposure increases the baseline risk 10 to 100 times) may be detectable with small or moderate-size study populations. If, however, exposure increases the risk of disease by a factor of 10 or less, extremely large populations may have to be studied before adverse effects are detectable.

Herein lies another Achilles' heel of environmental epidemiology. Even if exposure can be documented adequately, epidemiology's lack of sensitivity—its inability to detect a small or moderate health effect even when the effect is truly present—limits the usefulness of such studies. As one environmental health professional put it:

> The definition of a public health disaster is an adverse effect so enormous that an epidemiological study can detect it.[13]

[13] D. Ozonoff, Professor and Chief, Environmental Health Section, School of Public Health, Boston University, personal communication, Jan. 12, 1990.

ate possible links between environmental contaminants and health effects in a particular community.

What follows is a discussion of the limitations that beset existing chemical-specific and media-specific environmental regulations in affording public health protection from contamination at the weapons sites, followed by descriptions and evaluations of the major site-specific types of health evaluations mandated by the laws and interagency agreements applicable to cleanup of the Nuclear Weapons Complex.

Limitations of Existing Chemical- and Media-Specific Standards

Environmental laws are necessarily limited by the sophistication of the science that frames them. Pollution at the Nuclear Weapons Complex includes many features that were unanticipated, and thus are not successfully addressed, by existing statutes and regulations, namely:

- a multiplicity of contaminants that pollute various media and thus necessitate accounting for many possible exposure routes to determine total exposure burdens;
- historical releases of contaminants that may not be detected in the course of regulatory compliance but can contribute significantly to the overall exposure burden of off-site populations; and
- contamination of large areas of soil and surface water sediments with radionuclides (e.g., plutonium, americium, cesium)—situations that are not addressed by Federal statutes.

In addition, standards governing exposure of the general public to off-site radiation released from DOE facilities have not been updated promptly to reflect new health risk information, and many are concerned about DOE's self-regulatory role in setting and enforcing radiation standards.

Media-Specific Standards Do Not Address Total Exposure Burdens

The possible health impacts of exposure to weapons site contaminants depend on the toxic effects of the total exposure burden resulting from all possible sources and pathways. Current laws are not well suited to consideration of total exposure burdens.

Some off-site exposures due to weapons site contaminants may involve more than one contaminant. For example, sediments in lakes and streams surrounding the Oak Ridge Reservation contain both radionuclides and polychlorinated biphenyls (PCBs) (172). The biological consequences of such multiple exposures may be very different from the effects of individual contaminants. Once inside an organism, environmental toxins can accumulate, interact by impinging on the same organ system, or alter the metabolism of other toxins (173).

Box 3-D—Exposure Assessment and Misclassification

In infectious disease epidemiology, exposure is a relatively clear-cut concept; there are usually simple and reliable medical tests that identify the presence of antibodies, bacteria, or other markers of definite internal exposure or infection. Environmental epidemiologists, on the other hand, often have to make do with very crude measures of exposure. For example, "exposed" and "unexposed" groups might be determined by separating people into categories based on the distance between residence and a source of pollution. This is clearly not a very precise way of identifying true exposure status.

Incorrect assessments of who is and is not exposed to an environmental contaminant can have serious consequences for epidemiological investigations. Misclassification of exposure status-incorrectly **assigning** people to "exposed" or "nonexposed' categories--can obscure the actual association between exposure and the risk of adverse health effects. Misclassification always decreases the apparent risk of getting sick if one is exposed: the relative risk appears lower than it truly is. [1] The effects of such misclassification become more serious as the true relative risk increases.[2]

For example, consider a study, sponsored by EPA, of plutonium burdens among people living around the Rocky Flats Plant.[3] This study analyzed the plutonium burdens of autopsy tissue taken from people who had resided in the vicinity of Rocky Flats and compared the results with plutonium burdens measured in the bodies of people who lived farther away. It was discovered that the amounts of plutonium in lung and liver samples were not appreciably different in people who lived in areas distant from the plant compared with the 'study group" of people who lived closer to the plant.

However, the majority of autopsy specimens came from subjects residing in areas distant from the plant-only three subjects had lived within 10 kilometers of Rocky Flats. Thus the study group-people assumed to be exposed to whatever emissions were coming from the plant—was diluted by samples from subjects who did not really live very close to plant premises. Such dilution of the exposed group by unexposed subjects would obscure any true risk of excess plutonium burdens that "exposure" to Rocky Flats operations (i.e., residence within 10 kilometers of the plant) might confer.

Exposure assignments could also be affected by migration in and out of the area around Rocky Flats. If, for example, a number of long-term residents had moved out of the area before the study began, or if significant numbers of people in the study had only recently settled around Rocky Flats and thus had little opportunity to be exposed to plant emissions, exposures among the group residing near the plant when the study began would miss many of the more highly exposed individuals and be diluted by the inclusion of newcomers.

The authors of this study recognized the possibility of misclassification, among other study limitations, and concluded that 'we cannot rule out the possible conclusion that people who lived near the southeast of RFP [Rocky Flats Plant] and near to the plant for the last 5 years of life, may have a larger proportion of weapons grade Pu [plutonium] in their lungs than did people who lived farther away with a pattern similar to that found in the soil in the same area.

Biological markers are indicators of changes in cellular or biochemical components or processes, structure, or function that are measurable in biologic systems or samples. There are three types of biologic markers: those that indicate an organism's *exposure to an* exogenous substance, those that indicate an effect of such exposure, and markers that indicate *susceptibility* to an organism's ability to respond to an exposure.[5] Biomarkers are desirable as indicators of exposure because, to the extent that they are sensitive and specific, they permit assignment of individual exposure status and make misclassification errors less likely.

In practice, direct evidence of individual human exposure- -i.e., evidence of actual contact between the Pollutant and an individual-"is rarely sought or measured when complying with environmental regulations or

[1] B. Barron, "Effect of Misclassification on Estimates of Relative Risk, " *Biometrics*, vol. 2, 1977, pp. 414-418.

[2] B. Gladen and W. Rogan, "~scl~sfication and the Design of Environmental Studies, ' *American Journal of Epidemiology*, vol. 109, 1979, pp. 607-616.

[3] J. Cobb, et al., *Plutonium Burdens in People Living Around the Rocky Flats Plant*, U.S. Environmental Protection Agency, EPA-600/4-82-069, 1979.

[4] Ibid., pp. 198-199.

[5] Subcommittee on Pulmonary Toxicology, Committee on Biologic Markers, National Research Council, *Biologic Markers in Pulmonary Toxicology* (Washington, DC: National Academy Press, 1989), pp. 2-3.

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Box 3-D—Exposure Assessment and Misclassification—Continued

conducting quantitative risk assessments. Instead, indirect indicators, usually computer models of exposure estimates derived from environmental monitoring data, are used to estimate exposure. Advanced computer capabilities and analytic techniques are now available that permit reasonably accurate modeling of environmental transport pathways followed by various contaminants.[6]

To complicate exposure assessments further, a long lag period or latency may occur between the time of exposure to an environmental toxicant and the manifestations of biological effects or the appearance of disease. Until the lag period has elapsed, health assessments of diseases, such as cancer, that are observed only after a latency of decades will not be informative.[7] It is difficult, however, to accurately reconstruct exposures that occurred years or decades in the past

Another issue that environmental health assessors must confront is the matter of exposure to combinations of contaminants. Communities located near nuclear weapons plants may be exposed to several environmental contaminants. The combined effects of such multiple exposures can be very different from the effects seen in response to individual contaminants. Once in the body, environmental toxins can accumulate, interact by impinging on the same organ system, or alter the metabolism of other toxins so that the biological impact of multiple exposure may differ significantly from the effect of exposure to individual substances.[8] Investigators attempting to achieve a comprehensive picture of the health consequences of exposure to multiple contaminants must use professional judgment in anticipating what biological response(s) might result from such exposure burdens and exercise caution in selecting or rejecting which specific health effects to study.

Long-lived biomarkers could, in principle, provide an accurate reflection of integrated exposure patterns and cumulative exposure levels. Levels of polychlorinated biphenyls (PCBs), for instance, persist in human fat cells for decades. Samples of adipose tissue can, therefore, provide an estimate of long-term exposure to PCBs.[9] In practice, however, few persistent biomarkers of exposure to environmental contaminants are available.

Another issue of relevance to the investigation of toxic exposures and their effects on populations is what statisticians call "variability." Exposures are seldom homogeneous through time and across populations. Instead, there are often episodic exposure excursions that may be many times greater than the average. The release of 7,500 curies of iodine-131 from Hanford in 1949[10] and instances of plutonium emissions from Rocky Flats due to serious fires in 1957 and 1969[11] are examples of such episodic releases. Because the pattern and intensity of exposure are so important in determining biological effects, computations based on average monitoring data may fail to represent real-world conditions accurately. It is difficult to design laboratory experiments or computer models that mimic such episodic exposure patterns.

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[6] P. Lioy, "Assessing Total Human Exposure to Contaminants," *Environment, Science, and Technology*, vol. 24, No. 7, 1990, pp. 938-945.

[7] C. He@ "Uses of Epidemiological Information in Pollution Episode Management," *Archives of Environmental Health*, vo1. 43, 1988, pp. 7S-82.

[8] U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, *Guidelines for the Health Risk Assessment of Chemical Mixtures*, 51 *Fed. Reg. 33992*, Sept. 24, 1986.

[9] C. Klaassen, et al. (eds.), *Casarett and Doull's Toxicology*, 3d ed. (New York, NY: MacMillan Publishing, 1986), p. 41.

[10] Technical Steering Panel, Hanford Environmental Dose Reconstruction Project, "Report of the Source Term Subcommittee," *Annual Report, 1988, Appendices* (Olympia, WA: 1988), p. 18.

[11] S. Poet and E. Martell, "Plutonium-239 and Americium-241 Conlamination in the Denver Area," *Health Physics*, vol. 23, 1972, pp. 537-548.

The effect of exposure to combinations of contaminants is an area that is seldom addressed and little understood by scientists. There is little scientitle basis for predicting the effects of mixtures of contaminants on biological systems (174). In particular, no convincing scientific rationale exists for predicting the health risks due to a combination of radionuclides and toxic chemicals (175-177). The guidance for performing quantitative risk assessments under CERCLA recommends that gaps in the understanding of such phenomena be dealt with by simple addition of predicted health effects (178). This pragmatic approach may not reliably predict the actual impact of combined exposures, however.

Multiple environmental media are contaminated at all weapons sites, providing many potential pathways for human exposure. Most regulatory standards, however, are media specific. Standards set allowable pollution limits for individual contaminants in a single environmental medium, such as air or water, and do not allow consideration of the total exposure burden resulting from contact with all contaminated media.

Quantitative risk assessments conducted under CERCLA[11] do require that the potential impact of all exposures from all media be considered. However, to separate individual weapons sites into manageable packages, CERCLA allows contaminated areas to be divided into "operable units. "[12] The tendency for regulatory standards to focus on individual contaminants in a single medium and for Superfund efforts to concentrate on operable units makes it difficult to synthesize, within the regulatory framework, a picture 'of total exposure from all possible contaminated pathways.

Regulations Do Not Address Historical Emissions

Neither the Resource Conservation and Recovery Act (RCRA) nor CERCLA addresses the contribution of historical emissions to the total exposure burden; both examine only current or projected pollution. Contaminants released from a site in the past, which have since decomposed, been diluted, or migrated off-site-and are not now detectabl---are ignored (179). Thus, the release of hundreds of thousands of curies of radioactivity into the air around Hanford in the 1940s and 1950s-direct measurement of which is now impossible-is not considered under these laws, even though the health impacts of such releases may have been considerable and may still be detectable and medically treatable .13

The Agency for Toxic Substances and Disease Registry has the statutory authority to consider the health impacts of past releases of environmental contaminants (180). In practice, however, it often lacks the resources needed to collect and independently review historic source-term information and environmental monitoring data.

Regulations Lack Guidelines for Radionuclides in Soils and Sediments

Existing laws fail to address some of the contamination at DOE weapons sites. In particular, there are no Federal standards for setting allowable limits of radionuclides in soil and sediments. Large quantities of soil at Hanford (181) and the Nevada Test Site (182), and lesser amounts at Rocky Flats (183), the Mound Plant (184), INEL (185), and LOS Akunos National Laboratory (LANL) (186), are contaminated with plutonium, americium, and other transuranic elements. Proposed guidelines for transuranics in soil were issued by EPA in 1979 and then withdrawn. EPA now estimates that it will be 5 to 10 years before new guidelines are fmalized (187).

Preliminary analyses indicate that surface water sediments have been extensively contaminated with radioactive materials both within weapons sites and off-site (see app. A). Methods for risk assessment of contaminated sediments and remediation practices for this type of pollution are especially primitive.

Regulation of Off-Site Radiation

DOE's authority to implement and enforce its own standards governing off-site radiation doses to the general public is an unusual feature of the U.S. regulatory system and has led to significant public controversy. As authorized by the Atomic Energy Act of 1954, as amended,[14] DOE is responsible for implementing and enforcing all regulations governing the monitoring and control of radionuclides released by DOE operations. Exceptions to DOE's authority to "self-regulate' radiation releases include EPA's authority to set release standards for airborne radionuclides released beyond the fence line of DOE facilities and to implement and enforce such standards under the Clean Air Act,[15] and EPA's authority to regulate discharges into water systems

[11] 42 U.S.C.A. §§6904 (i)(6)(A), (F) (West Supp. 1990).

[12] EPA defines operable units as "discrete part(s) of the entire response action that decrease a release, threat Of release, Or pathway of exposure'' (Superfund, Emergency Planning, and Community Right-to-Know Programs, 40 CFR §300.6 (1989)).

[13] Information about these releases, which spurred the establishment of the Hanford Dose Reconstruction Project, did not result from the CERCLA and RCRA investigations in progress at Hanford; rather, it was discovered by a citizens' group reviewing DOE documents obtained under a Freedom of Information Act request.

[14] 42 U.S.C. $2011-2296 (1982& Supp. IV 1986).

[15] 33 U.S.C.A. $1251-1376 (West 1983 & Supp. 1990).

under the Clean Water Act.[16] Off-site releases of radioactivity from DOE facilities me also subject to the Safe Drinking Water Act.[17] In general, DOE orders, the internal system of regulation by which DOE promulgates radiation standards governing allowable exposures to workers and to the general public, specify radiation standards that are equivalent to those promulgated by the Nuclear Regulatory Commission and the EPA regulating radiation releases from non-DOE facilities.

It is a fundamental premise of radiation protection that all exposure to radiation should be limited to levels "as low as reasonably achievable" (ALARA). The ALARA principle is joined to another axiom of radiation safety that states, "Each man-made contribution to population exposure [to radiation] should be justified by its benefits" (188). The exact levels of radiation dose that are considered 'safe,' acceptable, or justifiable have undergone successive revisions as scientific understanding of radiation effects grows more sophisticated (see box 3-E). Almost all of these revisions, including the most recent recommendations of the International Commission on Radiation Protection (ICRP), have lowered permissible radiation doses.

Both EPA and DOE have been slow to adopt revised radiation standards. The guidance that governs allowable exposure of workers and the public to radiation released by DOE operations was frost promulgated in 1960.[18] In 1987, EPA reduced allowable occupational exposure to radiation,[19] 10 years after ICRP recommended such reductions (189). To implement the EPA guidance, in 1988 DOE issued Order 5480.11 mandating tightened restrictions on allowable occupational radiation doses. The levels of exposure permitted for the general public as a result of DOE operations were updated by DOE in May 1990 and reduced to the levels suggested by the 1977 ICRP guidelines.

ICRP recently announced that it will lower the recommended radiation exposure levels for workers and medical personnel still further, from the annual limit of 5 reins recommended in 1977 to 2 rems (190, 191).[20] These lower limits are based on findings published in 1989 by the National Research Council's Committee on the Biological Effects of Ionizing Radiation (BEIR V) indicating that the risk of cancer from exposure to low doses of ionizing radiation is higher than previously believed (192, 193). DOE has convened two panels to review the implication of BEIR V for DOE radiation guidelines, but has not issued any new orders. DOE officials believe that radiation limits set by previous DOE orders were sufficiently low that they will be unaffected by BEIR V findings (194).[21]

DOE maintains that, in the recent past, radioactive emissions from its operations have seldom, if ever, subjected off-site populations to doses approaching the recommended limits. Radiation standards governing exposure of the general population are based on estimates of received radiation doses. There are two practical ways of determiningg such dosages (196). One is to create computer models of off-site radiation doses that use approved models of air pathways and data that describe the amounts of radiation released from a discharge point, the distance to human populations, local weather conditions, and so forth, to estimate the radiation doses that would be experienced by the average off-site individual or the most exposed individual. The second method incorporates actual measurements of the amount of radiation present in the air or water at monitoring stations representative of local residences or point of use into calculations of individual radiation doses.

A review of the environmental safety and health practices of six weapons facilities audited by Tiger Teams through December 1989 revealed many problems with DOE's radioactive monitoring practices and dose assessment methods. Air sampling techniques were "inadequate" at 83 percent of the facilities assessed; 67 percent of the sites visited

[16] 42 U.S.C.A. $7401-7626 (West 1983 & Supp. 1990).

[17] 42 U.S.C.A. §300f-j (West 1982 & Supp. 1983-1989).

[18] Federal Radiation Council, Radiation Protection Guidance for Federal Agencies, 25 Fed. Reg. 4402 (1960).

[19] Radiation Protection Guidance t. Federal Agencies for Occupational Exposure; Approval of Environmental Protection Agency Recommendations, 52 Fed. Reg. 2822 (1987).

[20] Rem (rad equivalent man) is a unit of dose equivalent that includes conversion factors to account for the different biological effectiveness of different types of radiation.

[21] Some DOE contractors have independently established occupational radiation exposure levels that are lower than those permitted by DOE orders (195).

Box 3-E—Scientific Controversy Over Low-Dose Radiation Effects

It is well established that high doses of ionizing radiation cause cancer. Indeed, more scientific research has been devoted to understanding radiation than to any other known human carcinogen. Yet, questions about the human health effects caused by low doses of radiation (less than 10 rem) are extremely controversial. The problem is that to discern the true effects of radiation at low doses, very large populations must be studied and years or decades must pass from the time of initial radiation exposure until a cancer (the usual health outcome investigated) is detected. The difficulties of following large numbers of people over long periods and of accurately accounting for individual radiation doses, cancer deaths, and risk factors other than radiation exposure, are obvious, and leave much room for uncertainty.

In addition to these logistical problems, scientists must contend with conflicting ideas about how observations of high-dose radiation effects should be incorporated into the mathematical models used to predict low-dose effects. Although the choice of different mathematical models hinges on arcane issues in biostatistics and molecular biology, the risk estimates produced by such models have important implications for radiation protection policies. For example, depending on whether a quadratic or linear dose-response model is used,[1] the interpretation of the excess cancer risk resulting from exposure to 1 rad varies by two orders of magnitude.

The National Academy of Sciences convened a series of expert committees to advise the U.S. Government on the health effects of radiation exposures. The BEIR Reports dealing with penetrating radiation[2] studied the health effects (cancer deaths, birth defects) among groups who had received relatively high doses of radiation such as the Japanese atomic bomb survivors and groups of patients who had received radiation for medical purposes. The committees then applied dose-response models to these findings to predict estimates of the heahh risks associated with low-dose radiation exposures.

The BEIR estimates of cancer risk have undergone successive revisions as the Hiroshima and Nagasaki survivors age and the available database and records of cancer deaths become more extensive. The BEIR V estimates for fatal cancer risks are three to four times greater than the highest estimates reported in the 1979 BEIR report. BEIR V predicts that a single radiation exposure of 0.1 Sievert (10 rem) would result in 800 extra fatal cancers occurring over the remaining lifetime of 100,000 exposed people.[3,4] The confidence intervals associated with the predicted point estimates are wide; nonetheless, the increase of the estimates of cancer risks associated with low-level radiation exposures calculated by successive BEIR committees illustrates the tentative nature of even the most authoritative analyses of low-level radiation effects. All BEIR reports have noted that the data cannot exclude the possibility that there may be *no risks* from low doses,

Another recent investigation of low-dose radiation effects has attracted much interest. This was a peer-reviewed study reporting an association between the risk of childhood cancer and a father's exposure to low-dose radiation among people living near the Sellafield nuclear reprocessing plant in Britain.[5,6] The observed association between fathers' exposure to low radiation doses (10 to 1OOmSv or 10 to 100rems) in the 6 months preceding birth and risk of leukemia among their offspring is not predicted by any previously identified dose-response data and was quite unexpected. The number of cases studied was small, which means it is possible that the findings occurred by chance rather than as a causal result of parental radiation exposure. The association

[1] B. Mo&u, "Cancer and Leukemia Risks After Low Level Radiation- -Controversy, Facts, and Future," *Medical Oncology and Tumor Pharmacotherapy*, vol. 4, No. 3/4, p. 452, 1987.

[2] BEIR Reports I, II, III and V all focus on the human health effects of external or 'penetrating'' radiation, such as that produced by x-rays, gamma rays, and neutrons. BEIR III reviewed the data on the effects of internal radiation, principally radon, an alpha-emitter encountered by uranium miners.

[3] National Research Council, committee on the Biological Effects of Ionizing Radiations, *Health Effects of Exposure to Low Levels of Ionizing Radiation, BEZR V* (Washington, DC: National Academy Press, 1989), p. 162.

[4] The views of scientists on the BEIR III Committee were so divided that a minority report was appended. A minority of the BEIR III committee believed the data favored cancer risk estimates that were higher than those advocated by the majority. These higher, minority-supported estimates, which were denounced by some as alarmist at the time, are in line with BEIR V's results.

[5] M. Gardner, M. Snee, A. Hall, C. Powell, S. Dowries, and J. Terrell, ''Results of Case-Control Study of Leukemia and Lymphoma Among Young People Near Sellafield Nuclear Plant in West Cumbria,' *British Medical Journal*, vol. 300, Feb. 17, 1990, pp. 423-429.

[6] M. Gardner, M, Snee, A. Hall, C.Powell, S. Dowries, and J.Terrell, "Methods and Basic Data of Case-Control Study of Leukemia and Lymphoma Among Young People Near Sellafield Nuclear Plant in West Cumbria,'' *British Medical Journal*, vol. 300, Feb. 17, 1990, pp. 429-434.

Continued on next page

Box 3-E—Scientific Controversy Over Low-Dose Radiation Effects—Continued

was statistically significant however, and the risk of childhood leukemia increased as the father's radiation dose increased, factors that argue against a chance association. Additional studies will be required to determine if as-yet unidentified factors, such as occupational exposure to genotoxic chemicals or exposure to viruses, might provide alternative explanations for the association.[7]

The Sellafield findings raised sharp questions about how much remains to be learned about the health effects of radiation.[8] [9] One response has been a study sponsored by the National Cancer Institute (NCI) that compares cancer death rates among populations living in counties adjacent to nuclear powerplants and DOE nuclear weapons sites to cancer mortality rates among people residing in counties that are not near nuclear facilities.[10] The study also compared cancer mortality rates in the study counties prior to the installation of the nuclear facility to rates some years after operations began. No significant patterns of excess cancer mortality among the study counties was observed.[11]

As the study's reviewers note however, the NCI study has a number of limitations. The large size of the populations investigated means that relatively few individuals in a study county may actually have lived near a nuclear facility. Small effects among these individuals may have been obscured by dilution of the study counties with people who did not reside near a facility. Also, data on cancer incidence, which are more sensitive to possible increases in cancer rates than are mortality data, were available for only four facilities, none of which were DOE installations.[12] It is difficult to make much of comparisons of cancer mortality rates before and after DOE operations began, since in many cases the weapons facilities were built before accurate records of cancer death rates were kept.[13]

[7]G. Anderson, "Leukemia Linked to Fathers' Radiation," Nature, vol. 343, 1990, p. 679.

[8]V. Beral, "Leukemia and Nuclear Installations" (editorial), *British Medical Journal*, vol. 300, Feb. 17, 1990, pp. 411-412.

[9]H.J. Evans, "Leukemia and Radiation," *Nature, vol. 345, May* 3, 1990, pp. 16-17.

[10]S. Jablon, H. Zdenek, J. Boice, and B. Stem, *Cancer Populations Living Near Nuclear Facilities, Volume 1: Report and Summary*, National Institutes of Health Pub. No, 90-874 (Washington, DC: U.S. Government Printing Office, July 1990).

[11]Ibid., p. 4.

[12]Ibid., p. xii.

[13]Ibid., pp. 56-62.

demonstrated deficiencies in effluent source monitoring; and 67 percent of the facilities had deficiencies in the meteorological monitoring programs or data utilized in dose assessment calculations (197). The Rocky Flats Plant, the Y-12 Plant at Oak Ridge, and the Mound Plant were found to have ' 'deficiencies with the pathway analyses, documentation, and/or environmental monitoring in support of dose assessment methodologies" (198). Scientists independent of DOE have also complained about similar shortcomings in radioactive release data at Rocky Flats and Fernald (199, 200). Shortages in personnel trained in radiation measurements and health physics were found at several sites.

Summary: limitations of Chemical- and Media-Specific Regulations

In sum, the contamination at DOE nuclear weapons sites is characterized by many features that current chemical- and media-specific regulations address least successfully and for which existing laws may be least protective. A relatively small number of environmental contaminants are regulated by chernical-specific or media-specific standards. Many situations throughout the Weapons Complex are not covered by such standards, including historic releases of contaminants that cannot be detected by current environmental samples and contaminant Ion of soil or sediments by radionuclides.

Furthermore, even when chemical-specific or media-specific standards do exist, their application to contamination at the Weapons Complex may not ensure adequate protection because of the complexities of multiple contaminants in certain media and multiple human exposure routes. Finally, outdated DOE radiation standards and the tradition of DOE self-regulation make it difficult to assure communities that compliance with existing standards will result in an appropriately or adequately safe environment.

Box 3-F-Quantitative Risk Assessments

Quantitative risk assessments typically consist of at least four steps:

1. hazard identification,
2. dose-response assessment,
3. exposure assessment, and
4. risk characterization.

Hazard identification is the determination of whether a substance causes adverse biological effects. The Environmental Protection Agency (EPA) uses a" weight of evidence" approach in judging the hazard potential of a substance. All available scientific evidence is reviewed and evaluated for accuracy, applicability, etc., so that the most suitable data are used to assess the nature of the hazard posed by a chemical.[1] The effects of substances that are structurally similar may be considered. Most available toxicological information comes from animal experiments and pertains to cancer-causing effects. In the absence of a compelling reason to evaluate the hazards of a particular mixture, only individual contaminants are considered.[2] If a substance is determined to be nonhazardous, or no data are available indicating that the substance is hazardous, the risk assessment ends here.

At Superfund sites, "indicator chemicals" are selected from lists of contaminants revealed by preliminary analysis to be present at the site. Indicator chemicals are those believed to pose the greatest health hazard at a site; they are chosen on the basis of toxicity (i.e., hazard identification), concentration and amount, mobility, and persistence in the environment. At more complex sites a proportionally largernurnberof indicator chemicals should be examined.[3]

Dose-response assessments specify the quantitative relationship between a given dose (absorbed amount) of a substance and the severity or probability of an adverse effect; they provide a measure of a substance's potency. Selection of a dose-response relationship can be controversial, in part because the interpretation of most available data requires extrapolation across several categories, usually including species, sex, age, dose range, exposure pattern, and absorption routes. Human data derived from epidemiological studies are allotted more weight when available, but most epidemiological studies focus on occupational exposures and situations that are not necessarily representative of environmental exposures in the general population. Deriving dose-response relationships of low dosages of potentially carcinogenic substances may be especially controversial because available data can often be reconciled with more than one mathematical dose-response model.[5]

Exposure assessments are estimates of the degree of individual exposure to a given substance and the number of people exposed. The determination of exposure is crucial in conducting quantitative risk assessments (QRAs). If the actual or potential exposure is not recognized, either because of failure to identify significant environmental transport pathways and exposure routes or because of inaccurate estimation of the number of people exposed or exposure levels, the resulting risk estimate will be misleading.

Direct measurements of human exposure (e.g., analyses of blood or urine samples that indicate individual exposure to a substance) are rarely used in QRAs, and most such measures remain research tools. Instead, QRAs typically use indirect measures of human exposure, such as computer models based on environmental monitoring data, to project estimates of individual dose. For example, some measure (mean, median, or upper confidence limit levels) of ambient contaminant concentrations may be multiplied by standard intake values (estimates of how much air one breathes, water one drinks, etc., over a 70-year lifetime or other appropriate exposure duration) to produce a dose estimate. The estimated dose is then related to the relevant legal standards or to exposure levels that have been predicted to pose no more than "acceptable" levels of risk for the health effect at issue.

[1] U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, *Risk Assessment Guidance for Superfund, Human Health Evaluation Manual Part A,* September 1989, pp. 7-1—7-20.

[2] Guidelines for the Health Risk Assessment of Chemical Mixtures, 51 *Fed. Reg.* 34014 (1986).

[3] C. Zamuda, "Superfund Risk Assessments: The process and Past Experience at Uncontrolled Hazardous Waste Sites," Risk Assessment *of Environmental and Human Health Hazards: A Textbook of Case Studies,* B. Paustenbach (cd.) (New York, NY: John Wiley & Sons, 1989), pp. 273-280.

[4] B. Paustenbach, "Health Risk Assessments: Opportunities and Pitfalls," *Columbia Journal of Environmental Law, vol. 14, 1989,* pp. *365-379.*

'Ibid., pp. 391-393.

DESCRIPTION AND EVALUATION OF SITE-SPECIFIC HEALTH EVALUATIONS REQUIRED BY REGULATIONS AND INTERAGENCY AGREEMENTS

Conditions at a toxic waste site may not be adequately addressed by existing chemical- and media-specific standards. For this reason, in addition to complying with ARARs, each site on the National Priorities List (NPL) is required to undergo quantitative risk assessment. Quantitative risk assessment (QRA) is a methodology for evaluating the health implications of environmental contamination in the face of incomplete knowledge of the molecular mechanisms that lead to disease (see box 3-B).

QRAs attempt to quantify the hazard associated with a particular pollutant under specific conditions of exposure. The product of a risk assessment is a "risk estimate"-a calculation that relates a contaminant's chemical characteristics, toxicological behavior, and conditions of exposure to the probable incidence of the adverse effect under consideration (usually cancer) in a given population (201) (see box 3-F).

Quantitative Risk Assessments Required by CERCLA

Quantitative risk assessments of conditions at weapons sites will be conducted by DOE, or DOE contractors and subcontractors, and reviewed by EPA. The baseline risk assessment describes the site "as is,' before any remediation work is begun, and is completed as part of the remedial investigation/ feasibility study (RI/FS) stipulated by CERCLA.[22] Refinements of the baseline analysis and additional risk assessments are incorporated into the final Record of Decision (ROD),[23] which documents the findings of the RI/FS and specitiesproposed cleanup actions (202).

The health risks that are projected to be associated with any proposed cleanup remedy, as calculated by quantitative risk assessment methods, are also presented in the ROD. Proposed cleanup strategies must yield "acceptable" risk estimates to win approval from regulators. Thus, the central purpose of CERCLA quantitative risk assessments is to assist cleanup managers in choosing among various cleanup strategies.

QRAs provide a useful format for performing a disciplined evaluation of some potential health impacts associated with environmental contaminants. They have proved valuable for formulating policy in the face of limited technical information. The quantitative risk assessment process under CERCLA is also associated with technical and procedural problems, however.

Technical Problems Associated With Quantitative Risk Assessments

The technical limitations of quantitative risk assessments stem from fundamental uncertainties in the scientific understanding of how environmental contaminants affect human health. Attempts to quantify the health risks associated with exposure to a chemical or a radionuclide must grapple with many uncertainties. Limited available data must be extrapolated across dose ranges, exposure routes, age, sex, and-in the case of animal data-species, to be applied to specific situations of human exposure. As discussed earlier, only a small proportion of the chemicals in use have been tested for toxic effects, and most of the available information pertains to a substance's cancer-causing potential. The effects of a substance on neurological, immunological, or reproductive functions are largely uninvestigated, as are the consequences of low-dose, chronic exposures.

EPA has attempted to deal with the pervasive uncertainties in the toxicological knowledge base by standardizing the assessment of the hazard associated with a certain chemical (203 -205).X At Superfund sites, "indicator chemicals" that are especially pervasive, persistent, or dangerous are selected from among all the toxic chemicals discovered at the site and subjected to detailed analysis. The selection of which and how many chemicals at a site should

[22] 42 U.S.C.A. §9620(e)(1) (West Supp. 1990).

[23] 42 U. S.C.A. §§9621(a)-(f) (West Supp. 1990).

[24] Radionuclides are, of course, chemicals. In some cases, the major toxic effects of a substance are a result Of its radioactive properties. With other radionuclides, however, chemical toxicity causes the most damage. For example, the radioactivity of natural uranium is very low and does not produce appreciable radiation damage when ingested or inhaled at dosages below the Annual Limit on Intake. However, at these doses the chemical toxicity of uranium can cause kidney damage (206, 207).

Such exposure models may or may not be validated and can vary widely in cornplexity.[6] At Superfund sites, because of the difficulties involved in identifying and mapping contaminants at a site, exposure assessments as currently conducted may be one of the risk assessment components most vulnerable to error.

Risk characterization is the process wherein all the foregoing pieces are incorporated into a mathematical model that represents the probable risks of exposure to a given population for which a risk estimate is being calculated. Risk characterization is clearly dependent on the accuracy of its components: the applied hazard information, dose-response relationships, and exposure estimates.

Risk characterization also requires judgments about how to handle uncertainties in the underlying data, how to select appropriate dose-response and exposure estimates from (often incomplete, ambiguous, or conflicting) available data,[7] how to assemble this information into an overall model, and how to present the results of the assessment and its attendant uncertainty to the risk manager.

[6] A. Finkel, "Is Risk Assessment Really Too Conservative? Revising the Revisionists," *Columbia Journal of Environmental Law, vol. 14*, ~0, 2, 1989, p. 430.

q~o~tt= o h ~ti~tio~ Mm for &sessm@t of ~~, Natio~ R~~~hco~Cil, RiskAssess~n# in *the FederaZGovernment: Managing the Process (Wasbingtom IX:* National Academy Press, 1983), p. 36.

serve as indicator chemicals is to some degree prescribed by EPA but is also a matter of judgment (208).

Many steps in the risk assessment process require the risk assessor to make judgments (209, 210). EPA has recommended algorithms that can supply some consistency in determining how such judgments or "inference points' might be determined. For example, EPA has developed computerized data sources describing the toxic effects and potency factors of chemicals, along with tables that assist the risk assessor in applying this information to the conditions at a specific site (211)

Risk assessors are not legally required to utilize EPA's recommended inference assumptions (212). The Risk Assessment Guidance that spells out EPA's preferred risk assessment algorithms does not have the force of law; such algorithms are meant to be flexible enough to accommodate the specific features and circumstances of a site and are not intended to serve as a "cookbook' of risk assessment techniques (21 3). However, DOE has not established any directives to ensure that DOE contractors and subcontractors follow consistent procedures for collecting environmental samples, analyzing data, or choosing among inference assumptions as risk assessments are developed throughout the Weapons Complex. Therefore, it is likely to be difficult, if not impossible, to compare risk estimates either within or among sites.

Although determination of the *hazard* term of a risk assessment has become increasingly startdardized as a result of EPA efforts, determination of the *exposure* term of CERCLA risk assessments is less clearly spelled out by EPA guidelines (214). Consequently, there is more variability in the methods used to assess exposure at Superfund sites. Estimates of how many people are exposed to toxic materials, and in what doses, depend both on a knowledge of environmental transport pathways and on approximations of how much of an environmental toxicant an individual might actually absorb from contact with contaminated air, water, soil, or vegetation.

The results of environmental sampling are clearly crucial to an accurate understanding of where contaminants have traveled in the environment. Characterization of environmental contamination is a difficult task with many elements of uncertainty (see app. B). If sampling strategies fail to detect a particular contaminant or if computer models of environmental transport pathways do not accurately map the presence and concentration of a contaminant, the exposure estimates derived from such results will be inaccurate.

Variability in the age and habits of individuals can also greatly affect exposure. Children, for example, typically have more contact with soil than do adults (215). People who spend a great deal of time outdoors or who use polluted waterways for recreation may have very different exposures compared with other members of a community. It is, therefore, important to obtain updated information describing land use and population characteristics in communities surrounding a waste site.

Any quantitative risk assessment, no matter how competently and carefully performed, contains many areas of uncertainty (216). It has been argued that EPA risk estimates are expressed in terms that imply more precision than is warranted. Some critics have urged EPA to institute formal processes for specifying and dealing with the uncertainty in QRAs and to publish risk estimates giving the entire range of values that are consistent with the observed and calculated features of a situation (217). Thus, rather than portraying risk as a single number or "point estimate' that gives an unwarranted impression of precision, or presenting very broad and unhelpful ranges of possible estimates (e.g., a risk between O and 100), risk assessors could present the range of calculated estimates along with an indication of the probability that the numbers in the range are correct (218).

Formal uncertainty analysis may produce a more detailed or realistic appraisal of some risks associated with a situation, but from the viewpoint of policymakers, this strategy also has problems. Uncertainty analysis introduces another layer of abstraction into a process that is already quite technical and difficult for risk managers to interpret. Concern also exists that the additional complexities of uncertainty analysis would increase public skepticism about risk assessment methods (219).

Furthermore, formal analysis does not alter the basic uncertainties embedded in quantitative risk assessments of environmental toxicants (220). Quantitative risk assessments are largely limited to the estimation of those health outcomes for which toxicological data are available-principally acute, high-dose, health effects and cancer risks. A QRA is inherently incapable of discovering health effects that have not yet been linked to a particular exposure or that are not predicted by available dose-response data.

Risk estimates are "probabilistic summaries of unknowable future events" (221) and it is difficult to test or verify their validity. EPA risk estimates, generated not for Superfund sites but for more generic regulatory policies, have been criticized for both over- and under-estimating actual risk (222, 223). Some critics contend that risk-based environmental regulations consistently overestimate "real risk' by employing deliberately conservative, health-protective assumptions throughout the assessment process (224-226). Others dispute this view and maintain that many "conservative" assumptions may overestimate the actual risk (227-230).

Procedural Problems Associated With Quantitative Risk Assessments

CERCLA risk assessments take a long time to caxry out. Review of the 1988 list of Records of Decision completed at Superfund sites revealed that 38 to 42 months elapse from the initial preliminary assessment phase of CERCLA until a ROD is complete (23 1). These long timeframes result partly from the technical challenges involved in characterizing a large or complex site, and partly from the slow pace of the regulatory review process. Although EPA and the States may have access to site characterization data and the baseline risk assessment as it is developed, years can pass before environmental monitoring results or completed risk estimates are released to the public.

Risk assessors are rarely involved in designing the approach to environmental sampling and site characterization (232). As a result, it maybe necessary for engineers to collect additional environmental samples or revise models of transport pathways to provide data that are needed for the risk assessment but were not acquired during the inital remedial investigation. In some cases, environmental engineers may expend great effort and money characterizing details of a site that have little or no bearing on human health risks.

EPA has recently urged site managers to involve risk assessors in the early stages of environmental characterization and to gather data with clear questions and information requirements in mind (233). In practice, however, engineers with little or no health background control the collection of environmental samples, and other experts, who may also lack expertise in toxicology or environmental health, develop the environmental transport models.

DOE has advocated that "risk-based cleanup priorities' be used to determine cleanup goals (234). This is a reasonable objective, but it fails to acknowledge the technical uncertainties and practical limitations of risk assessment techniques. In some instances, the available data may be too sparse to conduct a meaningful risk estimate. In other situations where risk assessment techniques can be reasonably applied, risk estimates do not automatically translate into coherent policies or explicit management decisions. For example, although risk analyses have been advocated as a means of devising a hierarchy of health-based cleanup priorities, it is not generally true that quantitative risk analyses are well-suited for prioritizing risks. When individual risk estimates are highly uncertain, comparing risks can be very misleading (235).

Disputes about the complexities and uncertainties of site characterization have long been sources of controversy at non-Federal facility Superfund sites. Different stakeholders, some interested in minimizing uncertainty about possible health effects and others concerned about holding down costs, have different views about how much information is needed to adequately characterize a site and formulate a cleanup plan (236). Questions about "how clean is clean enough?" to protect public health are similarly problematic. The basic difficulty is that scientific understanding of the health effects of environmental contamination is very limited. As the National Research Council Committee on Risk Assessment in the Federal Government has pointed out, there is no ready solution to this problem (237).

EPA recommends early and ongoing community involvement in the QRA process (238). Residents' observations and suspicions of possible toxic exposures or health outcomes could provide valuable clues to risk assessors. Early and ongoing interactions among communities, regulators, and potentially responsible parties (PRPs) might enhance community appreciation of the purposes and limitations of QRAs, and improve acceptance of proposed cleanup remedies.

In practice, however, community members are seldom consulted during the risk assessment process. Instead, final risk estimates are presented with accompanying technical analysis and a chosen remediation plan. Affected communities often interpret such risk estimates as justifications of the cleanup remedy preferred by the PRP (239). Private citizens and community groups typically lack the time and expertise needed to critically review a complicated risk analysis. Also, people often have difficulty relating mathematical functions to concerns about the well-being of themselves or their families. Residents may not be reassured to learn that the lifetime chance of dying of cancer as a result of contarnination of their neighborhood is only one in 10,000.

CERCLA risk assessments sometimes fail to address specific issues of concern to local communities. For example, residents may be worried about whether their children's learning disabilities are due to pollution, whereas the QRA focuses on evaluating the risk of cancer deaths. Communities left to worry for years while a QRA is completed may become disappointed and angry when the long-awaited risk estimates fail to resolve their concerns.

Finally, although QRAs will be conducted at all weapons sites on the NPL, those facilities that do not contain Superfund sites are not legally required to undergo risk assessment. Thus, some potentially important sources of toxic contaminants will not be subjected to QRAs. Corrective action measures at those RCRA sites that have released toxic materials must be evaluated in light of the potential health risks they are designed to mitigate. However, EPA has not issued agencywide guidelines stipulating how such risks should be assessed (240). Consequently, "risk assessment" at RCRA sites varies among EPA regions but, when done, is generally far less detailed than Superfund QRA methods.

Site-Specific Health Assessments Conducted by the Agency for Toxic Substances and Disease Registry

Statutory Authority

The Agency for Toxic Substances and Disease Registry (ATSDR) was established by CERCLA in 1984 and began operating with the passage of the 1986 Superfund Amendments and Reauthorization Act (SARA) .[25] Along with the National Institute for Environmental Health Sciences (NIEHS), which conducts basic research into the biological mechanisms of environmental hazards, and the National Institute for Occupational Safety and Health (NIOSH), which studies risks faced by workers at hazardous waste sites, ATSDR is designed to be one of the Nation's principal agencies for the study of human health effects resulting from exposure to environmental contamination.

ATSDR is required by statute to perform a health assessment on the potential public health impact of every Superfund site within 1 year of a site's being

[25]Pub. L. No. 99-499, 100 Stat. 1615 (1980) (codified in scattered sections of the I.R.C. and 10, 19, 33 and 42 U.S.C.).

proposed for inclusion on the NPL.[26] If the available site information is insufficient to support a complete health assessment in that timeframe, a preliminary health assessment may be issued, with subsequent documents adding refinements and details as data become available. A completed health assessment may, therefore, be a series of documents or reports released as information is generated and conclusions or recommendations are modified (241).

Operators of RCRA sites are required to submit information to EPA (or to the State in the case of State sponsorship) describing any "reasonably foreseeable potential release" that might result from routine operations or accidents. Under RCRA, documentation must address the nature and magnitude of possible releases, as well as describe potential pathways of human exposure.[27] If EPA or the responsible State determines that a RCRA site poses a' 'substantial potential risk to human health," ATSDR may be requested to perform a health assessment. RCRA goes on to say that 'if funds are provided in connection with such request, the Administrator of ATSDR shall conduct such health assessment. " Federal facilities are required to pay their own CERCLA costs. Presumably, DOE would be the funding source for ATSDR health assessments at RCRA facilities. It is unclear whether an ATSDR health assessment would be performed at RCRA sites in the Weapons Complex if such funds were not made available.

ATSDR's authority and responsibility at RCRA sites within the Weapons Complex may be further expanded by two provisions of CERCLA. Under CERCLA, ATSDR can consider health risks to populations residing near Superfund sites that arise from sources other than the facility in question.[28] Thus, at weapons facilities that contain both CERCLA and RCRA sites, ATSDR could invoke its CERCLA authority to perform health assessments at RCRA units as well.

Furthermore, CERCLA requires ATSDR to respond to petitions from Congress or individual citizens requesting evaluation of any exposure to toxic substances for which the probable source of exposure is an environmental release.[29] Thus, ATSDR health assessments could be conducted at weapons facilities that do not contain Superfund sites if local citizens or Congress requests such investigations.

Health Assessment Methods

ATSDR health assessments have three purposes (242, 243):

1. to evaluate the public health implications of a site,
2. to address these implications by identifying the need for any additional health or environmental studies, and
3. to identify actions necessary to mitigate or prevent adverse health effects and to recommend that EPA take the steps required to carry out such actions (e.g., provision of alternate water supplies, relocation of individuals).

The basic approach to be used in conducting health assessments at Superfund sites is outlined in the ATSDR Draft Health Assessment Guidance (244). The health assessment is based on environmental data, health outcome data, and community concerns. Environmental data include those descriptions of contaminants and migration pathways developed by EPA in the course of its own preliminary assessment and remedial investigation, as well as demographic data pertinent to the site. Health outcome data may include medical records; morbidity and mortality figures obtained from local, State, or National databases; tumor and disease registries; birth statistics; and surveillance data. Community concerns are those site-specific health issues raised by local residents and identified in public meetings, during "house calls," and from the recommendations of State or local health officials (245).

If the results of a health assessment point to the need for additional studies, ATSDR has authority to exercise the full scope of environmental health investigative methodologies at Superfund sites, including the administration of symptom questionnaires and health surveys, the establishment of health surveillance and exposure registries, and the design and execution of pilot studies and full-scale epidemiological investigations (see box 3-B). ATSDR employs the range of professionals and technical

[26] CERCLA Section 10, 42 U.S.C.A. §6904(i)(6)(A) (West Supp. 1990).

[27] 42 U.S.C.A. §§6939a(a)-(b) (West Supp. 1990).

[28] CERCLA Section 10; 42 U.S.C.A. §§6904(i)(6)(F)-(G) (West Supp. 1990).

[29] CERCLA Section 10; 42 U. S.C.A. §6904(i)(6)(B) (West Supp. 1990).

experts needed to carry out comprehensive environmental health assessments, including hydrogeologists, toxicologists, physicians, epidemiologists, biostatisticians, and health physicists.

ATSDR could, for example, carry out pilot studies to test the need for, or feasibility of, more elaborate health investigations. Such studies might examine evidence of exposure to hazardous materials among individuals. Unlike EPA and site contractors conducting exposure assessments under the QRA provisions of CERCLA, ATSDR has on occasion used direct measures, such as blood and urine assays, to detect individual exposure to environmental contaminants (246). When available, such direct methods are more reliable and specific than indirect exposure measures such as computer models. Direct exposure measures can also be used to help validate the computer models used in QRAs at a site.

In addition to conducting pilot studies, ATSDR can subject sites to more complex epidemiological investigations, including case-control studies, cohort studies, or cross-sectional studies. In some cases, ATSDR staff designs and carries out such investigations. CERCLA also allows ATSDR to enter into cooperative agreements with State health departments and State universities in conducting such studies.

When exposure to potentially hazardous materials has occurred but the severity or nature of resulting health impacts is unclear, ATSDR can establish exposure registries to track exposed individuals over time and arrange for periodic medical surveillance, evaluation, and documentation of health status. In this way, scientific understanding of the consequences of such exposure is enhanced, and exposed populations have concrete evidence that their concerns are being acknowledged and their health monitored. ATSDR has established two exposure registries to date, one for individuals exposed to dioxin and the other for populations exposed to the solvent trichlorethylene (247).

Evaluation of Health Assessment Methods

The scope of health issues that ATSDR may consider is broader than that required of EPA or of potentially responsible parties at Superfund sites. CERCLA-mandated quantitative risk assessments deal only with toxic chemicals, whereas ATSDR health assessments can consider both chemical and physical hazards. Thus, ATSDR can recommend, for example, that potentially explosive materials be immediately removed from a site, that a dangerous site be fenced off, or that open pits be covered. ATSDR may also consider all past aspects of a site's operations, including historical releases, if they are believed to impact on human health. QIL4s consider only present and future risks posed by the site, that is, what toxic chemicals are in the environment now and where they are moving (248).

A major strength of ATSDR'S policy is the emphasis placed on establishing effective and ongoing communication with affected communities. The Draft Health Assessment Guidance states that ATSDR will deliberately seek out members of communities neighboring Superfund sites and solicit their concerns and ideas in public meetings. Specific health concerns voiced by residents are to be taken seriously and addressed without exception. Responses to such concerns may vary horn verbal reassurances that no cause for alarm exists to full-scale health investigations where warranted (249).

Such a commitment to early and ongoing public participation in health studies reflects the strongly held view of public health officials interviewed by OTA who maintain that it is essential to apprise communities of the purposes, nature, and limitations of all health studies planned or underway therein (250-253). According to health officials and researchers experienced in investigating the health effects of environmental exposures, the most serious barrier to successfully communicating the import of health studies to the public is not the lay public's lack of scientific sophistication. If the technical details are described competently and are regarded as important, people will take the necessary pains to understand them. William Ruckelshaus, who twice served as EPA Administrator, has also stated his belief that "it is possible for people subject to toxic risk to think rationally about it" (254).

Rather, the most common-and often disastrous-barrier to communication is the failure of professionals and technical experts to listen to communities, to provide meaningful opportunities for the exchange of information as a study proceeds, and to acknowledge the uncertainties involved in the scienttilc analysis used to support decisions. These observations echo the findings of the National Research Council Committee on Risk Perception and Communication (255).

Limitations on Health Assessments

In practice, ATSDR's accomplishments are limited by a small staff and inadequate resources. The Agency is small: it consists of about 200 people (256). ATSDR is also new and just beginning to establish itself. ATSDR is part of the Public Health Service in the Department of Health and Human Services; however, it must compete for attention with the CDC, whose director is' also the director of ATSDR, although ATSDR is not itself part of CDC. ATSDR obtains its funding from EPA. These convoluted lines of authority create cumbersome bureaucratic procedures.

The l-year deadline for completion of health assessments was designed to ensure that health issues at Superfund sites are addressed in a timely manner. Although this goal is laudable, the effect of the l-year deadline has been to force ATSDR to rely on whatever information about the site has already been collected by EPA and is available at the time. In most cases, this information is neither reliably accurate nor comprehensive.

Furthermore, environmental data gathered to inform engineers about needed remediation strategies are not necessarily the same data required for health studies. For example, in some cases, the PRP at a Superfund site may not be motivated to collect environmental monitoring information that suggests a possible public health problem, or the data needed to evaluate proposed remedial activities may not include information about the possible health impacts of past releases. ATSDR can request that EPA or the site contractor collect more detailed information or generate data directed at particular concerns, but such requests are usually not complied with in time for the results to be included in the health assessment.

ATSDR scrambled to meet the regulatory deadine for completing the backlog of health assessments that existed when it came into being: 951 health assessments were prepared within a few months, many by outside contractors (257). The quality of these reports was predictably poor. ATSDR now maintains that its health assessments are subjected to considerable internal oversight and review. The Agency has recently reevaluated its guidelines for performing health assessments and attempted to make the process more rigorous.

Health assessments performed by ATSDR at Federal facilities and other Superfund sites have been criticized as superficial and even misleading (258, 259). The health assessment performed at Colorado's Rocky Mountain Arsenal, an Army facility that is comparable in size and complexity to some of the DOE weapons sites, was criticized for its failure to consider air pathway exposures, the use of inaccurate demographic data, and its reliance on incomplete and preliminary toxicological data (260-262). The Colorado Department of Health, the U.S. Army, and EPA all criticized ATSDR's failure to review more than a small portion of the available site characterization information. The EPA review acknowledged that ATSDR's effort was constrained by limited staff and noted, "Given the size, complexity, national significance and environmental and public health concerns associated with [the site], EPA strongly suggests the application of a much larger ATSDR resource level henceforth. . ." (263).

ATSDR currently lacks the staff necessary to critically evaluate the accuracy and adequacy of environmental characterization data supplied to EPA by site contractors. Resource limitations also prevent the Agency from utilizing teams of experts at a single site. Although ATSDR employs the appropriate range of health professionals and technical experts, in practice its staff is spread too thin to permit in-depth, multidisciplinary examination of conditions and potential health threats at each CERCLA site.

At non-Federal facility Superfund sites, ATSDR has shared or delegated responsibility for conducting health assessments through cooperative agreements with State health departments and State universities (264). These arrangements provide a means for ensuring local input into the assessment process and augmenting the ATSDR staff. Federal authorizing statutes do not permit ATSDR to make use of the resources of private or out-of-state colleges and universities, however. ATSDR has determined that for Superfund sites at Federal facilities, including DOE weapons sites, it will not delegate its authority to conduct health assessments to the States (265). (This decision does not bar cooperative agreements between ATSDR and the States to carry out specific health studies at weapons sites, however.)

DOE/ATSDR Memorandum of Understanding

In the fall of 1990, after more than a year of negotiation, DOE signed a Memorandum of Understanding (MOU) with the Department of Health and Human Services (HHS) (266). This MOU authorizes ATSDR to begin discussions with the seven individual DOE Operations Offices in pursuit of interagency agreements that will eventually provide ATSDR with the resources to conduct health assessments at the nuclear weapons sites on the NPL.

Although the MOU represents a signficant step forward, much further negotiation remains to be accomplished. ATSDR must now sign IAGs with each of the DOE Operations Offices to specify the procedures DOE will follow in disclosing "all relevant information and data (toxicological, human health and environmental operations data)" concerning each weapons site where a health assessment is planned "or where ATSDR in consultation and cooperation with DOE, determines that other health related activities are needed" (267).

The potentially circumscribed authority given to ATSDR by this MOU may seriously impede its ability to effectively address the major health issues raised by environmental contamination at Weapons Complex sites. The DOE/ATSDR MOU stipulates that all "long-term health-related activities" (i.e., any health studies other than the CERCLA health assessment) will be "provided to" an advisory committee established by HHS as part of the agenda under development for "energy-related analytic epidemiological studies" (268) (see box 3-G). It is unclear, therefore, whether ATSDR, CDC, or nongovernrnent scientists would design and conduct such studies, or whether ATSDR would require consent from the advisory panel to proceed with investigations deemed necessary.

ATSDR's limited resources are also constraining. An ATSDR internal memorandum notes, "Of all the sites proposed for listing on the NPL, the Federal facilities are among the most complex" (269). Present plans call for the formation of two types of health teams: "one focusing on the health issues and concerns of the communities and their officials," and the other focusing on environmental contamination and human exposure pathways. Each team would consist of two persons who would spend the equivalent of 1 month visiting a site; meeting with community members, local, State, and health department officials, and environmental agencies; reviewing and interpreting available characterization information to determine which sites or parts of sites pose or have posed the greatest threat to human health; and identifying, planning, and executing appropriate DOE followup health studies (270).

ATSDR explicitly acknowledges that this plan is severely circumscribed by limitations of staff and money (271). It is difficult to imagine how such an effort-which is heroic by ATSDR standards-will achieve even modest success. It is doubtful that two people, no matter how expertly trained, can adequately review the situation at a single weapons site and produce even a rough assessment of potential public health impacts, let alone establish contacts with communities, critically evaluate available characterization data, and design future assessment interventions. Such a strategy may identify some glaring problems and information needs but is also likely to produce a spate of superficial assessments that will be of little help in guiding the cleanup and may undermine ATSDR's credibility and future assessment efforts at the site. The prohibition against ATSDR entering into arrangements with private academic institutions is especially constraining because it bars the agency from drawing on the talent and advice of a large and experienced pool of environmental health researchers.

Summary: ATSDR Health Assessments at DOE Weapons Complex Sites

In summary, ATSDR's statutory mandate to investigate the health effects of environmental toxicants makes it the logical Federal agency to carry out site-specific evaluations of possible health impacts of Weapons Complex contamination. On paper, the methodological approaches embraced by ATSDR in investigating environmental health effects are sound. However, ATSDR has yet to accomplish much work at the weapons sites, largely because of staff shortages and delays in completing negotiations between HHS and DOE. Some observers, including university-based environmental health professionals and State health officials, are skeptical that ATSDR, with its limited resources and insecure position within the HHS bureaucracy, can successfully conduct scientifically rigorous and independent health assessments at the weapons sites.

Role of State Health Departments and Federal Centers for Disease Control in Health Assessments

Status of State Health Department Efforts

One remarkable aspect of the DOE cleanup is the limited involvement of State and local public health professionals. Although State health officials are frequently in direct contact with communities potentially affected by the contamination early and over the long term, the ambiguity of their health departments' authority at Federal facilities (272, 273) and the limitations on staff expertise and funding have left many State health departments without a clear role in the cleanup.

Often, State governments are structured so that separate departments preside over health and environmental issues and have little experience in collaboration (274). In many States hosting weapons facilities, departments of the environment have taken the lead role in designing plans for site characterization, remediation, and health assessment; local health officials often have limited knowledge of, or involvement in, the cleanup. In Colorado, where environmental and health protection functions are both part of the Department of Health, health officials have been directly involved in negotiating details of the interagency agreements among the State, EPA, and DOE. Yet, even when health officials are involved in the cleanup, the authority of their departments to enforce State health or safety regulations at Federal facilities has been disputed (275).

The resources available to State regulators vary but are generally modest. Most State health departments are struggling with limited budgets and experiencing problems in attracting strong leadership (276). Many States do not have experts trained or experienced in environmental health or employ only a few such individuals who are responsible for a wide range of projects. In some locations, past deficiencies in the expertise of health officials have left citizens distrustful of State regulators.

All of the involved States are attempting to negotiate agreements with DOE that include funds enabling them to hire more regulators and to cover overhead costs. Colorado and Idaho have signed agreements in principle (AIPs) that require DOE to fund State-sponsored health studies (277-280). The State of Tennessee is seeking to negotiate similar assurances of finding for site-specific health studies, dose reconstruction projects, and birth defects and cancer registries (281, 282).

The Colorado Department of Health was very active in formulating the interagency agreement and the AIP worked out by the State, DOE, and EPA. Activities under the Colorado IAG address the cleanup requirements of RCRA and CERCLA and call for the Governor to appoint independent advisory panels to review the adequacy of DOE's environmental monitoring at Rocky Flats and to design any health studies deemed necessary once preliminary characterization data are available (283).

The Colorado AIP is broader than RCRA or CERCLA in terms of conditions for compliance and envisions health studies including toxicological reviews, dose reconstruction, and risk characterization based on historical data. The proposed studies would be contracted out by the Colorado Department of Health to independent investigators (284). Funding sources for such studies were not identified in the IAG or AIP. It is unclear what will happen to Colorado's plans for independent health studies if Congress fails to appropriate the money necessary for DOE to fulfill all promises made to the State.

Status of Centers for Disease Control Efforts

Several States have turned to experts at the Federal Centers for Disease Control for advice and assistance in assessing possible health consequences of contamination at the weapons sites. Staff members from the CDC Center for Environmental Health and Injury Control (CEHIC) have played central roles in establishing the epidemiological study of thyroid disease that will follow the Hanford Environmental Dose Reconstruction Project. This study will be carried out by independent researchers from the Fred Hutchinson Cancer Center in Seattle, WA, in collaboration with CDC. CEHIC also plans a dose reconstruction of airborne uranium emissions from the Feed Materials Production Center in Femald, OH (285).

The CEHIC effort at DOE sites is being carried out by a staff of 12 scientists. 'The success of their efforts thus far and the fact that CEHIC is the only real public health presence at weapons sites have placed them in demand by other States. The Governor of Colorado has requested that CEHIC staff

Box 3-G—Authority Over DOE Health Data

The Department of Energy (DOE) has been engaged in negotiations with the Centers for Disease Control (CDC) to transfer partial responsibility for future epidemiological studies having to do with weapons sites operations to CDC. Such a transfer was recommended in March 1990 by the Secretarial Panel for the Evaluation of Epidemiologic Research Activities (SPEERA) for the U.S. Department of Energy, appointed by Secretary James Watkins. SPEERA was charged with providing an "independent evaluation of the DOE epidemiological program, and the appropriateness, effectiveness, and overall quality of DOE's epidemiological research abilities."[1]

SPEERA recommended that responsibility for conducting epidemiological investigations of DOE operations be transferred out of the Department after finding that the Department's role in promoting energy and weapons production represented an "inherent potential conflict of interest between immediate production goals and health and safety goals."[2] SPEERA also heard testimony that DOE and its contractors had endeavored to "influence epidemiological findings inappropriately" and had made it difficult for researchers other than DOE's major long-term contractors to conduct health studies at DOE facilities by avoiding open competition for epidemiologic research projects.[3]

The SPEERA recommendations, which the Secretary pledged to adopt,[4] and their codification in institutional arrangements have important implications for health studies related to weapons site cleanup. Open access to records of exposures and health outcomes among DOE employees at the weapons plants may be important in providing clues about what hazardous exposures and health effects should be considered among off-site residents.

Additionally, the institutional recipient of DOE worker data will also be awarded the funding and staff allotments necessary to carry out future analyses on the database. Such resources could create a new center of expertise in radiation-related health issues. Currently, such expertise is restricted to a few government employees scattered throughout several agencies, a situation that is problematic for the evaluation of health effects stemming from contamination at the Weapons Complex.

The institutional embodiment of the SPEERA recommendations will also be a signal of DOE's new ethic of openness regarding health data. In accord with an out-of-court settlement, DOE recently turned over a portion of the worker data to an independent epidemiologist who has long been critical of DOE contractor analyses of the health effects of radiation exposures among weapons plant employees.[5] The transfer of responsibilities for "analyticall epidemiology' studies to the Department of Health and Human Services (HHS) is seen as the next step in instituting DOE's "new culture' of openness and is awaited as evidence of DOE's commitment to environmental, health, and safety issues.

However, the draft Memorandum of Agreement between DOE and HHS indicates that formidable barriers may continue to confront independent researchers who seek access to the DOE occupational health database. Under the proposed conditions, investigators must obtain a formal interagency agreement approved by the Secretary of Health and Human Services and the Secretary of Energy to gain access to the Comprehensive Epidemiological Data Resource (CEDR).[6]

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[1]U.S. Department of Energy, Secretarial Panel for the Evaluation of Epidemiologic Research Activities, Report to the Secretary, March 1990, p. i.

[2]Ibid., p. 20.

[3]Ibid.

[4]U.S. Department of Energy, *Environmental Restoration and Waste Management Five-Year Plan, Fiscal Years 1992-1996*, DOE/S-0078P (Springfield, VA: National Technical Information Service, June 1990), pp. 57-58.

[5]*Three Mile Island Public Health Fund* v. *U.S. Department of Energy*, C.I.V. Action No. 1: CV-89-1185 (M.D. Pa).

[6]U.S. Department of Energy and U.S. Department of Health and Human Services, Draft Memorandum of Understanding for the Management of the Department of Energy Analytical Epidemiologic Research Program (undated, 1990).

participate in State efforts to draft a dose reconstruction study at the Rocky Flats Plant. The Governor of Idaho has asked CEHIC to represent the State on a committee to review a dose reconstruction effort carried out by DOE at the Idaho National Engineering Laboratory (286).

Traditionally, CDC's role in local public health issues has been to send small teams of scientists and physicians from the Epidemiological Investigation Service to areas reporting outbreaks of infectious disrase Such teams study the probable causes of the outbreak; design and carry out the necessary epidemiological investigations; and advise local officials on appropriate responses. Since its inception during World War II, the Epidemiological Investigation Service has been instrumental in the identification and control of hundreds of infectious disease outbreaks; it has also served as the training ground for a generation of epidemiologists (287).

CDC as a whole has not embraced the mission of environmental epidemiology, possibly in part because it was unclear how responsibility for environmental health issues should be divided between CDC and ATSDR. Some of CEHIC's efforts in this field have been controversial, although OTA investigations have revealed that community groups and State health agencies are pleased with and supportive of CDC efforts thus far in facilitating the Dose Reconstruction Project at Hanford.

CDC has no independent authority to investigate health problems at weapons sites and no independent source of funding for such activities. CEHIC was ''invited' to lend assistance by the States of Washington and Ohio. Funding for the Hanford and Fernald projects was provided to CDC by congressional appropriations (288).

CEHIC's small staff and resources are fully engaged in current projects at the weapons sites and probably cannot take on a greatly extended role without a significant expansion in staff and funding. Also, CDC's expertise is primarily in epidemiology. It does not employ a full range of environmental scientists who could, for example, provide independent assessment of environmental monitoring data.

There is little evidence of cooperation or consultation between CEHIC and ATSDR on health issues related to the Weapons Complex. This is unfortunate because each agency has contributions to offer and the overall pool of governmental expertise in environmental health is quite limited (289).

It appears that responsibility for investigating the health consequences of weapons sites contamination will be divided so that CEHIC investigates radioactive releases and ATSDR investigates the effects of toxic chemicals. Such a division of duties will further complicate the already difficult tasks of assessing total exposure burdens and integrating the health risks resulting from exposure to multiple contaminants.

Evaluation of the State-Specific Approach to Health Assessment

State-directed health studies could presumably take advantage of all available research methodologies, including risk assessments, dose reconstruction projects, and epidemiological investigations. Colorado's plan to request proposals from independent researchers for specific studies of questions identified by preliminary monitoring data incorporates a variety of investigative tactics and could make use of the talent available in the academic and private sectors of the environmental health community. The question of how such plans might be scaled back or eliminated in the face of inadequate funding remains unanswered.

The State-specific approach to health studies also allows local community concerns to be raised and reflected in study aims and designs. Structuring such investigations so that interested members of the public can be actively involved in all steps of the research is feasible, and State health department are likely to be sensitive to such needs.

There are also disadvantages to the State-specific approach to health assessments at weapons sites. The State-specific approach, if utilized at several sites, increases the likelihood that some studies will be redundant, whereas other important health issues may go unexamined. It also lessens the chances that the investigation of generic issues—problems confronted at more than one site—will be allotted high priority, unless such issues are also of great importance at individual sites.

States will, in effect, be bidding against each other for the services of a relatively small community of environmental health professionals. In a competitive atmosphere with limited funding sources, the danger of poorly designed studies that yield ambiguous or misleading results becomes more real, especially in view of the methodological challenges that are widely recognized to plague environmental health research. Although Colorado plans to subject all submitted project proposals to peer review, some States may lack the expertise to conduct such reviews.

Also, the size of populations living in proximity to weapons sites may not provide samples for large enough statistical analysis. Adequate samples might be assembled by combining populations from communities around various sites that share common exposures, but studies of this type would be feasible only if researchers had access to data and communities from several sites. Collaborative efforts could, in theory, be organized by individual States, but in practice this would place significant logistical demands on State officials.

Reports of an association between exposure to environmental toxicants and adverse health effects invariably engender strong and conflicting responses from different segments of a community. Affected residents are typically eager for health officials to "do something," even when the appropriate reaction is unclear. On the other hand, indicated solutions (or even the possibility that a town has a "cancer problem") can unfavorably affect economic development and result in angry attacks from local businesses (290). State health officials are sometimes caught in the crossfire between such warring factions of a community.

The desire to reassure worried citizens and to avoid the negative consequences of an association between toxic contamination and adverse health effects may induce some State health officials to require very stringent criteria of proof before any such association is acknowledged. The tradition in laboratory sciences is to reject any new hypothesis unless there is great confidence that it accurately portrays the true state of nature. The rationale for demanding equally strict criteria for coping with a public health incident is less clear, especially because the "natural experiments" upon which environmental epidemiology depends do not afford the level of control possible in laboratory settings (291).

The technical difficulties and time-consuming nature of environmental health studies make it very difficult to obtain incontrovertible evidence that a given exposure has caused adverse health impacts. Resource limitations sometimes force State health departments to use weak study designs and analytical techniques that almost guarantee that no definitive answers will be found, or that real associations between exposures and health outcomes will not be recognized (292-294).

CEHIC has played an important part in establishing the epidemiological study of thyroid disease that will build on the results of HEDRP. CEHIC's experience in working with DOE and individual States and its expertise in epidemiological investigations could be useful in designing future studies. CDC also has experience in collaborating with independent scientists whose knowledge and assistance is likely to be needed in assessing possible health impacts of Weapons Complex contamination. CEHIC does not, however, possess the multidisciplinary capabilities necessary to evaluate monitoring data and to design or review exposure models.

CEHIC investigators currently involved in projects at Hanford, Fernald, and INEL appear to have the confidence of State officials and local residents. There is some danger, however, that the perception of CDC's scientific approach to health studies at the weapons sites will shift if CDC, in becoming keeper of DOE worker data (295), pursues investigations of this controversial database with anything less than aggressive vigor (see box 3-G). The condition of the MOU between DOE and CDC that permits the former to carry out initial investigations of possible community health impacts from operations and contamination at weapons sites may be especially troublesome. If CDC must await DOE permission to investigate sites or can proceed with health studies only if DOE findings indicate that a problem exists, affected communities may soon cease to regard CDC as an independent scientific body.

Summary of Site-Specific Public Health Assessments

In sum, present site-specific efforts to assess the public health implications of environmental contamination at DOE nuclear weapons sites consist of an assortment of independent, uncoordinated activities. There is no overall coordination or oversight of the health evaluations that are being planned or carried out at weapons sites, nor does any single agency currently have the authority or resources to provide such coordination and oversight.

DOE is relying on existing environmental laws and interagency agreements to provide the organizational framework for addressing possible public health impacts of weapons site pollution. This approach means that quantitative risk assessment will be the site-specific health assessment method that engages the most resources.

Quantitative risk assessments may prove useful in guiding specific remediation activities at individual sites, but the need for extensive environmental monitoring data at complex sites, and the time required to gather and review such information, may delay the availability of completed QRAs. These delays, as well as technical and procedural problems in interpreting the policy implications of different risk estimates, may curtail their usefulness in setting near-term cleanup strategies.

Deficiencies in the scientific database that informs QRAs may limit the comprehensiveness and reliability of health risk estimates at some sites. The current process for conducting quantitative risk assessments does not encourage or, in some regions permit, the participation of affected communities. The lack of appropriate forums for citizen involvement makes it likely that some health issues of great concern to local communities will not be addressed and increases the chance that risk estimates, when finally made public, will be misinterpreted or disputed. Furthermore, risk assessments performed by DOE and its contractors may not be accepted as credible by some residents.

ATSDR will conduct preliminary health assessments at those sites that are proposed for or on the NPL, and possibly at RCRA sites as well. The need to apportion a small staff among a number of extremely complex sites, and bureaucratic delays in establishing ATSDR's presence at weapons sites, place this Agency at a disadvantage, as does its inability to enter into cooperative agreements with independent scientists. On the other hand, ATSDR's statutory mandate, its staff trained in the multiple disciplines of environmental health, and particularly, its capability for constructive engagement with communities are potentially important assets.

The abilities of individual States to design and oversee environmental health studies of the off-site impacts of Weapons Complex contamination vary, depending on the expertise of local health officials and the degree of their involvement in the cleanup. Most State health departments have few staff trained in environmental health and exercise ambiguous authority at Federal facilities. The conflicting pressures engendered by threats of adverse health impacts due to environmental toxicants may make it especially difficult for some local health officials to evaluate issues as potentially controversial as those that might result from Weapons Complex pollution.

The lack of coordination among different agencies involved in conducting health assessments at weapons sites and the competition among States for the services of limited numbers of environmental health professionals are likely to increase the costs and perhaps diminish the quality of the resulting investigations.

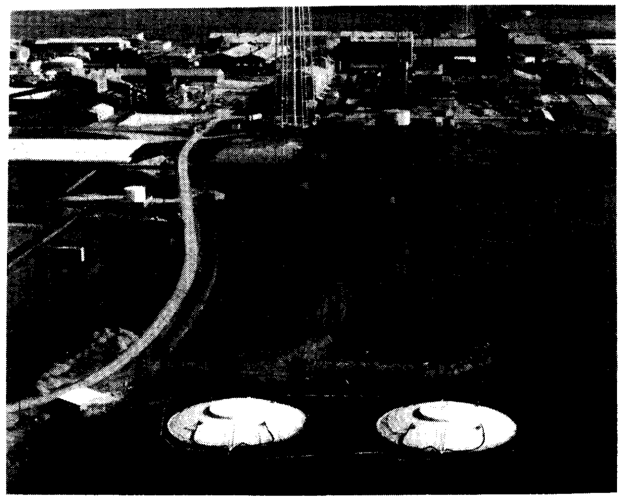

Photo credit: U.S. Department of Energy

K-6 Silos at Fernald containing uranium residues from the early years of Weapons Materials Production.

Poorly designed or conducted environmental health studies can be expected to produce ambiguous or misleading results, an outcome that can only increase the distrust and anxiety of the concerned public. Erosion in the credibility of assessments of the health impacts of contamination from the Weapons Complex may contribute to the delay and costs of the cleanup if demands are raised for additional environmental monitoring, more elaborate risk assessments, or more sophisticated health studies. If the responsible health agencies do not provide credible responses to local concerns about health effects, affected communities will look to other sources, including elected officials and the courts, for satisfaction.

OTA investigations indicate that the present structure of Federal and State health assessment efforts will fail to accomplish many of the important health-related objectives integral to a successful cleanup. The next section discusses the nature and rationale for such health-based cleanup objectives.

DEVELOPING HEALTH-BASED CLEANUP OBJECTIVES

Because the scope and the complexity of Weapons Complex pollution make immediate cleanup of all contamination impossible, there is a need to identify and address in a timely manner those sources or areas of existing contamination that pose the most significant and urgent health hazards. There is also a need to determine what cleanup levels will protect public health. The latter task may require additional research into the biological effects of toxic exposures unique to the weapons sites.

At the same time, however, the cleanup must encompass the major health issues raised by past environmental contamination and address questions that extend beyond the identification and remediation of current contamination. Failure to frame relevant health issues broadly enough may jeopardize public support for the cleanup effort as a whole.

In addition, remediation activities should include disciplined consideration of potential risks to workers and surrounding communities. Finally, methods to gauge the progress of remediation efforts should be developed.

Based on these needs, OTA has identified five basic health-related objectives that must be realized if the cleanup is to be successful. These health-related objectives are interrelated and interdependent. It is unlikely that any single objective will be realized unless significant progress is made in all five. Five health-related cleanup objectives are discussed in the material that follows:

1. addressing current and future exposure threats,
2. identifying environmental characterization and research needs,
3. satisying community health concerns,
4. minimizing risks to cleanup workers and nearby residents, and
5. developing methods to establish remediation levels adequate to protect public health.

1. Addressing Current and Future Exposure Threats

Situations that pose a current threat of off-site exposure to toxic materials should be addressed immediately and efforts undertaken to contain all such contaminants and, where feasible, to eliminate exposure. Situations that represent a potential for future exposure should be addressed next, and so forth, until all toxic centarninants are either eliminated, securely contained and monitored, or reduced to levels consistent with the protection of public health.

To identify the most serious contarnination scenarios or to craft interim strategies to prevent current problems from getting worse, it will be necessary to assemble a reasonably complete qualitative picture of pollution at the Weapons Complex and to obtain at least preliminary data on human exposure and dose levels. Exposure estimates are key factors in evaluating the potential for, or past occurrence of, specific health impacts stemming from contamination at particular weapons sites. Obviously, health impacts cannot occur if people have no contact with toxic contaminants.

A picture of which contamination scenarios present the most significant or imminent threat of human exposure is likely to narrow the issues of urgent concern to a manageable number. Currently, there is no way of knowing which of the hundreds of areas of environmental contamination at the Weapons Complex are most pressing, or most in need of further study or interim containment action, because no complexwide strategy exists for relating environmental sampling data to possible health effects.

Until recently, only rudimentary methodologies were available for assessing individual exposure to environmental centaminants (296). More refined, multidisciplinary approaches to exposure assessment are now feasible and include sophisticated computer models that incorporate detailed environmental transport pathways, multiple human exposure routes, and demographic data of who is exposed to what. Efforts to validate such models with environmental sampling and biological monitoring (see app. D) have rendered them more reliable. In some cases, where contaminants can be detected in blood, urine, or exhaled breath, measurements of individual exposure can be obtained. These more accurate exposure models are not in wide use, however, and most biological markers of exposure remain research tools that are available for only a limited number of contaminants (297).

Exposure assessments will be included as components of the quantitative risk assessments required at all Superfund sites. Health assessments performed by ATSDR and also required by CERCLA will include assessments of how many people are potentially exposed to what toxic materials. However, these steps in the Superfund process usually do not occur until long (3 to 5 years) after environmental characterization is begun (298). Thus, many contamination scenarios within the Weapons Complex will not be subject to exposure assessments for years to come.

Whether weapons sites that are not Superfund sites will undergo formal exposure assessments *is* unclear. In addition, there is no assurance that the exposure assessments ultimately done will be of high quality. EPA, charged with the responsibility of reviewing all Superfund risk assessments, has not yet been granted the resources necessary to conduct credible oversight functions at the weapons sites.

Exposure assessments are difficult to execute and are not infallible. They will not provide a quantitative comparison of the relative risks of contamination scenarios across all weapons sites. However, as discussed, CERCLA risk estimates are not likely to establish a meaningful ranking of health risks either. Understanding where human contact with existing centamination is occurring, or is most probable, is the first step necessary to determine whether and where off-site health impacts are of concern. Robust exposure estimates are likely to be more attainable and less controversial than QRAs, and could provide, in a relatively short time, "first-cut" assessments of those areas of contamination that require immediate attention or further study. Refinements of initial exposure assessments could be carried out as additional environmental data become available.

2. *Identifying Environmental Characterization and Research Needs*

Situations requiring more in-depth characterization or further research should be identified early so that the requisite information is available when needed for remediation efforts.

The process of obtaining a detailed and accurate picture of the migration routes, concentrations, and chemical forms of environmental contaminants is time-consuming, *technically* demanding, and costly. It is important, therefore, that environmental characterization efforts be well planned and clearly linked to defined information needs. Preliminary qualitative exposure assessments and initial environmental monitoring data could be used to design strategies for additional environmental data collection and health studies, and they could also highlight issues suitable for further field or laboratory research.

The information needed to conduct health studies is often different from the data required to conduct a CERCLA risk assessment. Failure to think carefully about appropriate health issues or the methodology and design of proposed health studies and to plan for the acquisition of health-specific data may delay completion of the health assessment process.

Scientists working in multidisciplinary teams would be more likely to recognize the potential health implications of early environmental monitoring results and to anticipate the additional information needed to assess possible health impacts or design remediation actions. Such a multidisciplinary approach could sharpen the focus of environmental sampling efforts and might help to contain costs or, at least, to establish whether proposed investments of time and money serve a useful purpose.

3. Satisfying Community Health Concerns

When the cleanup is complete, communities should be satisfied that good-faith efforts to achieve comprehensive analyses and effective mitigation of all significant past and present off-site health impacts have been carried out.

It is essential that the public see decisions about health impacts, cleanup strategies, and remediation goals as fair and credible. No matter how much money or effort is expended on the cleanup, many areas of great uncertainty and many controversial issues will remain. For example, situations may exist in which the best scientific analyses indicate that the safest course is to leave contaminants undisturbed, at least until improved remediation technologies are available. Some communities are likely to contest and resist such findings, however, unless the decisionmakers are perceived as unbiased and mindful of potential health and environmental impacts.

Forums for eliciting community views and ideas will be needed. The concerns that preoccupy communities neighboring weapons sites have not been addressed effectively and are unlikely to be resolved solely by compliance with environmental regulations (see figure 3-l). It is ATSDR policy to consult with local communities as part of every health assessment done at Superfund sites. However, ATSDR is unlikely to have the resources necessary to implement this policy fully. Serious and sustained efforts will be required to educate community members about technical aspects of the contamination, proposed remediation plans, and associated problems or scientific uncertainties. Similarly, DOE managers and technical experts must solicit, acknowledge, and respond to the health concerns of local communities.

Unless measures are taken to recognize and respond to the health concerns of community members, disputes over the details of regulatory compliance will likely become the focus of attention and the courts will be the arena of negotiation. Repeated challenges to the adequacy of proposed remediation strategies, along with demands for examination of and compensation for the consequences of releases from the Weapons Complex, are likely to occur. Such challenges could significantly delay the cleanup and increase costs.

4. *Minimizing Risks to Cleanup Workers and Nearby Residents*

Characterization and remediation activities should be conducted so as to avoid subjecting cleanup workers or off-site residents to greater health risks than those posed by the pollution itself.

The collection and analysis of some weapons site centarninants, such as the highly radioactive waste stored in tanks at Savannah River and Hanford, may impose significant risks on cleanup workers. Disturbing some buried waste or contaminated sediment may prove more dangerous to humans and more disruptive of local ecosystems than leaving the contamination in place.

Risk Assessment Guidance for Superfund does not stipulate that the risks to cleanup workers or the public as a consequence of environmental sampling or remedial actions be addressed explicitly. The need to consider possible adverse impacts of cleanup activities is obvious, however, and it would be useful to analyze these issues in a disciplined and organized way. DOE and EPA have stated that they intend to consider these factors, but no rigorous approach has yet been formulated.

5. *Developing Methods To Establish Remediation Levels Adequate To Protect Public Health*

Methods of measuring the threat of contamination and the progress of the cleanup should be developed and utilized to determine when remediation efforts are sufficient to protect public health.

DOE has stated that it is not clear what levels of centamination will be considered “clean enough” to satisfy regulators. Some situations, notably contamination of soil and sediments by radionuclides, have not yet been addressed by Federal law. In many cases throughout the Weapons Complex, decisions about appropriate cleanup levels are likely to be controversial, largely because insufficient information exists to predict the health consequences of centamination. Reliable exposure data, including estimates of future exposure potential, would be helpful in such debates. If no one is exposed to, or likely to come in contact with, certain contaminants, there is at least the opportunity for careful study and discussion of alternative remediation strategies while the contaminants are securely stored and monitored.

In addition, methods of verifying the accuracy of risk estimates should be considered and applied to situations that present the highest risks or are attended by a great deal of uncertainty. There is no ready method for accomplishing this goal, but means of assaying the efficacy of remediation efforts, possibly involving ecotoxicological analyses, should be considered and developed to gauge the progress of the cleanup and to inform future remediation decisions.

CONCLUSION

Off-site health impacts are an unproven but plausible consequence of environmental contamination from the Nuclear Weapons Complex. Published reports and available data can neither demonstrate nor rule out the possibility that adverse health effects have occurred or will occur as a result of weapons site pollution. Investigations beyond those already completed will be necessary to pursue questions about the occurrence of off-site health effects and to produce the information required to identify the most pressing cleanup priorities.

DOE has barely begun to gather the data that would indicate whether off-site populations are exposed or likely to be exposed to contaminants from the Weapons Complex. DOE has not organized a coherent strategy to address the possibility of off-site exposures to toxic materials from the weapons sites or to investigate the possibility of health effects resulting from such exposures. Instead, DOE has maintained that the contamination poses no “near-term’ or “immediate’ health risks and is relying on the site-specific health studies called for by environmental laws and regulations to disprove the threat of long-term or chronic health impacts. This approach may prove troublesome in a number of ways.

Limitations in the scientific understanding of the adverse health impacts due to environmental toxicants make it difficult to establish conclusively the safety or degree of hazard associated with many exposures to environmental pollution. Existing chemical- and rnedia-specific environmental standards address only a limited number of contaminants and pollution scenarios and, in some cases, were never intended to connot "safe" levels of exposure. Compliance with chemical- and media-specific standards will still leave many of the complicated situations at the weapons sites unaddressed and may fail to ensure protection of the public health in all cases.

The array of site-specific health studies stipulated by CERCLA and various IAGs is aimed at determining the nature and degree of health risks associated with environmental centamination. The CERCLA-mandated quantitative risk assessments will command much attention and resources. The data intensive nature of QRAs, the long timeframes required to collect and analyze such data, and the technical uncertainties associated with the risk assessment process make QRAs problematic as a framework around which to organize cleanup activities and will render decisions based on risk estimates vulnerable to controversy and dispute. As the QRA process is currently conducted, it does not encourage community participation or acceptance, a factor that will weigh heavily as the cleanup proceeds.

Although the creation of risk-based cleanup priorities is an attractive goal, CERCLA risk estimates may not be effective vehicles for constructing a reliable hierarchy of health risks. The failure of risk assessors throughout the Weapons Complex to use consistent inference assumptions and the great uncertainties associated with many aspects of the risk assessment process will make comparison of risk estimates very difficult.

It may prove more useful to base immediate cleanup priorities on analyses of whether and which centarnination scenarios pose a potential for causing off-site exposure to toxic materials. The difficulties of deterrnining the occurrence and extent of individual exposure to environmental toxicants are considerable, but some effective methods do exist for conducting such assessments. Given adequate resources, access to data, and appropriately multidisciplinary staff, preliminary exposure assessments at the weapons sites could be conducted relatively quickly.

Although OTA did not evaluate site-specific environmental characterization data in detail, it is unlikely that a great many areas of contamination throughout the Weapons Complex pose a clear and signnificant threat of exposure to the off-site public. Comprehensive and scientifically rigorous exposure assessments would probably reveal that only a small number of the thousands of areas of contamination present the risks of human exposure. Such assessments could thus provide a scientifically credible foundation for identifying health-based characterization and cleanup priorities.

The scientific challenges involved in linking particular exposures to specific health outcomes are formidable. The information available to OTA indicates that the most probable off-site exposures will involve exposure to low doses of contaminants occurring episodically or over long periods. Scientific understanding of what, if any, biological effects result from such exposure patterns is very limited. Therefore, it is important that health studies investigating such linkages be carefully designed and take advantage of all available research techniques and scientific talent. Poorly designed studies are likely to yield ambiguous or misleading results and to further alienate an already skeptical public.

The ATSDR health assessment effort is problematic because it does not appear to be supported by sufficient resources to ensure that completed assessments are comprehensive and scientifically sound. In some instances, health studies negotiated in interagency agreements, or initiated at the request of individual States, may accomplish some public health objectives at individual sites, but the quality and scope of such studies are likely to vary across the Weapons Complex. It remains unclear whether State-sponsored health studies agreed to in IAGs will proceed if DOE fails to obtain appropriations adequate to its commitments.

The fundamental problem involved in assessing the off-site health effects due to pollution at the Nation's nuclear weapons sites is not, however, simply a matter of uncertainties or gaps in the science but has much to do with the coherence and credibility of the process employed to carry out such assessments. The responsibility for conducting off-site health evaluations is currently dispersed among several Federal and State agencies, none of which has sufficient staff or resources to effectively design, coordinate, or oversee the conglomeration of site-specific health studies called for by law or inter-agency agreements. The available talent in environmental health sciences is limited; government agencies must have access to the expertise available throughout government and in the academic and private sectors if state-of-the-art research methods are to be employed. If professional and other resources are not efficiently utilized and coordinated, State and Federal agencies will be competing against each other for funding and expert advice. This situation is likely to affect the caliber of health studies performed throughout the Weapons Complex, increase the likelihood that some studies will be of poor quality and, by inciting controversy and demands for repeated studies, increase the overall costs of the cleanup.

The current processes and procedures for conducting site-specific health studies lack adequate forums for allowing members of affected communities and the interested public to voice their concerns. The fear and anger that now beset some communities surrounding weapons sites must be replaced by a realistic appreciation of what is known and what is uncertain about past or current health risks from decades of nuclear weapons production. The public must understand the appreciable difficulties involved in studying the potential health effects associated with particular waste sites. Definitive answers to some important questions may simply not be attainable with existing research methods. A process is needed that would assist affected communities or their representatives in understanding the technical details and uncertainties of environmental characterization and health assessments; and that would permit the affected public to participate in weighing the tradeoffs implicit in making cleanup decisions and in setting priorities.

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Policy Initiatives To Improve Cleanup Prospects

IMPROVING PROSPECTS FOR CLEANUP

The waste and contamination problems at the Department of Energy (DOE) Nuclear Weapons Complex are serious and complicated, and the resources required to deal with them are great. Citizens at the community and national levels have expressed concern about the potential health and environmental impacts of conditions at the complex, urging that sites be cleaned Up to minimize the risks. The present state of technology, however, does not offer reliable techniques with which to characterize and remediate contaminated soil or water, or to safely treat, store, and dispose of accumulated waste. Nor have waste disposal standards and cleanup levels that protect public health and the environment been developed, agreed to, or applied at each site. Also, it is unlikely that the necessary technology and resources will be available to meet the requirements for site characterization and for interim containment or long-term remediation.

A key issue in evaluating the prospects for cleaning up waste and contamination at the Weapons Complex is whether the strategies and priorities for waste management and environmental restoration being pursued by DOE and other involved parties will actually result in cleanup and attain public acceptance. The responsible State and Federal agencies are attempting to carry out their legally mandated responsibilities with respect to waste management and environmental restoration at the Weapons Complex. However, they have yet to develop an effective process for making sound and credible policy and technical decisions about cleaning up waste and contamination problems at the sites. Adequate personnel and "infrastructure" are lacking. Also missing is continuous and effective coordination within and among the government agencies that have operational, research, or regulatory responsibilities affecting cleanup of the Weapons Complex.

As presently organized, the cleanup lacks a credible and reliable approach to identify and reduce potential public health risks and to effectively address community concerns about health impacts. The absence of a coherent strategy for evaluating potential off-site human exposure to Weapons Complex waste and contamination, or for understanding the possible health effects of such exposure, will make it difficult to establish health-based cleanup priorities. Failure to address health concerns in a comprehensive, scientifically rigorous, and open manner may erode public support for the cleanup.

A fundmental problem underlying present cleanup efforts is a lack of credibility that stems from past failures by DOE and its predecessor agencies to deal effectively with environmental contamination and to make full public disclosure regarding the impacts of those failures. DOE's efforts to achieve credibility may be hindered by the continuing lack of effective public involvement in waste management and environmental restoration decisions, and by its self-regulatory role in many activities pertaining to radioactive waste.

For these reasons, the Office of Technology Assessment (OTA) finds that prospects for effective cleanup of the Weapons Complex in the next several decades are poor and that significant policy initiatives are required if those prospects are to be improved. The objectives of such initiatives should include the following:

1. improving the performance and coordination of DOE and other Federal and State government entities involved in conducting or regulating waste management and environmental restoration activities;
2. conducting human exposure assessments and other health studies that would provide a scientifically sound basis for establishing immediate remediation and information needs and establishing processes to address the speific health concerns of communities around the weapons sites;
3. enhancing the credibility and public acceptability of the decisionmaking processes for waste cleanup at each site; and
4. eliminating self-regulation by DOE over radioactive waste management.

OTA believes that the policy initiatives outlined below could help meet the objectives and improve cleanup prospects.

POLICY INITIATIVES

The following policy initiatives could enhance current cleanup prospects by improving the decisionmaking processes, performance, and credibility of responsible agencies:

I. Increase congressional oversight of environmental restoration and waste management activities that require improved performance by the responsible agencies.
II. Enhance the structure and process for assessing potential public health impacts from Weapons Complex waste and contamination in order to evaluate the possibility of off-site health effects, develop health-based priorities, and address community health concerns.
III. Develop a structure and process to provide public participation in key cleanup policy and technical decisions in order to enhance the credibility and quality of those decisions.
Iv. Establish a national mechanism to provide outside regulation of DOE radioactive waste management programs in order to enhance the effectiveness and credibility of those programs.

The following discussion explains the rationale for these policy initiatives and evaluates some possible approaches to implementing them.

I. Increase Congressional Oversight of Environmental Restoration and Waste Management Activities That Require Improved Performance by the Responsible Agencies

Congress could increase its oversight of DOE and other Federal agencies to ensure that the agencies implement existing legislative authority to effectively conduct and properly coordinate activities relating to waste management and environmental restoration activities.

Congressional oversight could usefully be directed toward encouraging agencies to improve their performance in the following areas, which could benefit from prompt attention:

1. strengthen agency personnel,
2. plan for safe waste storage,
3. improve technological development processes,
4. increase public access to information,
5. coordinate and accelerate standard-setting, and
6. strengthen site monitoring programs.

1. Strengthen the Personnel of Involved Agencies To Conduct Waste Management and Environmental Restoration Programs

DOE has begun to address centamination problems due to past releases of waste at Weapons Complex sites. Activities to date include restructuring relevant parts of the Department, preparing a Five-Year Plan that includes environmental restoration and technological development programs, and negotiating agreements with the Environmental Protection Agency (EPA) and the relevant States pursuant to regulatory requirements under the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). However, actual characterization of sites is just beginning, and hardly any remediation has been accomplished.

A major problem highlighted by DOE in the 1990 Five-Year Plan is a serious shortage of qualified personnel in DOE, EPA, and other involved Federal and State agencies required to manage and carry out waste management and environmental restoration programs. Some environmental restoration projects and activities will involve judgment, talent, and expertise currently in very short supply.

The skills involved in weapons production do not encompass all of the multidisciplinary expertise necessary for dealing with environmental restoration problems or properly supervising contractors that conduct the cleanup. DOE will need to retrain many existing personnel. In addition, DOE and the Federal and State regulatory agencies must recruit and train significant numbers of outside personnel with the necessary skills to accomplish the goals of environmental restoration in a timely manner. Specific plans are necessary to begin developing dedicated, technically proficient managers and teams that can work effectively and cooperatively throughout the waste management and environmental restoration process.[1]

To that end, DOE, EPA, and other involved Federal agencies, in cooperation with the States,

[1] Congress has recently enacted a program to strengthen national defense science and engineering education. See National Defense Authorization Act for FY 1991, (the "Act") Pub. L. No, 101-510, §247 (1990); H.R. Rep. No. 101-923, 101st Cong., 2d Sess., at 38 (1990).

could prepare a coordinated plan that identifies personnel needs for the cleanup program and outlines a process for developing the cadre of professionals required in these areas.[2]

2. Plan for Safe Storage of Waste

For many years, DOE has been developing plans and programs to dispose of the stored high-level waste (HLW) and transuranic (TRU) waste at weapons sites. Some of the facilities that are key to those programs—such as the Waste Isolation Pilot Plant (WIPP) in New Mexico and the vitrification plant at Savannah River-have been constructed. However, many of the assumptions underlying DOE's waste management plans have now changed. For example, repository delays have affected key aspects of DOE strategy for the disposal of high-level and transuranic waste. Also, regulations for storing mixed waste require changes in some of DOE's earlier plans.

These and related developments require that more attention be devoted **to** storing waste safely on-site for a longer period of time. The potential release of toxic materials from all types of waste stored on-site for long periods should be monitored, evaluated, and prevented. DOE is just beginning to consider the implications of these longer on-site storage requirements.

High-1evel waste is now expected to remain on-site for more than 20 years (in tanks or, later, as glass logs). An important issue is whether the planned vitrification operations at Savannah River and Hanford will result in a waste storage system that will meet all requirements for long-term safe operation should the opening of the planned deep geologic repository continue to be delayed.

Also at issue is whether vitrification will proceed at a pace adequate to prevent or reduce the adverse impacts of HLW tank storage at the weapons sites. A related issue is whether the capacity and integrity of certain tanks are adequate to store additional liquid waste generated during the production of new weapons materials or the processing of old ones pending vitrification of existing tank waste. A more pressing and specific concern is whether the potential explosion hazard of the Hanford tanks can be satisfactorily dealt with until the vitrification facility at Hanford becomes available (10 years or more in the future).[3]

An issue with respect to transuranic waste is whether it can continue to be stored **at current** facilities and in some of the older drums for the years required until WIPP is operational. There may be technical and regulatory limits on how long the waste can be stored safely in its current form. This suggests the need to investigate further whether a portion of that waste should be repackaged, treated, or stabilized in some way while it awaits transportation to, and disposal at, WIPP.

In addition, regulatory and technical issues relating to mixed waste at the weapons facilities may not be resolved for some time. Unfortunately, there seems to be no quick or easy solution to this problem because the mixed waste must remain in controlled storage until it has been fully characterized, adequate treatment capacity has been designed and built, and proper operating permits have been obtained from EPA or the States. Without construction of additional treatment capacity, DOE's future storage capability may have to be increased.

To enhance prospects for safe on-site storage of waste, DOE could prepare a detailed plan for long-term storage of high-level and transuranic waste and for storing and treating mixed waste.

3. Improve Technological Development Processes

The capability of existing technologies to clean up or even contain Weapons Complex contamination is uncertain. For some problems, no proven technologies exist at all. Developing more effective technologies for remediation, or even containment, will be a slow and difficult process. For all practical purposes, that process is just beginning.

The availability of effective technologies, when needed, for interim as well as long-term remediation depends on whether DOE can establish a technological development process focused on solving the most immediate, intractable problems hindering

[2] Section 3135 of the Act directs the Secretary of Energy to develop a comprehensive 5-Year plan for the management of environmental restoration and waste management activities at DOE facilities, including a description of management capabilities and resources to carry out the plan, and submit a report to Congress on this management plan by June 1, 1991. (See supra note 1, at 262).

[3] Section 3137 of the Act directs the Secretary of Energy t. report t. Congress on actions taken to promote the safety of these tanks and the timetable for resolving outstanding issues on how to handle the waste in such tanks. (See supra note 1, at 363)

effective cleanup. DOE has created an Office of Technology Development to conduct research pertinent to the Weapons Complex cleanup. The present challenge for DOE, EPA, and the States is to improve the slow rate of introduction of new technology that has prevailed over the past decade and to adequately test the effectiveness of available technologies. New technologies must meet existing or anticipated cleanup standards, must focus on reducing public health and environmental risks, and must be developed in a process involving the public.

The procedure for developing and implementing more effective technologies could be improved by more open analysis of the requirements and alternative solutions for the most important cleanup problems. More focused and long-term support should then be devoted to testing and evaluating the most promising technologies identified. EPA and the States may need increased support to participate in the technology testing and evaluation process.

In addition, the technological development process must be driven by cleanup needs rather than by the skills of the current work force or the traditional expertise within the DOE national laboratories. Careful decisions should also be made regarding when—and under what circumstances-it would be beneficial to involve the private sector in the development, testing, and implementation of technology. If the large investment of effort and funding now planned for technological development can be focused on the most critical problems requiring technical solutions, the likelihood increases that such an investment will be worthwhile.[4]

To achieve these objectives, DOE could accelerate efforts to structure a program clearly identifying immediate technological needs and to develop timely solutions to address the more urgent contamination problems.

4. Increase Public Access to Information

Public dissatisfaction stemming from past events at the Weapons Complex may limit what can be accomplished in the cleanup. In particular, the distrust of DOE (and, to a lesser extent, of other involved agencies) by many affected and interested parties pervades much of the discussion of cleanup issues. That distrust results largely from the failure of DOE, or predecessor agencies, to responsibly manage weapons waste. It also stems from DOE's failure to disclose information relevant to safety, health, or other impacts of Weapons Complex operations and from a mode of classifying information that shielded DOE's problems in environmental, health, and safety areas from outside scrutiny. Many affected and interested parties are thus skeptical about the accuracy and reliability of DOE's statements regarding the cleanup.

DOE has made some efforts to overcome this public image, and initiatives at the very top of the organization to change the Department's past "culture" are cited as evidence of its change in attitude. Although these positive developments may improve future prospects to some extent, they are probably insufficient to overcome the lack of credibility that still attaches to many DOE efforts. These efforts also continue to be hindered by the slow process through which information relevant to waste management or environmental restoration is separated from classified information and made available to the public.

DOE should open its cleanup activities to full public scrutiny and aggressively expand its effort to inform the public about waste management and environmental restoration activities. As a first step toward this end, Congress could direct DOE to institute new procedures to provide the public with all information relevant to waste management and environmental activities, including all documents and reports dealing with past releases of contaminants to the environment, especially at the site-specific community level.

To increase public access to information, DOE could accelerate its declassification efforts relevant to waste management and environmental restoration. DOE could also institute improved procedures to make requested material available promptly and to continually update mailing lists for the purpose of notifiing interested parties of meetings, hearings, comment periods, and the availability of new materials.

5. Coordinate and Accelerate Standard-Setting

Adequate standards, especially those for radioactive soils and sediments and mixed waste, are not being developed in a coordinated and timely man-

[4]Sections 1801-03 of the Act establish the ' 'Strategic Environmental Research and Development Program,' to provide support for basic and applied research and development of technologies that can enhance the capabilities of DOE (and the Department of Defense) to address environmental concerns, including environmental restoration. (See supra note 1, at 277)

ner. Regulations governing the allowable amounts of radionuclides in soil have yet to be developed, and prospects are dim that such regulations will be available soon. In addition, important elements of EPA's radiation protection standards for the disposal of high-level and transuranic waste are undergoing revision, and when they will be available for public comment is unknown. Mixed waste standards have been developed principally for the hazardous component of that waste, with little coordination between EPA's hazardous and radioactive waste specialists or between EPA and other agencies. Expertise for different aspects of standards is scattered throughout the Federal Government.

To *improve and accelerate the standard-setting process as it applies to the Weapons Complex, DOE, EPA, and other involved agencies could establish more effective coordination mechanisms among and within agencies and assign appropriate personnel to set, apply, and enforce health-based standards incorporating current information about the public health impacts of both radioactive and hazardous waste.*

6. Strengthen Site Monitoring Programs

Hundreds of waste management units within each of the weapons sites contain complicated mixtures of radioactive and hazardous centaminants. The centamination is very site-specific, and major uncertainties exist about its nature, location, and impact. The enormous amounts of contaminated soil and water are especially difficult and time-consuming to assess and remediate with existing technologies.

Although a few technologies to prevent contamination from migrating are being used (e.g., capping soils or pumping and treating centaminated groundwater), long-term monitoring is necessary to ensure centainment. Long-term operation of some groundwater ''pump and treat' measures will be necessary to reduce centaminants to desired levels.

Current prospects for DOE's environmental restoration efforts indicate that much of the existing contamination at weapons sites will remain unremediated for decades. Among the environmental restoration decisions to be made is whether contaminated soil, sediment, or buried waste should be exhumed and removed from specific weapons sites (and, if so, where it should be treated or placed) or whether it should be treated and contained and remain on-site. The risks and benefits associated with each of these options should be evaluated with full public involvement.

Given current technical limitations, some contamination problems may not be cleaned up within the 30-year timeframe put forth by DOE, and other contamination problems may never be cleaned up fully. If some sites or portions of sites cannot be cleaned to the point of unrestricted use, institutional controls (including continuous monitoring and oversight, as well as notification and warnings) will be necesswy to ensure that the public and the environment are not adversely affected.

To *ensure that it deals effectively with uncertainties surrounding the environmental restoration process, DOE could strengthen its programs for monitoring and control of sites that may continue to have contamination.*

II. Enhance the Structure and Process for Assessing Potential Public Health Impacts From Weapons Complex Waste and Contamination

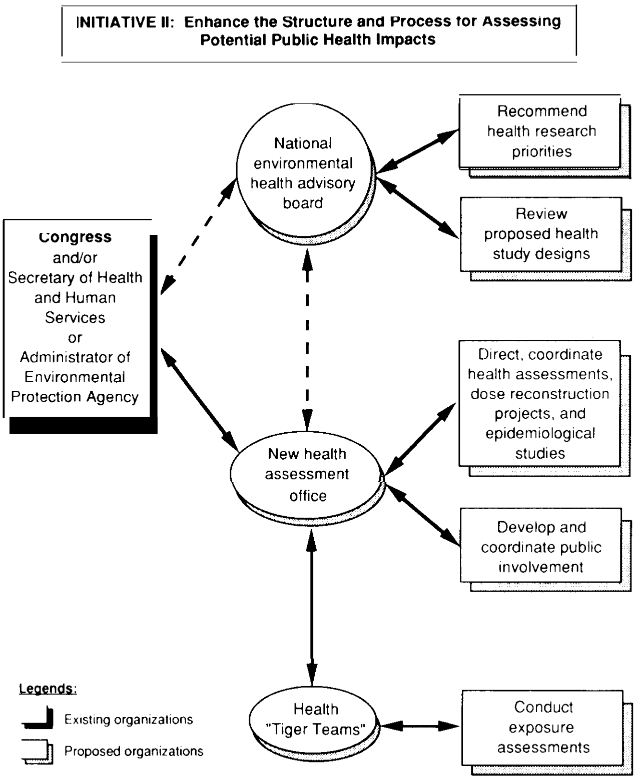
Congress could establish an institutional framework and process to effectively assess potential health impacts from the weapons facilities in order to evaluate the possibility of off-site health effects, develop health-based priorities, and address community health concerns.

This policy initiative could strengthen the assessment of potential off-site health impacts, improve the prospects that community concerns about possible off-site health effects are addressed, and provide a scientifically sound basis for developing health-based priorities. It could also help ensure that site-specific assessments provide a way to evaluate comprehensively the past, current, and potential public health impacts of contarnination. A new structure and process could accelerate scientifically rigorous exposure assessments to determine the most urgent or significant health issues posed by the contaminants.

To implement this policy initiative, Congress could consider all or some of the following approaches (see figure 4-l):

1. Establish a new office to direct and coordinate Federal risk assessments, health assessments, State-organized health studies, and dose reconstruction projects.

Figure 4-l-Organizational Diagram for Initiative II



SOURCE: Office of Technology Assessment.

2. Establish a new program to conduct site-specific assessments of whether and where weapons site centarninants pose a threat of exposure to the surrounding communities.
3. Establish a national, independent environmental health advisory board to provide guidance regarding exposure assessments, health effects evaluations, and health research needs.
4. Require DOE to make all information pertinent to possible health impacts, including data on past environmental releases and current centaminants, generally available.

1. Establish a New Office To Direct and Coordinate Federal Risk Assessments, Health Assessments, State-Organized Health Studies, and Dose Reconstruction Projects

No one agency or organization has the necessary authority to assess overall health impacts from Weapons Complex waste and contamination. There is virtually no coordination of CERCLA risk assessments, Agency for Toxic Substances and Disease Registry (ATSDR) health assessments, State-organized health studies, or dose reconstruction projects within or among the sites. Although DOE's recently established Office of Epidemiology and Health would, among other responsibilities, conduct community health studies, the focus and scope of such studies are unclear. Even if funding and additional personnel slots are approved, it is uncertain whether DOE can successfully recruit the required staff in the near future. Also, any community health study designed, conducted, or supervised by DOE is unlikely to achieve public acceptance.

To improve the present structure and process, Congress could establish a new health assessment office to direct and coordinate comprehensive health assessments at Weapons Complex facilities and to coordinate with DOE, EPA, the Department of Health and Human Services (HHS), and State health departments on all matters of potential public health impacts from these facilities. The new office could also develop and implement a process for identifying community concerns about potential public health impacts and for obtaining broad public involvement in these assessments.

The frost task of the new office should be to establish teams of environmental health experts (the health "Tiger Teams" described below) from government agencies, universities, and the private sector, to design and direct human exposure assessments at each of the weapons sites. The new office would be responsible for initiating and directing additional health studies, including dose reconstruction projects, based on the exposure assessment findings. These health studies could be designed and conducted by government staff or by scientists from universities and the private sector.

This approach addresses some of the deficiencies in the current structure and process of health assessments conducted by ATSDR and the States. For example, ATSDR is a small, understaffed agency, whose funds for conducting currently required health assessments at the Weapons Complex come from DOE, with whom it must negotiate an agreement before an assessment can begin at any particular site. Because of its current limited resources, ATSDR health assessments are likely to be too cursory to determine the existence or severity of health risks posed by contarnination, to provide a comprehensive baseline evaluation of current and potential public health effects, or even to identify areas in which more elaborate studies are required. State-sponsored site-specific health studies will vary considerably in comprehensiveness and sophistication. Not all interagency agreements incorporate funding for State-organized health studies. Also, although some States are planning to evaluate potential health effects at specific weapons sites, sufficient Federal funds may not be available to carry out such plans. Although anew Federal office might be viewed initially as impinging on State autonomy in health issues, it could ultimately help the States make more effective use of their resources by eliminating duplication and facilitating coordination among involved agencies.

By establishing a mechanism to direct and coordinate the various site-specific health studies, this initiative could strengthen the current approach to health effects evaluations. This would ensure that important questions about possible off-site health impacts of weapons site contamination are addressed, that research designs are adequate to the many methodological challenges faced by environmental health studies, and that the multidisciplinary talent in environmental health available in government agencies, academia, and the private sector is effectively utilized. It could also help achieve timely and effective resolution of urgent or sensitive public policy issues.

The new office can perform these functions most effectively if it is adequately staffed and has sufficient independence. The new office could be established within HHS, possibly as a new and separate office within the Agency for Toxic Substances and Disease Registry, or as an independent center within the Centers for Disease Control. The office could report directly to the Secretary of HHS and to Congress. Alternatively, the office could be established within EPA and report directly to the EPA Administrator and to Congress. Or, the new office could be established as a separate entity outside of any existing agency, and report directly to Congress.

The new office should be given the time and resources to secure competent leadership and the necessary expertise to succeed and to be accepted by concerned communities. Giving the new office independent authority and funding would eliminate the need to use scarce personnel time to negotiate MOUs (memoranda of understanding) and funding levels with DOE operations offices and thus avoid delays in initiating health studies. If the new office is given the resources to function well, it could help ensure that site-specific health evaluations conducted at each site are comprehensive, scientificlly sound, and credible to local communities. The office could also help avoid duplication of effort by different health agencies and encourage more efficient use of health experts or other scarce resources. In addition, it could provide an institutional memory for health-related lessons learned as the cleanup progresses.

There are important advantages to establishing an identifiable institutional focal point for weapons site health evaluations. By enhancing coordination and cooperation, the new office could promote a more efficient use of resources and scientific talent. By providing an opportunity for input from all segments of the environmental health professional community, the new office could ensure that the most effective research designs are used. By establishing consistent policies for community involvement in all stages of the health assessment process and permitting early identification of community health concerns, the new office could enhance the credibility of the assessment process and more efficiently resolve the concerns of local communities. By determining which areas or sources of contamination may pose the greatest threat of off-site exposure, the new office could provide a sound and reliable basis for formulating health-based cleanup priorities. Finally, by reporting directly to Congress and having access to agency heads, the new office can achieve enhanced visibility and signal that health issues are receiving appropriate attention in the cleanup effort.

2. Establish a New Program To Conduct Off-Site Exposure Assessments

The proposed health assessment office described above could be required to establish health “Tiger Teams” to conduct rigorous, comprehensive health assessments of the potential for human exposure to current waste and contamination at each site. Recruiting personnel for health Tiger Teams from the limited pool of available experts who can do this work may take some time, so the effort should begin as soon as possible. Team members could be drawn from government agencies as well as from universities and the private sector. Teams could have a duration of 3 to 5 years and might be organized in a manner similar to the Technical Steering Panel of the Hanford Environmental Dose Reconstruction Project (HEDRP). When constituted, the Tiger

Teams would require full and immediate access to weapons sites and all relevant data.

The health Tiger Teams could be directed to conduct several tiers of exposure assessments. Initial, first-cut assessments of any current contamination scenarios that might pose the risk of current or future human exposure could be made available in 6 to 12 months. If the teams discover situations that warrant immediate attention to protect public health, existing schedules, milestones, and finding priorities might have to be changed.

After the initial assessments, more refined studies could be performed as additional demographic and environmental monitoring data become available. Parallel with these efforts to assess the potential for exposure to current contaminants, separate exposure assessment teams could review source documents and historical emissions data to determine if further evaluation of historic releases or a formal dose reconstruction project is warranted.

Exposure assessments could better equip responsible agencies and the public with data that may be useful in developing and implementing health-based priorities in a timely manner. They could eventually provide a basis for developing a more workable, health-based priority system. Although health considerations are stated as top priority in the DOE Five-Year Plan, adequate data on potential health impacts are not available, nor does DOE have a strategy for acquiring or evaluating such data.

Exposure assessments conducted independently by health Tiger Teams could also guide Federal and State officials who negotiate interagency agreements in choosing among alternative schedules allowed under current laws and regulations. The assessments can also focus on problem areas that require additional environmental characterization efforts or immediate attention through interim remediation measures. As additional exposure information is developed, parties can reevaluate schedules and milestones in that light.

3. Establish a National, Independent Environmental Health Advisory Board To Provide Guidance Regarding Exposure Assessments, Health Effects Evaluations, and Health Research Needs

A national independent advisory board could be established to provide advice and guidance with regard to health assessments and studies relating to the Weapons Complex. The board could be composed of experienced environmental health scientists and report to Congress and to the Secretary of HHS or the Administrator of EPA. The board could provide guidance regarding the methodology and design of exposure assessments and health effects evaluations. It could also provide advice on health research needs related to the cleanup. As one of its first tasks, the national board could review plans submitted by the health Tiger Teams for conducting exposure assessments.

Although it maybe difficult for part-time advisers to grapple with the scope and complexity of weapons site issues, a prestigious national advisory board could still provide invaluable guidance and advice to decisionmakers. With its state-of-the-art environmental health knowledge and expertise, an independent, nongovernmental body could provide a structure for recognizing and coordinating health research needs, study designs, and strategies, and thereby advance the science of environmental health as it relates to problems posed by the Weapons Complex. The board could also provide advice and recommendations about the use of health assessment results to establish both short- and long-term health-based cleanup priorities.

4. Require DOE 10 Make Health Impact Information Generally Available

Congress could require DOE to make all data relevant to health impacts available to the scientic community without restriction or limitation. This would encompass data concerning past emissions and envircmmental releases, including previously classified data on these matters. In addition, Congress could require that the same information be made available to the general public.

At present, there are no clear requirements to ensure that health agencies such as ATSDR or State departments of health have access to DOE records relating to possible health impacts or to historical releases of radioactivity. Yet access to these records is important in understanding and assessing the potential impacts of existing contamination. Also, public perception of the scientific and political objectivity of health studies will be a major factor in its acceptance of reported findings or recommended actions. In the wake of growing indications that DOE failed to disclose past actions that endangered public health and withheld information on the adverse health effects of those actions, statements by

DOE or other government agencies on the health effects of current waste and contamination are likely to be suspect. Without full disclosure of information relating to health, including information on past releases, the public will likely have little confidence in the reliability of current or future health studies.

This initiative could involve additional resource requirements for DOE. Staff will be required to collect historical records and review them for national security implications prior to declassification. In addition, appropriate measures may have to be taken to minimize opportunities for misinterpretation. The investment of resources in this effort is important, however, if community concerns about health impacts are to be addressed. A community that has already experienced exposure may be at greater risk from current pollution than a community with no previous exposure. Until all information pertinent to total contamin ation exposure burdens on the population around sites is available, no reliable estimates can be made of relative health threats within and among sites. Release of this information should also bolster DOE's credibility and demonstrate its commitment to the "new culture" and to the protection of public health and the environment.

III. Develop a Structure and Process To Provide Public Participation in Key Cleanup Policy and Technical Decisions

Congress could establish at each site and at the national level an independent public advisory board to provide policy and technical advice with respect to key cleanup decisions and require the agencies involved to consider such input in order to enhance the credibility and quality of those decisions.

Despite efforts at cooperation by many of the involved parties-including environmental organizations, affected communities, the States, EPA, the present Secretary of Energy, and DOE officials concerned with the cleanup-the current process is inadequate to deal effectively with issues such as site characterization and remediation, cleanup priorities, or technological development. Further, it will be extremely difficult, and perhaps impossible, to dispel the legacy of distrust of DOE in time to foster the cooperative, consensual approach required if real progress is to be made in cleaning up the weapons plants. There is thus an overriding need for a decisionmaking process–-acceptable to all interested parties—through which public concerns can be addressed and resolved. Without such a process, large sums of public funds could be spent on activities that will not gain public acceptance or advance any important aspects of the cleanup.

By taking this policy initiative, Congress could supply the means to involve the public much more effectively in cleanup decisions. By encouraging independent input to the policy and technical aspects of those decisions at the site-specific level, this initiative could broaden the policy and technical review of cleanup efforts and foster a decisionmaking process that is open to scrutiny and credible to affected communities and to the general public. This is particularly important in light of the lack of credibility resulting from several decades of Weapons Complex operation pervaded by secrecy about, and apparent indifference to, potential health and safety impacts on workers and the public, and a persistent lack of willingness to comply with some applicable laws and regulations.

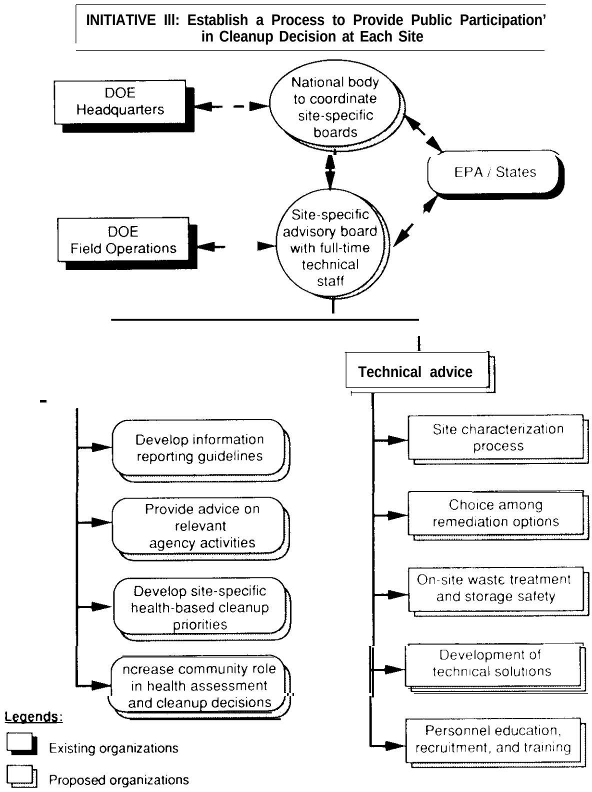
This policy initiative could help develop a meaningful role for affected communities and the general public in setting and implementing cleanup objectives and health-based funding priorities and could provide a process for involving the public in the development of site-specific environmental restoration priorities based on the results of health assessments by competent and independent bodies.

To implement this policy initiative, Congress could (see figure 4-2):

1. Establish advisory boards with full-time technical staff at each site to provide both policy and technical advice to DOE, EPA, and other involved Federal and State agencies.
2. Establish a national board to coordinate site-specific boards and provide advice to the headquarters level of involved Federal agencies.
3. Require DOE and other involved agencies to consult with the boards prior to making key decisions and report to the boards the manner in which their advice has been incorporated into those decisions.

The boards could provide a mechanism for helping to resolve fundamental policy and technical issues that continue to arise with respect to cleaning up past contamination, assessing and reducing public' health risks, and safely storing and disposing

Figure 4-2--Organizational Diagram for Initiative III



SOURCE: Office of Technology Assessment.

of past waste. By having access to the information, technical support, and other resources needed to participate effectively in key aspects of the cleanup, the boards could foster a process characterized by an openness, trust, and cooperation among interested parties that is not being achieved at present.

1. Establish Advisory Boards With Full-Time Technical Staff at Each Site

Congress could establish a board with full-time technical staff for each site (or group of sites in close proximity) in the Weapons Complex. These site-specific boards could provide policy and technical advice and guidance regarding key aspects of environmental restoration and related public health assessment to the responsible agencies and also recommend measures for expanding public involvement in these activities and in developing cleanup priorities.

The boards could be composed primarily of residents of the communities or regions in which a particular site is located. The size of the boards should be limited to promote efficiency and encourage participation. Board members could include representatives of community and environmental groups and Indian Nations in the area, as well as experts in relevant subjects, who would serve on either a full- or a part-time basis compatible with their occupations.

Board members could be chosen by, and report to, the Governors and Members of Congress from the respective States in which the sites are located. In addition, the boards could provide their advice and recommendations to the chief executive officers of DOE, EPA, HHS, and other involved Federal or State agencies. Advice could also be provided to the chief officer of the relevant regional entity (e.g., the head of the DOE Operations Office responsible for the site, the head of the EPA region in which the site is located, the head of the ATSDR division responsible for health assessments at the site, and heads of relevant State agencies).

The boards could be authorized to develop guidelines for relevant information to be reported to them by all involved agencies (including DOE, EPA, and ATSDR) and to require the agencies to provide information consistent with those guidelines. This authority would enable the boards to maintain continuing awareness of the relevant activities and upcoming decisions of these agencies.

The site-specific boards could provide policy and technical advice and guidance regarding key cleanup decisions, including, for example, those arising in connection with the conduct of site characterization; the choice among remediation options; the safe operation of waste treatment and storage conditions on site; the focus of technological development programs relevant to the site; the design and conduct of site-specific health assessments; the permitting of treatment, storage and disposal facilities; the development of interagency agreements; the application of ARARs (applicable or relevant and appropriate requirements) to the contaminated sites; and the preparation of National Environmental Policy Act documentation. Each board could also review the education, recruitment, training, and personnel needs of all involved Federal and State agencies and recommend measures for obtaining the professionals required at that site.

The boards could also help develop mechanisms for increasing the role of affected communities in the decisionmaking processes of involved agencies with respect to cleanup priorities at a particular site. To encourage development of a useful and acceptable priority-setting system for each site, Congress could direct DOE and other involved agencies to work with the boards to develop cleanup priorities that address community concerns and incorporate the results of off-site health assessments at the respective sites. The boards could thus play a key role in developing, with broad community input, site-specific, health-based cleanup priorities.

Establishing the boards should not delay the cleanup process. Progress on that work, which is at a very early stage, need not be interrupted while site-specific boards are established and the boards' activities could be conducted in parallel with the agency decisionmaking process. Any additional time the agencies might require to consider input from these boards prior to making decisions could well save time that could be wasted in furture confrontations if decisions are made and priorities set without meaningful public involvement.

The funding required to establish and maintain the boards would constitute a relatively modest portion of total cleanup expenditures. In fact, if the process is acceptable to the public and directs resources toward publicly acceptable decisions and priorities, cost savings could be realized.

2. Establish a National Board To Coordinate Site-Specific Boards and Provide Advice on National-Level Issues

In addition to site-specific boards, Congress could establish a national board to coordinate the site-specific boards and to provide advice and guidance regarding policy or technical issues affecting several Weapons Complex sites or the complex as a whole.

Designated persons from each site-specific board and other experts could constitute a national board that would meet periodically to coordinate the activities of site-specific boards and provide advice and guidance on matters that apply to more than one site, and on the national aspects of issues considered by site-specific boards, including technological development, personnel needs, and public involvement. The national board could also recommend health-based cleanup priorities across the Weapons Complex. The national board could prepare an annual report to Congress and the Secretary of Energy, integrating the advice and recommendations of the site-specific boards, drawing any relevant national implications, and making recommendations applicable to the Weapons Complex as a whole.

3. Require DOE and Other Involved Agencies To Consult the Boards Prior to Making Key Decisions and To Report Those Decisions to the Boards

To ensure that each board's input is duly considered by DOE and other involved Federal and State agencies, Congress could require those agencies to consult with the appropriate board on a regular basis prior to making key decisions and then to inform that board how its advice and recommendations were taken into account in arriving at the decision. Congress could either establish this requirement and direct agencies to comply or authorize the boards themselves to develop and enforce the requirement. The frequency of consultation could be specified in advance either by Congress or by the boards, or the boards could determine periodically what specific decisions they wish to consider.

Establishing strong public advisory mechanisms at the site-specific and national levels and requiring the agencies to consider, respond to, and incorporate such input in their decisionmaking processes might conceivably slow down some activities. Also, even with extensive public involvement, consensus on outcomes may not be easy to achieve. However, incorporating meaningful public participation into the cleanup process is a worthy goal in and of itself because credibility is required in that effort. Making cleanup decisions through a process that is open and acceptable to the public can go a long way toward achieving sound and credible outcomes.

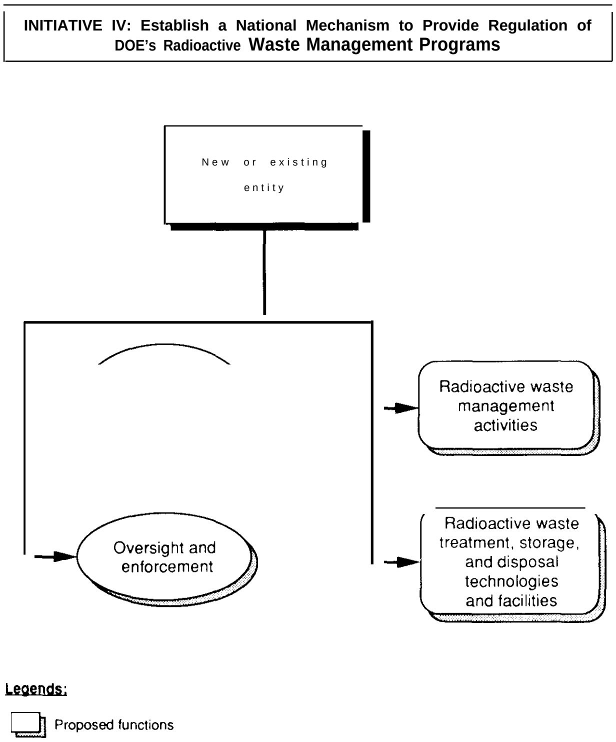
IV. *Establish a National Mechanism To Provide Outside Regulation of DOE Radioactive Waste Management Programs*

Congress could authorize an institution other than DOE to regulate those aspects of radioactive waste management activities now subject to DOE authority, and over which no other agency has authority, in order to enhance the credibility and effectiveness of those programs.

To implement this policy initiative, Congress could consider one of the following organizational options (see figure 4-3):

- Establish a permanent, fill-time, independent national commission and give it regulatory and enforcement authority with respect to radioac-

Figure 4-3-Organizational Diagram for Initiative IV



SOURCE: Office of Technology Assessment.

tive waste management activities at the Weapons Complex.

- Authorize an existing body to exercise those functions.

By limiting DOE self-regulation and providing appropriate independent regulation of radioactive waste management at the Weapons Complex, Congress could provide a credible and effective mechanism for addressing the issues, problems, and prospective solutions related to the safe treatment, storage, and disposal of existing and future radioactive waste.

To implement this policy initiative, Congress could require the new commission or existing body to:

- Promulgate rules and regulations, pursuant to ''notice and comment' and other relevant procedures of the Administrative Procedure Act,[5] applicable to radioactive waste management at DOE weapons facilities (including treatment, storage, and disposal of such waste) and governing the release of radionuclides.
- Enforce DOE compliance with promulgated rules and regulations.

Areas subject to such regulation could include vitrification and subsequent interim storage of high-level waste; immobilization and disposal of "low-level" waste from HLW tanks; storage, treatment, and disposal of TRU waste; and other high-level, transuranic, and mixed waste treatment or storage facilities. When promulgated, the rules and regulations would supersede any conflicting DOE orders or guidelines.

Under existing law, DOE regulates its own activities relating to certain aspects of the treatment, storage, and disposal of radioactive waste through orders (currently unmodified) that are not promulgated through "notice and comment' or other procedures set forth in the Administrative Procedure Act. These include many elements of the high-level and transuranic waste management programs for radioactive materials, on-site storage of radioactive materials, and various decisions concerning WIPP.

DOE has exclusive jurisdiction over radioactive waste storage practices at the Weapons Complex. With respect to mixed waste, even after the hazardous component is treated to levels specified by EPA, the management of any remaining radioactive components is still under the purview of DOE. An independent regulatory process could help ensure that on-site storage and disposal facilities are protective of human health and the environment and could thus increase public confidence in the absence of potential harmful releases from these facilities.

Also, under present practices, there is little or no independent monitoring or certification of certain aspects of DOE's high-level or transuranic waste programs. For example, DOE has sponsored all the evaluations of the integrity of the waste form produced through processes such as vitrification. Independent monitoring and external oversight of DOE waste management efforts would supplement the requirements of existing regulations and could enhance public credibility of DOE's efforts.

As proposed, the regulatory and enforcement functions would complement, but not supersede, the authority of EPA under existing laws and regula-

[5] 5 U.S.C.A. §§551-576, 701-703, 3105, 3344 (West 1977 and Supp. 1990).

tions over the treatment, storage, and disposal of the hazardous component of mixed waste at the Weapons Complex. Assignment of these functions to an agency other than DOE would, however, supersede much of DOE's exclusive authority under the Atomic Energy Act to regulate certain aspects of radioactive waste management. Transferring these regulatory and enforcement functions over radioactive waste management at the Weapons Complex to a body other than DOE would help address the deficiencies in the present system, particularly the credibility issues associated with current DOE self-regulation.

Congress Could Choose Among the Following Organizational Options

***Establish a New Commission*-Congress** could establish a permanent, full-time, independent national commission with regulatory and enforcement authority with respect to radioactive waste management activities at the Weapons Complex. Membership of the commission could include persons with expertise in technical, scientific, and other relevant fields to be appointed by the President upon nomination by Members of Congress, with input from Governors of affected States, leaders of Indian Nations in affected regions, and national and regional environmental organizations.

Establishment of a new body would obviously require startup time and new fimding. Time would be needed to recruit both the members and the staff of such a commission, who in turn would need time to establish their organization and procedures, and to review regulatory and technical information relating to the Weapons Complex that is relevant to their functions. On the other hand, a new entity to deal solely with the above-mentioned functions could perhaps focus more immediately and exclusively on providing the best regulatory and technical input to the current process than an existing body with other responsibilities.

***Assign the Functions to an Existing Body*—** Congress could authorize an existing body to exercise regulatory and enforcement responsibilities for radioactive waste management.

Assigning these functions to an existing body would avoid the time and costs involved in establishing a new organization and would draw upon existing organizational structures, capabilities, and skills. Additional staff and resources may have to be provided, however, to assist in carrying out new responsibilities. Although some startup time and additional costs would be necessary in connection with this option, the decisionmaking structure, and the institutional structure within which staff could be expanded, are already in place and might thus more quickly gear up to take on the additional functions. However, the viewpoints of constituencies or critics of any existing organization would have to be taken into account in considering this option. Existing modes of operation and relationships within the organization, with other Federal and State agencies, and with outside interested parties could affect the timeliness and effectiveness with which new responsibilities are carried out.

One body whose authority could appropriately be expanded to assume these types of responsibilities is the Nuclear Regulatory Commission (NRC). In addition to its regulatory and licensing authority over commercial nuclear power facilities, NRC is responsible for developing and implementing regulations to ensure public health and safety for storage of high-level radioactive waste (except for waste at the DOE Weapons Complex) and for final isolation of high-level radioactive waste and waste created in the mining of uranium ore. As such, it has extensive regulatory and licensing experience and technical capability. However, it would be necessary to address any new interagency coordination problem that may result if NRC were given authority over the radioactive portion of mixed waste while EPA retains jurisdiction over the hazardous portion.

Another agency whose authority could be expanded to cover these responsibilities is EPA. Because EPA already has regulatory authority over the hazardous portion of mixed waste, there maybe advantages in extending this authority to radioactive waste as well. In this way the sometimes difficult task of regulatory coordination between two agencies with split authority over the same waste could be avoided. EPA would need to add expertise in the radioactive waste area and make organizational changes to provide adequate technical and regulatory capabilities in this area. Therefore, startup time and new resources would be necessary.

Another possibility is the Defense Nuclear Facilities Safety Board (DNFSB), which already has the Weapons Complex under its purview for different purposes. The DNFSB was established by Congress to provide independent oversight regarding the safety of nuclear facilities and operation at the Weapons Complex. The Board, as presently constituted, functions as an advisory panel and has limited regulatory authority. The Board would also require additional staff and resources to carry out its new responsibilities.

CONCLUSION

Progress in cleaning up the waste and contamination at the Weapons Complex is being hampered by a paucity of data and qualified personnel, inadequate efforts to assess possible off-site health impacts, lack of ready technical solutions, and public skepticism about government agency decisions and activities relating to waste management and environmental restoration. The policy initiatives outlined above are aimed at improving and strengthening the decision-making process for setting and meeting cleanup objectives.

Increased congressional oversight could improve prospects for enhancing the agency irdiastructure, accelerating standard-setting, and providing more effective approaches to site characterization and remediation, waste storage and disposal, technological development, priority setting, and other aspects of the cleanup. The direction and coordination of site-specific health assessments by an independent and authoritative entity could improve prospects for achieving scientifically sound and credible evaluations of possible off-site health impacts, resolving community health concerns, and developing health-based cleanup priorities. Establishing site-specific advisory bodies to provide independent policy and technical advice could improve prospects for open, credible, and cooperative decisionmaking on key aspects of the cleanup. Substituting independent regulatory authority for DOE's self-regulation in radioactive waste management activities could enhance the credibility and quality of waste management decisions.

Although the cleanup will be a long and difficult task, OTA's analyses indicate that the policy initiatives outlined in this report could significantly improve the prospects that sound and credible cleanup decisions will be made.

Appendixes

Appendix A

Summary of Contaminated Sites and Initial Cleanup Work

INTRODUCTION

This appendix reviews the work underway throughout the Department of Energy (DOE) Nuclear Weapons Complex to identify and characterize contaminated sites, to comply with environmental laws and regulations, and to initiate cleanup projects. The Office of Technology Assessment (OTA) first assembled a report using data published in draft form by DOE during its 1987-1988 Environmental Survey and obtained through interviews with Environmental Protection Agency (EPA) officials in field offices who have been in charge of regulatory oversight at various weapons facilities. That report was then reviewed by DOE officials in headquarters and in the field.[1] This appendix, therefore, contains information deemed accurate by these sources as of July 1990.

The appendix is organized in two parts. The first part contains summary data concerning all facilities in the Nuclear Weapons Complex; the second part summarizes work at each facility. Because this is an overview, some specific data and some smaller sites have been omitted. These omissions were OTA's decision and were made to facilitate brief and direct presentation of status and trends throughout the Nuclear Weapons Complex.

ENVIRONMENTAL ASSESSMENT PROCESS

Prior to EPA becoming intimately involved in the assessment of media contamination problems at the Nuclear Weapons Complex (NWC) sites, DOE had initiated a program designed to address environmental problems and concerns. That program was the Comprehensive Environmental Assessment Response Program (CEARPS). Under CEARPS, DOE developed an approach for gathering information on current and past waste management practices. This program was initiated in light of the growing concern about contamination problems at DOE sites and the knowledge that remediation of contaminated areas would be required. The CEARPS program has been revised and is now referred to as the Environmental Restoration program.

In the early 1980's, EPA became involved with determining how DOE sites and waste management activities at those sites should be regulated under the Resource Recovery and Conservation Act (RCRA) or the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The level of coordination and cooperation between EPA and DOE has varied significantly from site to site. In general, the degree of cooperation and coordination between the two agencies was 1imited at first. However, during the late 1980's, DOE and ERA developed a better working relationship. Both agencies must work together to implement EPA's procedures for evaluating contamination problems under the RCRA and CERCLA programs. At present, DOE is, for the most part, assessing environmental problems as they would normally be assessed under either RCRA, CERCLA, or both. As a result, site assessment activities currently underway at DOE sites are at various initial stages of the environmental assessment process. DOE is progressing through EPA's sequential phases of site assessment in accordance with guidance documents for RCRA and CERCLA.

STATUS OF SITE ASSESSMENT ACTIVITIES

At all DOE sites, RCRA-regulated units have been identified and are in various phases of the RCRA process. For these units, work is proceeding in compliance with respective requirements and in accordance with project schedules. Units that operated under interim status either are closed, are in the process of closing, or have sought part B permits. Sites for which DOE submitted part B permit applications to ERA: 1) have had the part B permit application approved and issued (normally at sites requesting storage permits), 2) have had the permit application reviewed and returned to DOE for more information, or 3) are under review. The RCRA permit process that DOE is following is the same process followed by the commercial sector under the guidance developed by EFA.

All 14 of the sites selected for this OTA review are performing assessment work under one or more of the following regulations: RCRA section 3008(h) order, CERCLA section 120 Federal facility agreement, interagency agreement, triparty agreement, or RCRA permit. DOE is entering an "agreement in principle" for the Nevada Test Site. Eight sites are addressed under an interagency agreement in which RCRA and CERCLA activities are being implemented. Seven sites are implementing activities under RCRA. At those sites, CERCLA will be applied only if conditions can no longer be addressed under RCRA.

All sites will be conducting site assessment activities during the next 2 to 5 years or longer. At the larger sites,

[1] Letter and attachments from R.P. Whitfield, Associate Director, Office of Environmental Restoration Department of Energy, June 22, 1990, to Peter A. Johnson, OTA.

solid waste management units (SWMUs) are grouped together into "operable units." Thus, site assessment work for an operable unit will encompass numerous individual units and should result in the most efficient expenditure of resources. For example, under current plans, at Savannah River 313 SWMUs will be addressed as 44 separate units, at Mound Plant 73 SWMUs will be addressed as 9 units, at Rocky Flats 178 SWMUs will be addressed as 10 units, and at Hanford 1,500 SWMUs will be addressed as 78 units.

All sites either have completed or are conducting RCRA facility assessment and visual site inspection (RFA/VSI) or preliminary assessment and site investigation (PA/SI). All but one (the Nevada Test Site) have finished the first phase of this process, having completed either the RFA/VSI or the PA/SI. Identification of SWMUs is an ongoing process at the sites. As the RCRA facility investigation and CERCLA remedial investigation (RFI/RI) progress, additional SWMUs are discovered. This is not unexpected, due to the nature of past waste handling and disposal operation at DOE sites. At sites with both RCRA and CERCLA activities the two programs are working cooperatively. DOE personnel and EPA's RCRA and CERCLA personnel are jointly evaluating the results of work performed under each program to ensure that program requirements are fulfilled.

SITE CHARACTERIZATION

At all of the NWC sites, DOE will be conducting additional hydrogeologic characterization to adequately define subsurface conditions. DOE's first efforts have focused on characterizing site hydrogeology on a macro scale (regional). Additional characterization must be performed to understand the micro scale (site-specific) associated with either operable units or individual units. The major aquifers or water-bearing zones, which supply water that is suitable for drinking or other domestic purposes, are known on a regional scale. The microscale (e.g., local perched zones that provide sufficient quantities of water for domestic use) is not yet understood.

Knowledge of contaminant fate and transport is inadequate at most DOE sites. Therefore, DOE studies to better define contaminant fate and transport either have already begun or are scheduled to begin within the next 5 years.

GROUNDWATER CONTAMINATION

Most sites exhibit some groundwater contamination, but DOE has yet to assess the full extent of this contamination. In most cases the types and concentration of hazardous constituents must still be determined. DOE will be developing that information through the remedial investigation (RI) or RCRA facility investigation (RFI) process. At the majority of DOE sites, groundwater contamination has the potential to impact aquifers supplying water used for domestic purposes. DOE plans to assess the degree of risk posed by groundwater contamination to human health and the environment. Understanding contaminant fate and transport is a major concern and applies to all sites exhibiting groundwater contamination.

Six sites have initiated some sort of remediation process for removing and treating contaminated groundwater from certain areas. These involve pump and treat systems alone, or with French drains or interceptor trenches. Treatment consists of air stripping, ultraviolet light exposure, physical-chemical treatment, and ozonation.

SURFACE WATER CONTAMINATION

All weapons sites in nonarid locations (i.e., those that have a net positive water balance) either have confirmed or suspected surface water contamination. This results from several factors, such as contaminated groundwater discharge to surface water, point source outfalls, and nonpoint source discharge to surface water (due to precipitation on contaminated soil and subsequent erosion of soil particles to surface water). Some arid sites also have surface water contamination.

In several cases of confirmed surface contamination, the contamination has traveled off-site. DOE needs to determine more fully the degree of exposure and the potential risk that exposure poses to human health and the environment. In general, DOE must pay increased attention to surface water contamination. Hazardous constituents present in contaminated surface water have not been characterized fully, but DOE expects to provide that information through the RI and RFI processes.

SEDIMENT

At sites having old surface impoundments that accepted waste, or where surface water contamination is known to exist, sediment contamination is either suspected or confirmed. The extent of contamination is not fully known, but some off-site migration has occurred, and DOE is beginning to examine the extent of both onsite and off-site sediment contamination. This includes site-specific and waste-specific information concerning the environmental fate and transport of constituents in contaminated sediments. DOE is removing or stabilizing in situ contaminated sediments from some units in an attempt to clean and close those units.

SOIL CONTAMINATION

At all NWC sites, soil contamination is suspected or confirmed. In each case the full extent of on-site as well as off-site contamination has yet to be determined. By the

RI or RFI process, DOE will initiate activities defining the nature and extent of soil contamination, including gathering site-specific and waste-specific information on the environmental fate and transport of constituents in contaminated soils and conducting an exposure assessment to determine the impact on human health and the environment. DOE will initiate a program to define treatment and remediation strategies for handling contaminated soil. DOE's proposed methods of handling contaminated soil will be part of the corrective measures study (CMS) under RCRA or the feasibility study (FS) under CERCLA.

INDIVIDUAL SITE SUMMARIES

This section presents summary data concerning the following facilities in the Nuclear Weapons Complex:

- Fernald,
- Hanford Reservation,
- Idaho National Engineering Laboratory,
- Kansas City Plant,
- Lawrence Livermore National Laboratory-Main Site,
- Lawrence Livermore National Laboratory---Site 300,
- Los Alamos National Laboratory,
- Mound Plant,
- Nevada Test Site,
- Oak Ridge Reservation,
- Pantex Plant,
- Pinellas Plant,
- Rocky Flats Plant,
- Sandia National Laboratory, and
- Savannah River Site.

Fernald

The Fernald site is listed on the National Priority List (NPL); therefore, environmental investigation and restoration activities are being addressed under CERCLA by an administrative order. A PA/SI conducted at the site identified several types of waste management units, including drum storage, tank storage, landfill, tank-incinerator, and surface impoundment.

Results of the PNSI led to several remedial investigations to identify contaminated groundwater, surface water, sediment, and soil. Contaminated groundwater poses the greatest hazard to human health and the environment because private, community, and industrial drinking water wells are affected by the contamination.

At present, five RIs are being conducted at the site. These will more comprehensively identify the types of contaminants, extent of contamination, and risks to human health and the environment from on-site units. The RIs are expected to be completed in stages ranging from 7 months to 2 or 3 years. Exposure assessments will be conducted to determine human health and environmental risks.

Table A-1 identifies the types of contaminants that have been released to the environment in the past.

Groundwater

Groundwater contamination has been confirmed both on-site and off-site. DOE has installed a pump and treat system to remediate on-site groundwater contamination. This pumping system sends contaminated groundwater to the on-site wastewater treatment plant, from which the treated water is discharged to surface waters, in compliance with the facility's National Pollutant Discharge Elimination System (NPDES) permit.

Surface Water

Surface water contamination has been confirmed. DOE has implemented some interim corrective measures. Storm water runoff is also being channeled into, and treated by, the wastewater treatment plant to reduce the impact on surface waters.

Sediment

Sediment contamination exists on-site and off-site; however, the full nature and extent of sediment contamination have not been determined.

Soil

Soil contamination has been confirmed at the facility. DOE has initiated interim measures by removing some contaminated soil in the production areas to reduce both surface and groundwater contamination. Future corrective actions will be conducted pursuant to the administrative order entered into by EPA and DOE.

Hanford Reservation

RCRA and CERCLA activities at the Hanford Reservation are being performed under a tri-party agreement (TPA) signed in May 1990 by DOE, the State of Washington Department of Ecology (WDOE), and EPA. Under this agreement, RCRA activities are performed under WDOE, and CERCLA activities under EPA as the lead agency.

The facility is separated into 78 "operable units" (OUs), about half of which are active units covered by RCRA and half are inactive units covered by CERCLA. The OUs include a total of 1,400 waste sites and four groundwater contamination plumes. The TPA outlines schedules for the investigation and remediation of all waste units. RCRA Part B permit applications have been submitted to WDOE for some of the RCRA-regulated units, but no operating permit has been issued to date. RFAs have been completed; RFIs and corrective measures are underway at some units.

Table A-l—Summary of Hazardous Substances Released to the Environment at the Feed Materials Production Center, Fernald, Ohio

Contaminant	Air	Soil	Surface water	Groundwater	Sediment
Radionuclides	Radon Radon-decay products Thoron[a] Uranium[b]	Radon Uranium		Cesium-137 Gross alpha Gross beta Neptunium-237 Potassium-40 Ruthenium-106 Strontium-90 Thorium-232 Uranium	Technetium-99 Uranium
Metals		Lead	Chromium	Barium Chromium	
Inorganic compounds	Hydrogen fluoride[c]		Cyanide	Chlorides Fluorides Nitrates Sulfates	
Volatile organic compounds (VOCs)	Perchloroethylene[d]	Perchloroethylene[d e] Trichloroethane[e]	Perchloroethylene[d e] Trichloroethane[e]	Perchloroethylene[d e] Trichloroethane[e]	
Miscellaneous	Particulates	Asbestos PCBs[f]	PCBs[f]	PCBs[f]	

[a]Although believed present, inappropriate methods have been used to detect the presence and Contamination Potential.
[b]Approximately 96 metric tons of this radioactive contaminant had been released up to mid-1986.
[c]An unspecified amount of this contaminant was released to the air from the uranium reduction plant (used for reducing UF_6 and UF_4) in January 1986.
[d]This VOC is also known as tetrachloroethylene or tetrachloroethene.
[e]The presence or potential contamination associated with this pollutant has not been fully determined.

SOURCE: U.S. Department of Energy, Office of Environmental Audit, "Environmental Survey Preliminary Report-Feed Materials Production Center, Fernald, Ohio," DOE/EH/OEV-1-P, March 1987.

PA/SIs completed for the CERCLA-regulated units identified 1,500 individual waste units. Of the 14 RI/FSs initiated thus far by DOE, only 2 (the 1100 Area and the 200 Area) have been approved by EPA. Field investigations under the RI/FS process are being conducted at these two operable units. No other RI/FS activities have been completed. The required risk assessments will be conducted at these and the remaining 76 OUs, as part of an overall Hanford risk assessment to address risks to human health and the environment.

Three major obstacles are inhibiting corrective or remedial action at Hanford. The first is the size and technical complexity of the site itself. The second is the difficulty and hazard of performing waste characterization analyses on samples known to contain hazardous and radioactive materials. The third is the high cost of characterization and remedial action. Although these obstacles have been identified at other weapons sites, they play a significant role at Hanford. The types of contaminants that have been released to the environment in the past are shown in table A-2.

Groundwater

The regional hydrogeologic regime is generally understood. However, additional hydrogeologic, waste characterization, and health risk assessments at the OU level are required to design appropriate remedial measures. Contaminants in groundwater have been identified. Tritium and nitrate contamination has been found in plumes totaling 122 square miles. Other pollutants have been detected in more localized groundwater areas at levels that exceed drinking water standards. Examples of these contaminants include carbon tetrachloride, chromium, cyanide, trichloroethylene, uranium, cobalt-60, technetium-99, iodine-129, and strontium-90. Most of this contamination has resulted from past waste disposal activities.

Wastewater containing hazardous and radioactive constituents continues to be discharged into the soil column at 33 Hanford locations. Although the radionuclide content is known, the nature and quantity of the hazardous components are being investigated. DOE plans to discontinue wastewater discharging into soil in June 1995. The underlying aquifer discharges to the Columbia River, which is a source of drinking water downstream of the site. Corrective actions for the contamination sources and groundwater pathways will be based on the results of investigations under the TPA.

Surface Water

Hanford Reservation is located in a desert climate. Preliminary studies indicate that only during the winter does significant rainfall permit surface water to infiltrate the soil and reach groundwater sources. The only two natural surface water features at Hanford are the Colum-

Table A-2—Summary of Hazardous Substances Released to the Environment at the Hanford Reservation

Contaminant	Air	Soil	Surface water	Groundwater	Sediment
Radionuclides	Argon-41[a] Radon-222[a] Strontium-90[a]	Cesium-137 Ruthenium-106		Cesium-137 Gross alpha Gross beta Iodine-129 Plutonium-239 Plutonium-240 Radium Strontium-90 Tritium	
Metals				Barium Cadmium Chromium Mercury	
Inorganic compounds	Ammonia[a,b]			Fluorides Nitrates	
Volatile organic compounds (VOCs)	Carbon tetrachloride[a]			Carbon tetrachloride[a] Chloroform Dichloromethane[a] Hexone[a] Methylcyclohexane[a] Perchloroethylene[c] Phthalates[a] 1,1,1-Trichloroethane	
Miscellaneous		Pesticide rinsate[a] Untreated wastewater[a d]	Untreated wastewater[a d]	Coliform Kerosene[a] Oil Pesticide rinsate[a] Temperature[e] Untreated wastewater[a d]	

[a]The present or potential contamination associated with current and past discharges of this pollutant has not been fully determined.
[b]Ammonia is released into the air by the plutonium Uranium Extraction facility (PUREX) located at the Hanford Site.
[c]This VOC is also known as tetrachloroethylene or tetrachloroethene.
[d]The direct discharge of untreated sanitary wastewaterand of process wastewaters containing radioactive and nonradioactive hazardous materials into the soil may have contaminated the soil and groundwater at the site.
[e]Changes in ambient groundwater temperatures have been caused by effluent cooling waters.

SOURCE: U.S. Department of Energy, Office of Environmental Audit, "Environmental Survey Preliminary Report-Hanford Site, Richland, Washington," DOE/EH/OEV-05-P, August 1987 and "Environmental Restoration and Waste Management Five-Year Plan for the Hanford Site—Predecisional Draft," April 1989.

bia River and Westlake. The presence of radionuclides in sediment from the Columbia River is attributed to DOE's past waste management practices. The total concentration of radionuclides contributed to river sediments by groundwater contamination at Hanford and the amounts that could be consumed by nearby residents are not known.

Sediment

Contaminated sediments are present in manmade ponds and ditches because of past disposal practices. These contaminants reach groundwater and the Columbia River. No treatment or removal is being performed at this time. Corrective actions under RCRA and CERCLA will be required to clean up contaminated sediments.

Soil

The extent of soil contamination with hazardous constituents has not been determined. The extent of radiological soil contamination, including vegetative uptake of radionuclides, is better understood. The environmental fate of the soil contamination has not been determined.

Idaho National Engineering Laboratory

In 1987, the Idaho National Engineering Laboratory (INEL) and EPA signed a section 3008(h) Compliance Order and Consent Agreement (COCA) to bring INEL into compliance with the permit and corrective action requirements of RCRA. In December 1989, INEL was added to the NPL of Superfund sites. As a result, EPA, DOE, and the State of Idaho are negotiating an agreement to integrate RCRA and CERCLA investigations and cleanup requirements. The agreement, which is to be developed under CERCLA'S section 120 is expected: 1) to supersede the COCA, 2) to define the responsibilities

Table A-3-Summary of Hazardous Substances Released to the Environment at the Idaho National Engineering Laboratory

Contaminant	Air	Soil	Surface water	Groundwater	Sediment
Radionuclides		Cesium-137 Cobalt-60 Iodine-131 Plutonium-238 Plutonium-239 Strontium-90		Iodine-129 Plutonium-238 Plutonium-239 Strontium-90 Tritium	Cesium-137 Cobalt-60 Strontium-90
Metals		Antimony[a] Beryllium Boron[a] Cadmium[a] Fluoride[a] Lead[a] Mercury[a] Palladium[a] Selenium[a] Thallium[a] Zirconium[a]		Beryllium Cadmium[a] Chromium Lead[a] Mercury[a] Palladium[a] Thallium[a] Zirconium[a]	Cadmium Chromium Lead Mercury
Inorganic compounds		Nitrates[a]		Hydrofluoric acid[a] Nitrates[a]	
Volatile organic compounds (VOCs)		Acetone[a] Benzene[a]		Acetone[a] Benzene[a] Carbon tetrachloride[a] Tetrachloroethylene[a] Trichloroethane[a]	
Miscellaneous		Asbestos[a] Fuel oil[a] PCBs[b]		Trichloroethylene[a] Asbestos[a] Fuel oil[a] PCBs[b] Sewage	

[a]The present or potential contamination associated with current and past discharges of this pollutant has not been fully determined.
[b]PCBs = polychlorinated biphenyls.

SOURCE: U.S. Department of Energy, Office of Environmental Audit, "Environmental Survey Preliminary Report—Idaho National Engineering Laboratory, Idaho Falls, Idaho and Component Development and Integration Facility, Butte, Montana," DOE/EH/OEV-22-P, September 1988 and "U.S. Department of Energy Technologies for Identification, Characterization, and Remediation of Environmental Contamination at Selected Sites," contractor report prepared for the Office of Technology Assessment, December 1989.

of the three agencies, and 3) to include schedules for conducting remedial actions.

Under the COCA, DOE has evaluated nearly 350 SWMUs. RFI work plans for two locations at INEL have been approved by EPA and are currently being implemented. Removal of contaminated sludge from an inactive injection well is being carried out as an interim measure.

RCRA part B applications have been submitted for most of the 180 active SWMUs. Although most of these SWMUs are generally in compliance, DOE will have to negotiate agreements with the State for certain high-level radioactive waste and transuranic mixed waste storage units to bring them into compliance. A schedule for submission of outstanding RCRA part B permit applications is being worked out with the State.

The Agency for Toxic Substances and Disease Registry has conducted on-site visits as part of a health assessment. CERCLA baseline risk assessments have been initiated at some release sites. Table A-3 identifies the types of contaminants that have been released to the environment in the past.

Groundwater

The Snake River Plain Aquifer underlies the 890 square miles of INEL at depths ranging from 200 to 1,000 feet. Although the hydrology of the regional aquifer is well understood, local flows at SWMUs are not sufficiently characterized to develop remedial actions, specifically where perched water and vadose zone contamination has occurred. DOE has identified three major sources of groundwater contamination: carbon tetrachloride and trichloroethylene from past waste disposal practices and radionuclides from reactor-related operations. An 8 1/2-mile-long (40-square-mile) plume of tritium has been identified at INEL; however, this radionuclide is barely detectable at the facility boundary. There is essentially no use of the Snake River Plain Aquifer many miles downstream of INEL.

Table A-4-Summary of Hazardous Substances Released to the Environment at the Kansas City Plant

Contaminant	Air	Soil	Surface water	Groundwater	Sediment
Radionuclides		Uranium[a]			PCBs[b]
Metals		Cadmium Chromium Copper Lead Nickel Zinc			
Inorganic compounds					
Volatile organic compounds (VOCs)	Trichloroethylene	1,2-Dichloroethene 1,2-Dichloroethane Toluene Trichloroethane Trichlorethylene	1,2-Dichloroethene Trichloroethene	1,2-Dichloroethane 1,1,1-Trichloroethane Trichloroethene Vinyl chloride	
Miscellaneous	Asbestos Methylene chloride Particulate matter[a]	Diesel oil and grease PCBs[b] Spent acids and plating wastes	PCBs[a b]	Diesel oil and grease Trichlorotrifluoroethane	

[a]The present or potential contamination associated with current and past discharges of this pollutant has not been fully determined.
[b]PCBs = polychlorinated biphenyls.

SOURCE: U.S. Department of Energy, Office of Environmental Audit, "Environmental Survey Preliminary Report—Kansas City Plant, Kansas City, Missouri," DOE/EH/OEV-11-P, January 1988 and "Comments on Site Summary" submitted by DOE on June 18, 1990.

Surface Water

Several intermittent surface water streams, including the Big Lost River, flow into INEL during the winter months and do not leave. A number of SWMUs located near the Big Lost River are protected from potential floods by diversion dams and dikes. INEL's surface waters contain no aquatic biota.

Sediment

Manmade impoundments and ditches at INEL contain sediment contaminated with chromium, mercury, oil, and radionuclides. These contaminants have also been detected in the Snake River Plain Aquifer.

Soil

Past operational and waste disposal practices at INEL have resulted in soil contamination at various locations within the facility.

Kansas City Plant

The environmental restoration activities at the Kansas City Plant are implemented under a RCRA section 3008(h). The authority of CERCLA is not being used but may be invoked in the future to address remedial activities not covered under RCRA.

The site has two closed surface impoundments and several storage areas. Although the standard RFA was not conducted at the site, DOE provided EPA with similar documents that included information normally contained in an RFA report. To date, 35 SWMUs have been identified under the consent order. Of these, 23 have been characterized as having no significant contamination and requiring no further action. The remaining 12 are active or are scheduled for investigation.

The facility is currently developing the required RFI work plans. DOE has already provided some plans to EPA, which has reviewed and commented on them. DOE has not developed a formal risk assessment for the entire facility. Table A-4 identifies the types of contaminants that have been released to the environment in the past.

Groundwater

Groundwater contamination has been confirmed. Under the section 3008(h) consent order, DOE is determining the extent of on-site and off-site contamination. Contaminants present in the groundwater are hazardous and nonradioactive. DOE has installed a pump and treat system for halting migration of the plume. The system includes interceptor wells with ultraviolet light, ozonation, and hydrogen peroxide as treatment processes. DOE has also excavated an interceptor trench to aid the withdrawal system. More than 100 groundwater monitoring wells have been installed on the 137-acre site.

No formal EPA order for conducting house-to-house evaluations of nearby private drinking water wells has been issued to DOE. However, comments by local residents on the real or perceived risks of contamination posed by the plant can be submitted to DOE through the community relations plan required by RCRA section 3008(h) and the facility's community outreach program.

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Surface Water

Some surface water contamination is suspected but not confirmed. One groundwater plume discharges to the Blue River. DOE is monitoring the river but has not found hazardous constituents above detectable limits. The entire site is located within the 70-year recurrence interval floodplain.

Sediment

The contamination found in sediments and soils associated with surface impoundments has been removed. Suspected groundwater contamination at the facility, however, is being investigated. High concentrations of polychlorinated biphenyls (PCBs) are known to exist in a former streambed (Indian Creek) adjacent to the site. Cleanup alternatives are being assessed by DOE and EPA.

Soil

Soil contamination has been confirmed in many areas at the site. DOE is in the process of evaluating areas in which soil contamination is likely. Soil gas analysis has been used to assist in detenninin g sample collection areas. However, the limited utility of the data obtained from this effort is probably due to the high clay content of the sampled soils. Where visual contamination was observed, the soil was excavated and disposed of as hazardous waste.

Lawrence Livermore National Laboratory—Main Site

The environmental activities at the Lawrence Livermore National Laboratory (LLNL) main site are being conducted under a Federal facility agreement (FFA) involving DOE, EPA, and the State of California. The FFA addresses the activities associated with identification and remediation of environmental problems that pose a threat to human health and the environment, in particular, soil and groundwater contamination caused by volatile halogenated hydrocarbons and metals at various spill sites and an inactive landfill. LLNL covers nearly 640 acres.

A RCRA facility assessment has been completed and, to the extent possible, SWMUs have been identified. However, because the laboratory is a Superfund site, the RCRA facility investigation tasks to determine the nature and extent of contamination associated with possible releases from SWMUs were incorporated into the CERCLA remedial investigation phase. The final "Draft Remedial Investigation Report" released by DOE on May 11, 1990 is now under EPA review. A baseline public risk assessment addressing the health risks associated with soil and groundwater contamination at the site was released the same day.

Groundwater

Extensive hydrogeologic characterization has been performed by DOE to define the extent of groundwater contamination. Although considered adequate by regulatory agencies, this characterization effort may be expanded to the study of contamination problems at selected SWMUs.

Contamination by volatile halogenated hydrocarbons has been confirmed in soil and groundwater on-site and beyond facility boundaries. Gasoline, organic lead, and chromium have been detected in soil and groundwater samples at concentrations exceeding background levels.

Approximately 20 local drinking water supply wells have been closed because of actual or suspected contamination by groundwater. As of June 6, 1990, more than 12,300,000 gallons of groundwater had been treated by one of two pilot treatment facilities to remove halogenated hydrocarbons. The removal of hydrocarbons is accomplished at the pilot treatment plant in a two-step process: the use of ultraviolet light and hydrogen peroxide to oxidize most of the hydrocarbons, followed by air stripping of the effluent water to extract the remaining halogenated hydrocarbons.

Surface Water

Surface water at the facility consists of two seasonal streams (which run only after infrequent periods of heavy rainfall) and a seasonal, manmade surface impoundment constructed by DOE for flood control purposes. The LLNL is a net negative water balance site where the minimum depth to groundwater is 30 feet. Thus, there is no likely path for the observed contamination of surface water.

Sediments

Some contaminants have been detected in the arroyo sediments from past operational practices. DOE is investigating the effect of these contaminants on public health and the environment, and initial observations indicate minimal impact.

Soil

Subsurface soil contamination has been confirmed in the vadose zone below some of the waste management units being investigated. DOE is addressing soil contamination under the remedial action process.

A second pilot treatment facility, operating in the south portion of the site, is used to vacuum extract gasoline from the soil and completely oxidize the product. Another portion of this treatment facility separates free product gasoline from the groundwater and collects it for disposal.

Lawrence Livermore National Laboratory— Site 300

Lawrence Livermore National Laboratory Site 300 has been proposed for inclusion on the NPL because halogenated hydrocarbons have been detected in groundwater. Thus far, however, environmental restoration activities have been carried out under the authority of RCRA, as administered by the State of California's Regional Water Quality Control Board. A work plan for the investigation and remediation of site 300 was sent to the Board outlining the schedule and scope of work there. Nine areas are currently being investigated for possible remediation. A draft RCRA section 3008(h) cleanup order was issued in February 1989, and a second draft of that order was issued in June 1990. The terms of this order are currently being negotiated.

The site contains several surface impoundments, landfills, and waste storage areas. All landfills are closed or in the process of closing. The only two surface impoundments that remain open at site 300 have been constructed to meet current regulatory requirements (double liners and groundwater monitoring) and are monitored to ensure that no RCRA hazardous wastes are disposed in them. Operating storage areas are included in the RCRA part A permit application. When the RFA was conducted, 179 SWMUs were identified. Since 1987, DOE has been performing work equivalent to an RFI under the direction of the State of California.

Formal risk assessments have not yet been performed for the site. A formal risk assessment will be required by the RCRA consent order. Currently, risk assessments for each area of contamination are being performed under a feasibility study for each area.

Groundwater

Site 300 is still being hydrogeologically characterized. Groundwater contamination by halogenated hydrocarbons has been confirmed both on-site and off-site, whereas tritium contamination has been identified on-site. The extent of all off-site plumes except one has been determined both vertically and horizontally.

All on-site groundwater wells located in the area of the plumes will be closed. None of these wells is affected by groundwater contamination. All groundwater wells located in the area of off-site contamination are monitored monthly for volatile organic compounds.

DOE has installed a pilot pump and treat system at one of the areas of contamination and plans to install similar units at other contaminated locations. DOE will obtain all required permits for discharge of air and water generated by these treatment facilities.

Surface Water

The on-site surface water consists of several seasonal streams (which run only after infrequent periods of heavy rainfall) and the two manmade surface impoundments permitted under RCRA. The site is located in a net negative water balance area. Tritium contamination of a spring has been detected, but given the negative water balance, all runoff from this spring recharges to the groundwater before leaving the site. In addition, an off-site spring in a seasonal creek basin has shown detectable levels of volatile organic compounds. Their source is believed to be the on-site contamination.

Because the seasonal nature of surface water streams allows only minimal water usage (and, therefore, limited exposure to pollutants), surface water contamination is a minor concern.

Sediments

Some contaminants have been detected in sediments from the closed waste management units. DOE is investigating the impact of these contaminants on human health and the environment. Initial laboratory results indicate no impact.

Soil

Soil contamination has been confirmed in the vadose zone below some of the waste management units being investigated. DOE is addressing this contamination problem as part of the site investigations and remedial actions.

Los Alamos National Laboratory

The Los Alamos National Laboratory (LANL) did not rank on the Hazardous Ranking System (HRS) for inclusion on the NPL. Therefore, environmental restoration activities at this site are being implemented under RCRA. The State of New Mexico issued the operating permit for incinerator and storage units in November 1989, and EPA issued the Hazardous and Solid Waste Amendments (HWSA) portion of the permit in May 1990. Both portions have been appealed.

The HWSA permit requires DOE to address some 603 SWMUs that have been identified at the site to date. DOE believes it will discover additional SWMUs as it proceeds through the RCRA RFI process. The permit contains the schedule under which DOE is to submit the RFI work plans for EPA review. The schedule calls for submission of RFI work plans on approximately 15 percent of the SWMUs per year for 4 years. All RFIs and CMSs must be completed within 10 years.

To date, sitewide risk or exposure assessments for all hazardous and radioactive constituents have not been performed, although substantial risk assessment and exposure information has been compiled by LANL for individual facilities, activities, or constituents. A sitewide Environmental Impact Statement was issued in 1979, which is expected to be updated in the near future. Annual environmental surveillance reports have been issued to the public since about 1980. Table A-5 identifies the types of contaminants that have been released to the environment in the past.

Groundwater

DOE has performed characterizations of macroscale hydrogeologic conditions. However, at some SWMUs, EPA anticipates that DOE must conduct additional site characterization work.

The primary aquifer is approximately 800 to 1,000 feet below the surface in most portions of the site. Production wells in this zone provide drinking water to LANL and the city of Los Alamos. To date, no contamination of this aquifer has been documented.

Additionally, groundwater exists in several isolated locations as shallow perched water zones and as shallow groundwater within alluvial deposits in some portions of canyon floors. Some shallow wells in these canyons have contained minimal contamination. However, EPA had indicated that no contamination has been documented in several springs that discharge to the surface within the site boundaries.

DOE originally received a RCRA groundwater monitoring waiver from the State for several operating units while under interim status.

Surface Water

Most of the site is located in a negative net water balance area. Thus, surface water exists onsite only as runoff following precipitation, and as discharges from the 120 permitted NPDES outfalls. None of the streams offsite flow normally. Except during high runoff events, surface water in the canyons does not reach the Rio Grande River, which is the nearest permanent flowing surface water in the vicinity of the site.

Surface water contains compounds which are permitted discharges pursuant to the site's NPDES permit. Some sediment contamination exists in the canyon bottoms. DOE monitors surface waters in accordance with the NPDES permit and may perform additional monitoring as part of the RFI process.

Sediment

The site has several areas that may contain contaminated sediment because of old point source discharges. Many discharge points simply released wastewater into the canyons. EPA has targeted 15 canyons for evaluation to determine if contamination has occurred.

Soil

In addition to the problem discussed for sediments, subsurface soil contamination is suspected in the vadose zone beneath old SWMUs, such as old surface impoundments and landfills. DOE will be required to investigate the extent of subsurface contamination by the RFI.

Mound Plant

The environmental restoration activities at the Mound Plant will be implemented under a CERCLA section 120 agreement that DOE and EPA are considering for signature as of this writing. The Mound Plant is listed on the NPL. The plantwide remedial investigation/feasibility study (RI/FS) work plan was submitted to EPA on April 13, 1990. Performing the RI/FS may require 8 to 9 years, whereas remediation efforts have tentative schedules of 20 years. An administrative order, presently under negotiation with the State of Ohio, is expected to be signed shortly.

The RFA/VSI conducted at Mound Plant identified the following SWMUs: storage areas, lagoons, a surface impoundment, glass melter, retort, thermal treatment unit, an energetic materials pretreatment unit, and various underground storage tanks. Nine RI/FSs will be prepared to address environmental restoration at the facility. For any operable units requiring remediation, DOE will prepare a remedial design and subsequently perform remedial action as established under CERCLA.

Exposure risk assessments were addressed in the 1979 Environmental Impact Statement (EIS) and Focused Risk Assessment of the Miami-Erie Canal. Annual environmental monitoring reports are released to document health impacts from plant operations. The EIS is 11 years old and will require updating to ensure that the risk assessment is still valid under today's regulatory climate and newer methods of dose calculation. Action is presently underway to address the best method to replace or update the EIS for this site.

Groundwater

Groundwater contamination has been confirmed both on-site and off-site. The most serious threat to human health and the environment is created by contaminated groundwater in a sole source aquifer. Contamination is below the maximum containment level (MCL) and is being monitored under a groundwater monitoring program. Groundwater contamination is being addressed under the CERCLA section 120 agreement.

Surface Water

Surface water contamination has been confirmed both on-site and off-site. Its exact nature and extent have not been determined but are being addressed under the CERCLA agreement. DOE has initiated some interim

Table A-5-Summary of Hazardous Substances Released to the Environment at the Los Alamos National Laboratory

Contaminant	Air	Soil	Surface water	Groundwater[a]	Sediment
Radionuclides		Americium-241 Beryllium-7[b] Cesium-134[b] Cesium-137 Cobalt-57[b] Manganese-54[b] Mixed fission products Plutonium-238 Plutonium-239 Plutonium-240 Sodium-22[b] Strontium-90 Thorium[b] Tritium Uranium[b]		Cesium Plutonium-238 Plutonium-239 Plutonium-240 Tritium Uranium	Plutonium-239 Plutonium-240
Metals		Barium[b] Beryllium Cadmium[b] Chromium Copper[b] Lanthanum[b] Lead[b] Mercury[b] Nickel[b] Silver[b] Thallium[b] Cyanide[b]	Barium[b] Beryllium[b]		Barium[b] Beryllium
Inorganic compounds		Ferric chloride	Methylene chloride	Hexachlorobutadiene	
Volatile organic compounds (VOCs)		Hydrochloric acid Hydrofluoric acid Phosphoric acid Sodium hydroxide Sodium thiosulfate Sulfuric acid Acetone[b] Benzene[b] Butyl acetates[b] Ethanol[b] Ethyl acetates[b] Methyl ethyl ketone[b] Tetrachloroethylene[b]		Methyl chloride Undefined VOCs	Acetone[b] Butyl acetates[b] Ethyl acetates[b] Methyl ethyl ketone[b]
Miscellaneous		Explosives[c]			Explosives[c]

[a]The groundwater medium at this facility essentially consists of perched groundwater with no beneficial uses.
[b]The presence or potential contamination associated with this pollutant has not been fully determined.
[c]Examples of the explosives used at the site include Baratol, TNT, HMX, RDX, PETN, and Cytocol.

SOURCE: U.S. Department of Energy, Office of Environmental Audit, "Environmental Survey Preliminary Report—Los Alamos National Laboratory, Los Alamos, New Mexico," DOE/EH/OEV-12-P, January 1988; "Summary for the Los Alamos National Laboratory" submitted by U.S. DOE, Los Alamos Area Office, Environment, Safety and Health Branch on Aug. 3, 1990; and Thomas Buhl, Los Alamos Area Office, Environment, Safety and Health Branch, personal communication, Aug. 7, 1990.

corrective actions to alleviate the impact of contamination on surface waters. Storm water runoff has been channeled into a settling pond prior to release through an NPDES monitoring point.

Sediment

Sediment contamination has been confirmed at the site. DOE has initiated some interim corrective measures by removing contaminated soils under the auspices of the Decontamination and Decommissioning (D&D) Program. The exact nature and extent of soil contamination have not been determined; DOE is addressing this issue under the CERCLA section 120 agreement.

Nevada Test Site

An ''agreement in principle'' is currently under negotiation with the State of Nevada to implement environmental activities at the Nevada Test Site. The State is

Table A-6-Summary of Hazardous Substances Released to the Environment at the Nevada Test Site

Contaminant	Air	Soil	Surface water	Groundwater	Sediment
Radionuclides	Krypton-85 Plutonium-239 Tritium Xenon-133	Americium-241[b] Antimony-125 Beryllium-7 Cadmium-109 Cesium-137 Cobalt-60 Europium-152[a] Europium-154[a] Europium-155[a] Gross alpha Plutonium-238[a] Plutonium-239[a] Plutonium-240[a] Radium-226 Rhodium-106 Strontium-90 Uranium-235 Uranium-238 Yttrium-90[a]	Cobalt-60[a] Gross beta Plutonium Tritium	Antimony-125 Barium-140 Beryllium-7 Cadmium-109 Cerium-141 Cesium-137 Cobalt-60 Europium-155 Iodine-131 Iridium-192 Krypton Lanthanum-140 Plutonium-238 Plutonium-239 Plutonium-240 Rhodium-106 Ruthenium-103 Sodium-22 Strontium-90 Tritium	Cesium-137 Plutonium-239 Plutonium-240
Metals		Cadmium Silver	Chromium[a] Lead[a]	Lead	
Inorganic compounds					
Volatile organic compounds (VOCs)	Acetylene Benzene Hydrochloric acid Hydrofluoric acid Nitric acid Perchloric acid Toluene	Acetone[a] Chlorobenzene[a] Methylene chloride[a] Xylenes		Methylene chloride	
Miscellaneous	Gamma radiation[a]	Acids Caustics Chlorinated solvents Fission activation products Gamma radiation		Gamma radiation	

[a]The present or potential contamination associated with current and past discharges of this pollutant has not been fully determined.

SOURCE: U.S. Department of Energy, Office of Environmental Audit, "Environmental Survey Preliminary Report—Nevada Test Site, Mercury, Nevada," DOE/EH/OEV-15-P, April 1987 and "Comments on Site Summary" submitted by DOE on June 18, 1990.

primarily responsible for assessment of the site, but by entering into an agreement with DOE, the State's current one-half, full-time equivalent (FTE) will be augmented. The one-half FIX has proved to be inadequate to address the site in a timely manner. Through this agreement, DOE will provide financing for the State to staff and operate an office devoted entirely to overseeing the Nevada Test Site.

The Nevada Test Site contains the following RCRA and CERCLA units: pits, trenches, a storage pad, injection wells, surface pond, leach fields, craters, and underground storage tanks. In 1989 DOE developed a Five-Year Plan to address the environmental restoration and waste management at the site. The State will oversee implementation of this Five-Year Plan until a determination is made by EPA as to the status of the Nevada Test Site as an NPL site.

DOE prepared a preliminary assessment for the site and submitted it to EPA Region IX in April 1988. No risk assessments for past release sites have been completed. Table A-6 identifies the types of contaminants that have been released to the environment in the past.

Groundwater

Groundwater contamination has been detected at the facility; however, the nature and extent are not known at present. DOE plans to drill 10 to 12 wells per year over the next 8 to 10 years in a coordinated effort to determine the extent and types of on-site and off-site contamination. A groundwater characterization work plan has been prepared and submitted to regulators for approval.

Surface Water

No information is available regarding the existence of surface water contamination problems at the Nevada site.

Sediment

No information is available regarding the existence of sediment contamination problems at the site.

Soil

Soil contamination is documented and believed to be a threat to human health and the environment. The exact extent of contamination is not known. DOE has taken interim actions to fence and post the contaminated areas in order to limit their accessibility. Future corrective measures will be conducted pursuant to the Five-Year Plan.

The closure plan for the "23 hazardous waste trench" was completed and submitted to State regulators for approval.

Oak Ridge Reservation

The environmental activities at Oak Ridge Reservation (ORR) will be conducted under a Federal facility agreement (FFA) involving EPA, the State of Tennessee, and DOE. The FFA addresses all activities associated with identifying and remediating environmental contamination problems that pose a threat to human health and the environment.

The entire facility was added to the NPL on December 21, 1989. As a result, environmental investigation and restoration activities are now regulated by CERCLA. Prior to that, RCRA was the authority under which DOE had conducted those activities. Those activities initiated under the RCRA corrective action process will proceed as planned, and CERCLA will be used for any new activities that are required. However, DOE has been implementing CERCLA requirements, guidelines, and procedures in the site investigation process initiated under RCRA.

The Oak Ridge Reservation includes the Oak Ridge National Laboratory, the Y-12 Plant, and the Oak Ridge Gaseous Diffusion Plant. Approximately 600 contaminated sites identified on the ORR may require further investigation and remediation. Offsite contamination is also being addressed.

Some operating permits have already been approved; others will be issued in the future. All of the surface impoundments are either closed or in the process of closing. Most of the postclosure permits are currently being processed; the schedule is for the bulk of the permits to be issued within a year. The most common obstacle to the issuance of postclosure permits is determining the scope of the activities DOE must implement to define groundwater contamination plumes. A trial burn permit has been issued for the new incinerator. The final permit will be issued when DOE successfully completes the next trial burn. DOE has completed short-term health assessments related to contamination problems. Tables A-7 and A-8 identify the types of contaminants that have been released to the environment in the past.

Groundwater

Groundwater contamination is known to exist at several locations throughout the complex. DOE is petitioning EPA for alternative concentration limits (ACLs); however, EPA determined that corrective action will be needed for contaminated groundwater. EPA stated that the extent of groundwater contamination is still unknown. Contaminated groundwater discharges to surface waters that are used for human consumption.

Surface Water

Surface water contamination has been confirmed at several locations throughout the complex. Surface water from the ORR empties into other surface water bodies that are used by a large population. Berms have been constructed around some areas of soil contamination to restrict the flow of precipitation across contaminated soil into surface water.

Sediment

Sediment contamination has been detected in the Clinch River and several of its tributaries. The exact nature and extent of that contamination are not known at present, but a remedial investigation is underway. EPA will require DOE to conduct further investigations to determine the nature and extent of the sediment contamination problem at this site.

Soil

Soil contamination exists throughout the ORR complex. The exact nature and extent of that contamination are not known, but RIs are underway. EPA will require DOE to conduct further investigations to determine the nature and extent of soil contamination at this site, and remediation may be required. Corrective measures implemented by DOE to date include the construction of berms around certain areas with known soil contamination. These berms can prevent storm water runoff traveling over the contaminated soil from entering nearby surface waters and sediments.

Pantex Plant

Environmental activities at the Pantex Plant will be implemented by a RCRA section 3008(h) corrective action order. The authority of CERCLA is not being used, but if conditions arise in the future that cannot be addressed under the RCRA program, CERCLA would be used.

Table A-7—Summary of Hazardous Substances Released to the Environment at the Oak Ridge Reservation

Contaminant	Air	Soil	Surface water	Groundwater	Sediment
Radionuclides	Questionable[a]	Americium-241 Cesium-137 Cobalt-60 Curium-244 Plutonium-238 Plutonium-239 Radium-228 Strontium-90 Uranium-232 Uranium-233 Uranium-234 Uranium-235 Uranium-238	Americium-241 Cesium-137 Cobalt-60 Curium-244 Gross beta Strontium Tritium	Antimony-125 Cesium-137[b] Cobalt-60[b] Europium Gross alpha Gross beta Plutonium Ruthenium-106 Strontium[b] Technetium-99 Thorium-232 Tritium[b] Uranium-232 Uranium-233 Uranium-234 Uranium-235 Uranium-238	Americium-241 Cesium-137 Cobalt-60 Curium-244 Europium Plutonium-238 Plutonium-239 Strontium-90 Uranium-232 Uranium-233 Uranium-234 Uranium-235 Uranium-238
Metals	Lead[b]	Mercury	Chlorine	Arsenic	Chromium
Inorganic compounds	Questionable[a]			Barium Cadmium Chromium Lead Mercury	Lead Mercury
Volatile organic compounds (VOCs)	Questionable[a]			Acetone Benzene Carbon tetrachloride Chloroform 1,1-Dichloroethylene Trans-1,2-Dichloroethylene Dimethyl phthalate Ethylbenzene Methylene chloride Naphthalene 1,1,2,2-Tetrachloroethane Toluene 1,1,1-Trichloroethane Trichloroethylene Xylene	Undefined VOCs[b]
Miscellaneous		Stored petroleum products[b]	Fecal coliform Total suspended solids	Endrin Stored petroleum products[b]	PCBs[c]

[a]Although radionuclide and chemical releases to the air are in compliance, the facility's lack of documentation and quality control regarding reported emission estimates, as well as the inappropriate design and calibration of air samplers, are of concern.
[b]The present or potential contamination associated with current and past discharges of this pollutant has not been fully determined.
[c]PCBs = polychlorinated biphenyls.

SOURCE: U.S. Department of Energy, Office of Environmental Audit, "Environmental Survey Preliminary Report—Oak Ridge National Laboratory (X-10), Oak Ridge, Tennessee," DOE/EH/OEV-06-P; "Comments on Site Summary" submitted by DOE on June 18, 1990; and Thomas Wheeler, Oak Ridge Reservation, personal communication, July 9, 1990.

The order was signed by EPA and DOE's Amarillo Area Office on December 10, 1990. The State of Texas has authority to implement the RCRA program, except for the HSWA provisions. The Texas Water Commission is drafting the RCRA operating permit.

The types of units at the site include storage units, surface impoundments, burning pads, nonhazardous landfills, and several enclosed buildings in which treatment of highly explosive wastewater occurs. The RCRA RFA/VSI identified 143 SWMUs. Because of the size of the Pantex Plant (more than 10,000 acres), additional SWMUs are likely to be discovered in the future.

No exposure or risk assessments have been conducted at this site. Table A-9 identifies the types of contaminants that have been released to the environment in the past.

Groundwater

Hydrogeologic characterization of the site is inadequate, and additional work must be done to fully understand subsurface conditions. Many of the SWMUs

Table A-8-Summary of Hazardous Substances Released to the Environment at the Y-12 Plant

Contaminant	Air	Soil	Surface water	Groundwater	sediment
Radionuclides	Gross alpha Gross beta Uranium-235 Uranium-238	Cesium-137[a] Gross alpha Gross beta Thorium Uranium	Gross alpha[a] Gross beta[a]	Gross alpha Gross beta Radium[a] Uranium	
Metals	Beryllium[a] Mercury[a]	Beryllium[a] Cadmium Chromium Copper Lead Mercury	Cadmium[a] Chromium[a] Copper[a] Lead[a] Mercury	Arsenic Barium Cadmium Chromium Copper Lead Manganese Mercury	Arsenic Cadmium Lead Mercury Nickel
Inorganic compounds	Hydrogen fluoride	Nitrate	Chloride[a] Nitrate[a]	Nitrate	
Volatile organic compounds (VOCs)	Perchloroethylene[b] Trichloroethene	1,2-Dichloroethane Perchloroethylene[b] 1,1,1-Trichloroethane Trichloroethene	1,2-Dichloroethane Perchloroethylene[b] 1,1,1-Trichloroethane Trichloroethene	1,2-Dichloroethane Perchloroethylene[b] Tetrachloroethene Trichloroethene	Anthracene Benz[a]anthracene Benzo[a]pyrene Chrysene Fluoranthene Phenanthrene Phenols Phthalates Pyrene
Miscellaneous	Particulate matter Unleaded gasoline	Asbestos Coal pile leachate Oil PCBs[c]	Coal pile leachate[a] PCBs[c]	Coal pile leachate Mineral oil PCBs[c]	PCBs[c]

[a]The present or potential contamination associated with current and past discharges of this pollutant has not been fully determined.
[b]This VOC is also known as tetrachloroethylene or tetrachloroethene.
[c]PCBs = polychlorinated biphenyls.

SOURCE: U.S. Department of Energy, *Office of Environmental Audit*, "Environmental Survey Preliminary Report—Y-12 Plant, Oak Ridge, Tennessee," DOE/EH/OEV-07-P; "Comments on Site Summary" submitted by DOE on June 18, 1990; and Thomas Wheeler, Oak Ridge Reservation, personal communication, July 9, 1990.

will be grouped together for the purposes of conducting the RFI. Additional site characterization work will be performed to define subsurface conditions in the immediate vicinity of these groupings.

The primary source of groundwater at the site is the Ogalkda Aquifer. The depth of the groundwater is approximately 450 to 500 feet. However, there are localized perched water zones with groundwater at 250 feet. Although groundwater contamination is not suspected in the Ogallala, low levels of contamination have been detected in the shallower, perched zones. DOE is currently assessing the extent of two gasoline leaks that have contaminated the shallow zones.

The facility has several active wells that withdraw groundwater from the Ogallala for drinking water and for production purposes.

Surface Water

The only surface waters in the vicinity of the site are ditches that drain from the production areas to the playa lakes. Water and sediment in the ditches and the playa lakes are believed to be contaminated. To date, DOE has not implemented any measures to determine the contamination of surface water. The corrective action order will require DOE to submit RFI work plans. These plans should contain the steps for assessing any surface water contamina tion.

Sediment

Like surface water, the sediments in the transfer ditches and playa lakes are suspected of being contaminated. DOE collected samples of the sediments from the ditches and dry lake beds in October 1989; however, the analyses have not been completed

Soil

Soil contamination is suspected, but not yet confirmed The old burning ground is probably contaminated because waste munitions were burned on the surface for many years. DOE will berequired to address this area in the RFI.

Table A-9-Summary of Hazardous Substances Released to the Environment at the Pantex Plant

Contaminant	Air	Soil	Surface water	Groundwater	Sediment
Radionuclides		Gross alpha[a]			
		Gross beta[a]			
		Plutonium[a]			
		Thorium[a]			
		Tritium[a]			
		Uranium[a]			
Metals		Beryllium[a]	Chromium[a]		
		Chromium[a]	Copper[a]		
		Copper[a]	Lead[a]		
		Lead[a]	Silver[a]		
		Silver[a]			
Inorganic compounds		Barium oxide[a]	Cyanide[a]		
		Hydrogen cyanide[a]			
		Hydrogen fluoride[a]			
		Sulfuric acid[a]			
Volatile organic compounds (VOCs)		Acetone[a]		Acetone[a]	Acetone[a]
		Benzene[a]		Benzene[a]	Benzene[a]
		Carbon tetrachloride[a]		Carbon tetrachloride[a]	Carbon tetrachloride[a]
		Chloroform[a]		Chloroform[a]	Chloroform[a]
		Dimethylformamide[a]		Dimethylformamide[a]	Dimethylformamide[a]
		Ethyl acetate[a]		Ethyl acetate[a]	Ethyl acetate[a]
		Methylene chloride[a]		Methylene chloride[a]	Methylene chloride[a]
		Methyl ethyl ketone[a]		Methyl ethyl ketone[a]	Methyl ethyl ketone[a]
		Methyl isobutyl ketone[a]		Methyl isobutyl ketone[a]	Methyl isobutyl ketone[a]
		Tetrachloroethane[a]		Tetrachloroethane[a]	Tetrachloroethane[a]
		Tetrahydrofuran[a]		Tetrahydrofuran[a]	Tetrahydrofuran[a]
		Toluene[a]		Toluene[a]	Toluene[a]
		Trichloroethylene[a]		Trichloroethylene[a]	Trichloroethylene[a]
Miscellaneous		2,4-D[a] [b]			
		Dioxin[a]			
		Gasoline			
		PCBs[a] [c]			
		TNT[a]			

[a]The presence or potential contamination associated with this pollutant has not been fully determined.
[b]2,4-D = (2,4-dichlorophenoxy)acetic acid.
[c]PCBs = polychlorinated biphenyls.

SOURCE: U.S. Department of Energy, Office of Environmental Audit, “Environmental Survey Preliminary Report-Pantex Facility, Amarillo, Texas,” DOEIE~OEV-08-P, Sept~rnber 1987.

Other areas of suspected soil contamination are associated with transfer ditches and with soil around the playa lakes.

Pinellas Plant

The environmental activities at the Pinellas Plant are currently proceeding under the RCRA permit and corrective action process. A PA/SI was conducted under CERCLA, but the site did not rank high enough for inclusion on the NPL.

The RFA/VSI completed under RCRA resulted in the identification of 14 SWMs. Corrective action requirements at the SWMUs were included in the RCRA operating permit issued to Pinellas on February 9, 1990. DOE plans to submit the RFI work to EPA for review 120 days after issuance of the operating permit. RI plans for two sites have been completed and sent to EPA for review.

No exposure or risk assessments have been performed at this site. Table A-10 identifies the types of contaminants that have been released to the environment in the past.

Groundwater

The site hydrogeologic characterization studies reviewed by a DOE Tiger Team were found to be incomplete, Therefore, as part of the corrective measures stipulated in the RCRA permit, additional site hydrogeologic characterization work will be conducted. This is planned for FY 1990.

Groundwater contamination has been confirmed in the shallow saturated zone. Groundwater is within a few feet of the surface at this site. The deeper aquifer (Floridan) is a major regional source of potable water. DOE has initiated a study to determine if the Floridan Aquifer has

Table A-10—Summary of Hazardous Substances Released to the Environment at the Pinellas Plant

Contaminant	Air	Soil	Surface water	Groundwater	Sediment
Radionuclides	Tritium		Tritium[a]	Tritium[a]	Tritium[a]
Metals	Chromium Lead Manganese Molybdenum	Lead[a]	Silver[a] Undefined heavy metals[a] Zinc[a]	Chromium Lead Undefined heavy metals[a] Anions Calcium chromate[a]	Undefined heavy metals[a]
Inorganic compounds				Fluoride	
Volatile organic compounds (VOCs)	Acetic acid Acetone Amyl acetate Butyl alcohol Chlorofluorocarbons[b] Ethyl alcohol Methylene chloride Methylenedianiline[a] Nitric acid Toluene diisocyanate[a] 1,1,1-Trichloroethane Trichloroethylene Urethanes[a]	Pinellas does not monitor VOCs in soils.	Spent acids[a] Solvents[a]	Sulfates Acetone trans-1,2-Dichloroethylene Methylene chloride Spent acids[a] Spent solvents[c] Trichloroethylene Undefined solvents[a] Vinyl chloride Biocides[a d]	Phthalate Spent acids[a] Solvents[a]
Miscellaneous		Construction debris[c]	Biocides[a d]	Construction debris[c] Diesel fuel[a] Insecticides Stored petroleum products[a]	Biocides[a d] PCBs[c]

[a]The present or potential contamination associated with current and past discharges of this pollutant has not been fully determined.
[b]Fluorocarbons released from the Pinellas Plant include CFC-11, CFC-12, CFC-113, and CFC-114.
[c]The land disposal of construction debris known to contain hazardous materials is a potential source of soil contamination.
[d]Biocides present in cooling water discharges may have potentially contaminated this medium.
[e]PCBs = polychlorinated biphenyls.

SOURCE: U.S. Department of Energy, Office of Environmental Audit, "Environmental Survey Preliminary Report—Pinellas Plant, Largo, Florida," DOE/EH/OEV-13-P; "Comments on Site Summary" submitted by DOE on June 18, 1990; and Thomas Wheeler, Oak Ridge Reservation, personal communication, July 9, 1990.

been affected by contamination from the site. Therefore, the exact nature and extent of groundwater contamination are not known at this time.

Surface Water

Two natural ponds are located within site boundaries. The ponds, which were part of the wastewater treatment process, have been identified as SWMUs. Although sediments from the ponds passed the extraction procedure (EP) toxicity test, a RCRA facility assessment must be conducted to evaluate all potential contaminants. Given the nature of operations at the facility, DOE officials indicate that surface water contamination is unlikely.

Sediment

The two natural ponds located within site boundaries are the only potential sources of sediment contamination. DOE sampled sediments from the ponds, and they passed the EP toxicity test. These sediments will be assessed in the RFI as required under the operating permit. As with surface water, DOE feels that sediment contamination at the ponds is not likely.

Soil

Soil contamination is suspected based on the observation of soil discoloration during the VSI. At present, analytical results indicate that soil contamination exists. The RFI work plan will include a requirement for conducting further soil sampling at selected areas within the site.

Rocky Flats Plant

The environmental restoration activities at the Rocky Flats Site are implemented by an interagency agreement (IAG) involving EPA, the State of Colorado, and DOE. The IAG encompasses all activities associated with identifying environmental problems and all measures to be implemented for remediation of those problems that pose a threat to human health and the environment.

The activities to be performed according to the IAG will be conducted under the regulatory authority and guidance of CERCLA and RCRA. All activities dealing with problems other than radioactive waste will be addressed under the RCRA program; CERCLA will be used if radioactive waste is present. The Rocky Flats Site was placed on the NPL in October 1989.

In the facility assessment completed by DOE, a total of 178 SWMUs were identified and grouped into 10 OUs. Included in these SWMUs are land application units, evaporation ponds, land disposal units, and land treatment units. As additional information is developed, SWMUs may be added or eliminated from these groups. Several SWMUs at the Rocky Flats Site have progressed through the various phases of the RCRA-CERCLA corrective action process. The 11 SWMUs in OU 1 are currently in the third phase of the RI/FS, and construction has been initiated as an interim remedial act for groundwater. OU 2 is currently in the second phase of investigation and evaluation, and conceptual interim remedial action plans for this OU are currently being prepared. No RFI/RI has been completed at the remaining SWMUs; however, contracting efforts to accomplish this goal are underway.

One exposure assessment has been completed. Table A-11 identifies the types of contaminants that have been released to the environment in the past.

Groundwater

Hydrogeologic characterization of the entire site is limited, and extensive work is required to develop an adequate understanding of the subsurface environment.

The facility has confirmed groundwater contamination in some SWMUs. One past action taken to halt the movement of contaminated groundwater was the installation of a French drain around the Solar Evaporation Pond. The intercepted water is recycled back to the ponds. Future containment of contaminated groundwater around OU 1 will include a French drain collection and a pump and treat system, which is currently under construction. Closure of the Solar Evaporation Pond in accordance with RCRA is underway. Corrective action is also underway for Hill 881.

Surface Water

Surface water contamination has been confirmed as a result of past practices. Contamination has migrated off-site to surface waters used by the western suburbs of Denver for drinking water. All surface water drainages at the plant have retention ponds within their flow paths. DOE will conduct a risk assessment of the contamination carried offsite via surface water.

Sediment

Radioactively contaminated sediments have been found in the water retention facilities. Risk assessment has yet to be completed so the actual risk to human health and the environment is not known. DOE will conduct the necessary risk assessment for those sediments and for the off-site contamination.

Soil

Soil contamination with radionuclides was confirmed at the site in the mid-1970's. DOE has also undertaken an analysis of the nature and extent of hazardous constituents in the soil.

Sandia National Laboratory

The environmental activities at Sandia will be accomplished under the authority of RCRA. At present there are no CERCLA activities at the site; however, the authority of CERCLA would be invoked if necessary. Currently, all RCRA units are entering closure with the exception of the storage units. The storage units will receive RCRA Part B operating permits.

The RFA/VSI has been completed, but no RFI work plan has been submitted to EPA for review. The draft RCRA-HSWA permit is expected to be ready by September 1990. This permit will contain the schedule for submitting RFI work plans; EPA requires DOE to submit these plans within 120 days following issuance of the permit.

There are approximately 135 SWMUs at the site; these will be combined in groups of about 10 so that several may be addressed under one RFI. EPA states it will evaluate information related to each SWMU and determine the areas that require the highest priority.

No risk or exposure assessments have been completed for this site. Table A-12 identifies the types of contaminants that have been released to the environment in the past.

Groundwater

Sandia is within the boundary of Kirkland Air Force Base and is very large. Given its size, characterization of the entire site is not appropriate, particularly when the "technical areas" are some 2 to 3 miles apart. Therefore, the work conducted to depict the subsurface has not been SWMU-specific. EPA will require DOE to conduct additional hydrogeologic site characterization work to define subsurface conditions relative to the groups of SWMUs addressed under the RFI.

Groundwater contamination in a well adjacent to an abandoned land disposal unit was identified in June 1990.

Surface Water

The only surface waters at the site are intermittent streams in the arroyos. These streams flow to the Rio Grande, approximately 5 miles away. However, flow from the arroyo streams infiltrates the ground before it reaches the Rio Grande. Surface water would leave the

Table A-11—Summary of Hazardous Substances Released to the Environment at the Rocky Flats Plant

Contaminant	Air	Soil	Surface water	Groundwater	Sediment
Radionuclides	Beryllium Plutonium[b]	Americium-241 Gross alpha Gross beta Plutonium Tritium[a] Uranium	Plutonium	Cesium-137[a] Gross alpha Gross beta Strontium[a] Tritium[a] Uranium[a]	Cesium-137 Plutonium-239 Plutonium-240
Metals		Lithium[a]		Beryllium[a] Cadmium Chromium[a] Lead[a] Manganese[a] Molybdenum[a] Nickel[a] Selenium[a] Thallium	
Inorganic compounds		Aluminum hydroxide[a] Ammonium persulfate[a] Cyanide[a] Ferric chloride[a] Hydrochloric acid[a] Lithium chloride[a] Nitrates Nitric acid[a] Sodium nitrate[a] Sulfuric acid[a]	Nitrates Sulfates	Aluminium hydroxide[a] Ammonium persulfate[a] Chloride[a] Cyanide[a] Ferric chloride[a] Hydrochloric acid[a] Lithium chloride[a] Nitrates[a] Nitric acid[a]	
Volatile organic compounds (VOCs)	Carbon tetrachloride	Acetone[a] Benzene[a] Carbon tetrachloride[a] Chloroform[a] Dichloromethane[a] Methylene chloride[a] Methyl ethyl ketone[a] Toluene[a]		Carbon tetrachloride Chloroform 1,2-Dichloroethane 1,1-Dichloroethylene Tetrachloroethylene 1,1,1-Trichloroethane Trichloroethylene	
Miscellaneous	Laundry wastewater[c]	Disposed waste[d] Friable asbestos Oil sludge PCBs[a e] Sanitary sewage sludge[d]	Disposed waste[d] Friable asbestos PCBs[a e]	Disposed waste[d] Friable asbestos Oil sludge PCBs[a e] Total dissolved solids	

[a]The present or potential contamination associated with current and past discharges of this pollutant has not been fully determined.
[b]Primarily due to past accidental releases.
[c]Significant releases of radionuclides into air may have occurred from 1969 to 1973 when radioactively contaminated sludges were dried at the facility's drying beds.
[d]There is a potential for soil, surface water, and groundwater contamination because current practices do not prevent low-level radioactive waste improperly disposed of in landfill designed for hazardous waste.
[e]PCBs = polychlorinated biphenyls.

SOURCE: U.S. Department of *Energy*, Office of Environmental Audit, "Environmental Survey Prelimhary Report-Rocky Flats Plant, Golden, Colorado," DOE/EH/OEV-03-P, January 1988; "Federal Facility Agreement and Consent Order-Rocky Flats Plant"; and "Report on Federal Facility Land Disposal Review," October 1987.

site only under severe precipitation. Therefore, surface water contamination is not suspected.

Soil/Sediment

DOE has sampled soil below the old impoundments and found contamination to a depth of 75 feet below the surface. The extent of surface soil contamination is not known. DOE is expected to address the existing subsurface and potential surface soil contamination in the RFI work plan.

Savannah River Site

The entire contiguous Savannah River Site (SRS) was recently finalized on the NPL. Prior to this, DOE had been proceeding under RCRA to address environmental corrective actions. Therefore, the RCRA process will lead to activities for addressing conlamination problems, whereas CERCLA will be used to address problems associated with radioactive waste and restoration activities not

Table A-12-Summary of Hazardous Substances Released to the Environment at the Sandia National Laboratory

Contaminant	Air	Soil	Surface water	Groundwater	sediment
Radionuclides	Argon[a] Tritium[a]	Uranium			
Metals		Chromium Lead			
Inorganic compounds					
Volatile organic compounds (VOCs)	Chlorinated hydrocarbons			Trichloroethylene[b]	
Miscellaneous		Explosives Petroleum products			

[a]Release data for this and other radionuclides either have not been verified or have not been collected.
[b]Trichloroethylene contamination has been detected at the chemical waste landfill area only. Ongoing efforts to characterize the nature and extent of environmental contamination throughout the facility are expected to be completed in 5 to 6 years.

SOURCE: U.S. Department of Energy, Office of Environmental Audit, "Environmental Survey Preliminary Report—Sandia National Laboratories: Inhalation Toxicology Research Institute, Bendix Albuquerque Operations, Central Training Academy, Transportation Safeguards Division, and Tonopah Test Range, Albuquerque, New Mexico," DOE/EH/OEV-06-P, July 1990.

covered under RCRA. An FFA involving DOE, EPA, and the State of South Carolina is being negotiated.

The SRS includes approximately 300 square miles and has container storage areas, tanks, landfills, and surface impoundments. SRS is planning to construct an incinerator that will be permitted under RCRA to incinerate RCRA and radioactive mixed waste. The RCRA facility assessment RFA/VSI identified 313 SWMUs. DOE will submit 44 site-specific RFI work plans that address contamination issues at the SWMUs contaminated with hazardous waste.

The State of South Carolina has RCRA authorization and is responsible for issuing RCRA part B operating permits. EPA is currently responsible for implementing the RCRA's HSWA provisions. The State of South Carolina has petitioned EPA for HSWA authority, and its application is pending.

DOE has submitted an Exposure Information Report but has not completed formal exposure or risk assessments. Table A-13 identifies the types of contaminants that have been released to the environment in the past.

Groundwater

Hydrogeologic characterization of all individual waste sites is not complete. DOE must conduct additional hydrogeologic investigations to adequately define subsurface conditions around the SWMUs. Groundwater contamination has been detected only within the facility boundaries.

SRS uses onsite groundwater for process water as well as for drinking water. One well in the M area was closed due to low levels of chlorinated solvents. A groundwater corrective action to address the chlorinated solvents has been implemented in the M and A areas. Known impacts to this aquifer have been minimal. EPA stated that releases have been detected from 35 individual waste management units. DOE will continue to define the type and extent of groundwater contamination at individual SWMUs.

Surface Water

Surface water bodies of known or suspected contamination have been identified and are reported to the public in annual environmental reports. Additional evaluation of surface water contamination problems at the facility has been suggested by EPA. The State of Georgia independently collects surface water data adjacent to and downstream from the SRS.

Sediment

Several areas are known or suspected to contain sediment contamination from accidental release sites and SWMUs. Sediment contamination has been confirmed as a result of RCRA closures and RFA/VSIs. The extent of on-site and off-site contamination is known to varying degrees at SWMUs and spill sites, depending on the stage of characterization. RFI work plans will contain proposed schedules for completing that work.

Soil

Soil contamination has been identified or is suspected in several areas by RCRA-CERCLA activities. The nature and extent of soil contamination are known to varying degrees at the SWMUs, depending on the stage of characterization.

Table A-13—Summary of Hazardous Substances Released to the Environment at the Savannah River Site

Contaminant	Air	Soil	Surface water	Groundwater	Sediment
Radionuclides	Carbon-14 Iodine-129 Technetium-99 Tritium Unknown nuclides[b]	Cesium-137 Gross alpha Gross beta Iodine-129 Iodine-131 Strontium-90 Tritium	Cesium-137[a] Cobalt-60[a] Gross alpha[a] Gross beta[a] Iodine-129[a] Iodine-131[a] Strontium-90[a] Tritium Uranium	Cesium-137[a] Cobalt-60[a] Gross alpha Gross beta Plutonium-238 Plutonium-239 Radium Ruthenium-106 Strontium-90 Tritium Uranium[a]	Cerium-243 Cerium-244 Cesium-137 Gross alpha[a] Gross beta[a] Iodine-129[a] Iodine-131[a] Strontium-90[a] Thorium-228 Tritium Uranium-235 Uranium-238
Metals	Mercury		Chromium Copper Mercury Silver	Barium[a] Cadmium Iron Lead Magnesium[a] Manganese Mercury Sodium[a] Zinc	Chromium Copper Mercury Nickel Silver
Inorganic compounds	NO_x[a]		Cyanide	Chloride[a] Sulfate	Cyanide
Volatile organic compounds (VOCs)	1,1,1-Trichloroethane Unknown VOCs			Tetrachloroethylene 1,1,1-Trichloroethane Trichloroethylene Trichloromethane	
Miscellaneous		Stored petroleum products[a]	Coal reject effluents Temperature[c]	Endrin Stored petroleum products[a] Phenol[a] Solvents[a]	

[a]The present or potential contamination associated with current and past discharges of this pollutant has not been fully determined.
[b]Releases of other radionuclides may also have occurred but sampling equipment and monitoring procedures were inadequate.
[c]Thermal impacts associated with the discharge of cooling waters to this medium include deforestation, changes in water levels, reduction of oxygen levels, and increased erosion and sedimentation.

SOURCE: U.S. Department of Energy, Office of Environmental Audit, "Environmental Survey Preliminary Report-Savannah River Plant, Aiken, South Carolina," DOE/EH/OEV-10-P; "Comments on Site Summary" submitted by DOE on June 18, 1990; and Thomas Wheeler, Oak Ridge Reservation, personal communication, July 9, 1990.

Appendix B
Groundwater Contamination

INTRODUCTION

Groundwater contamination has been detected at all of the Nuclear Weapons Complex sites. The extent and types of contamination have not yet been fully characterized. It is not known with sufficient accuracy where the contamination is located, where it is moving, how it is changing, and how soon it might begin to cause problems for human health or the environment, to allow an appraisal of remediation alternatives. However, characterization is underway through the regulatory processes of the Resource Conservation and Recovery Act (RCRA) and Superfund. Work is underway at some sites to correct some contamination problems, and the Department of Energy (DOE) has identified an ambitious research program to develop more cost-effective techniques for characterizing and correcting groundwater and soil contamination problems. Investigations by the Environmental Protection Agency (EPA) and DOE Tiger Teams of some of the characterization and remediation efforts have revealed deficiencies.

This appendix discusses the state of the art of groundwater characterization and cleanup as well as DOE activities.

CHARACTERIZATION OF GROUNDWATER CONTAMINATION

Site characterization is important for understanding the nature and extent of a contamination problem (including pathways to exposure of people). It is also important for designing remediation measures and monitoring their effectiveness. Characterization of groundwater contamination problems has three major elements: detecting the presence of contaminants, understanding their movement and change since entering the subsurface, and predicting their subsequent fate and transport. That is, these elements are simply what they are, where they are and in what concentration, and where they are going and how fast. Data requirements depend on the objectives of cleanup, specific sites, and the remedial technologies that will be considered.

Characterization is a difficult task that requires a high level of expertise to implement properly. Poor characterization is a result of poor field procedures, unjustified choice of methods, and poor initial planning. However, even by following the best approaches, the results concerning fate and transport may be highly uncertain. This uncertainty is a particular problem for certain contaminant ts (e.g., dense, nonaqueous-phase liquids and complex mixtures of contaminants) and certain hydrogeologic environments (e.g., fractured rock systems, karst, and unsaturated zones).

The basic data to characterize groundwater contamination problems come from properly constructed and sampled wells. Wells offer a window into the subsurface that can provide information on the physical, chemical, and biological properties of both the aquifer media and the water. Such information is useful in predicting the occurrence, fate, and transport of contamination. However, wells can be expensive to construct and still provide a very limited view of the subsurface. Skilled hydrogeologists can extrapolate information between wells, but methods that provide a more comprehensive view of the subsurface are always preferred. Geophysical and remote sensing techniques and computer modeling provide additional means of gaining information about the subsurface, but they also have limitations.

Detecting Contaminants

Detecting contaminants is an iterative process. Samples are taken and analyzed. The results are interpreted to identify additional sampling needs. This procedure can be followed repeatedly until information needs are satisfied. Traditionally, the process can take many months, partly because of delays associated with obtaining laboratory results.

A major difficulty in detecting contaminants is the lack of accepted analytical and safety procedures for many of the contamination problems likely to be encountered at DOE sites; these include the number of radionuclides, the presence of radionuclides mixed with other chemicals or materials (mixed waste), and the specialty chemicals used by DOE (l). This is an issue that has been identified by DOE and is currently being addressed in its Research Development, Demonstration, Testing, and Evaluation (RDDT&E) program. There is also a special problem of detecting small quantities of highly potent chemicals. These situations may remain undetected for years, but suddenly show up at a point of use. Currently available sampling techniques for such problems are either prohibitively expensive because of the large numbers of samples required or not accurate enough to detect such low concentrations.

However, technologies to identify the types and concentrations of materials present are changing. Techniques are becoming available for on-site and in situ measurements. On-site measurements require that samples be extracted, but measured in the field rather than transported to a laboratory. In situ measurements are made directly in wells or boreholes, without the need to extract a sample. On-site and in situ techniques have both advantages and limitations. These new techniques avoid some of the time and expense associated with laboratory analysis and can help maintain sample integrity (2). However, it may be difficult to ensure adequate quality control for these techniques, and instruments may require modification to be effective in different types of aquifer materials (3).

On-site techniques are valuable because they allow for rapid evaluation of results and the ability to take additional measurements at the same or different locations when needed, without waiting for results from a laboratory. In situ techniques are also useful because many problems are associated with obtaining representative samples, particularly from groundwater, due to chemical and physical changes that may occur when groundwater is extracted. For example, dissolved gases or volatile contaminants can be lost, or the presence of oxygen can change the sample. Yet, no technique is likely to be capable of identifying the full range of contaminants present at the Nuclear Weapons Complex. In addition, some problems are always likely to require laboratory analysis.

The application of new monitoring technologies to problems at the Nuclear Weapons Complex depends on whether the technique can detect the contaminants of concern with the necessary sensitivity. Information gained in laboratory tests of an instrument may not always be indicative of field performance. In the field, other chemicals may interfere with instrument readings. The instrument must also be capable of detecting the contaminant at the level of concern; ideally an instrument should be able to detect a contaminant from below any regulatory standard to its volubility limit in water (4). However, this ideal range is rarely achieved. Other concerns include response time for on-site measurements, reversibility of in situ measurements to allow readings as the concentrations of contaminants decrease, and field operability.

In a study for DOE, Pacific Northwest Laboratory prepared an evaluation of chemical sensors for on-site and in situ monitoring of high priority contaminants found in groundwater at the Hanford Reservation (5). Table B-1 shows the contaminants of concern and the sensitivity of various instruments to those contaminants, based on laboratory analysis. Of the 14 contaminants considered, the authors found that each contaminantt could be detected by several types of technologies. Detection of only five types of contaminants has been demonstrated in the laboratory (cyanide, chromium, uranium, trichloroethylene (TCE), and hydrocarbons). Detection of seven contaminants (carbon tetrachloride, methyl ethyl ketone (MEK), nitrate, perchloroethylene (PCE), 1,1-dichloroethane (DCA), 1,1,1-trichloroethane (TCA), and 1,2-dichloroethylene (DCE) by in situ methods appears feasible but has not been demonstrated by the instrument systems studied. Continued technology evaluations of this type, as more contaminants are identified at other sites, would help to focus DOE sensor development research.

The report concludes that technology for chemical sensing is in an early stage of development and will probably remain so in the near term. This is an active area of research by universities, government, and industry that is rapidly changing. However, few technologies have been commercialized, and even those have not been tested sufficiently under field conditions. Also, private companies are apparently reluctant to field test prototype sensors because of the fear of adverse publicity if they do not work as well as advertised in the specific testing environment (6). Pacific Northwest Laboratory has a field testing program to demonstrate, test, and evaluate new or prototype sensors. Testing is scheduled for two prototype sensors developed with the support of DOE for two contaminants of concern, uranium and ferrous cyanide. Such a testing program is necessary to allow DOE to identify and ensure the development and availability of instruments that will meet the needs at the Nuclear Weapons Complex. The study further identified the need for DOE to concentrate future research support on the development of sensor coatings that are highly selective for contaminants of concern.

The EPA Measurement and Monitoring Technologies Development Program has focused its attention on immunoassay techniques and the development of fiber optic sensing for in situ analysis. Immunoassay techniques are not applicable for most of the contaminants identified at Hanford as shown in table B-1.[1] Fiber optic systems are an integral part of many in situ detection techniques, but further work is required to develop the appropriate sensor for contaminants of concern.[2]

In situ methods are limited by the need to develop new sensors to detect the contaminants of concern. Many of these emerging methods will provide the opportunity for real-time analysis and remote transmission of data. Real-time analysis may allow monitoring of disposal sites for signs of containment failure and monitoring around well fields for incoming contaminant plumes.

Techniques that are currently available for on-site or in situ measurements include field gas chromatography (GC) and specific conductance electrode screening (7). GC is useful for low-molecular-weight organics and for

[1]EPA has initiated work on immunoassays for benzene, toluene, ethylbenzene, phenol, chlorobenzene, and nitroaromatic compounds.

[2]Fiber optic sensors have been developed for chloroform, oxygen, carbon dioxide, pH, trihalomethane, and gasoline. EPA is currently working to develop sensors for benzene, cyanide, iron, nitrate, phosphate, toluene, and xylene.

Table B-1—Applicability of Chemical Sensors to Contaminants at Hanford

	Chemical sensors[a]									
Selected Hanford contaminants	Fluorescence spectroscopy	Surface-enhanced Raman spectroscopy	Spark excitation—FOSES[b]	Chemical optrodes	Stripping voltammetry	Catalytic S-M ion electrode[c]	Immunoassay sensors	Resistance/ capacitance	Quartz piezobalance	SAW devices[d]
Organics										
Carbon tetrachloride	NA	?	NA	?	NA	?	NA	?	?	?
Trichloroethylene	NA	?	NA	ppb	NA	?	NA	?	?	?
PCE, DCA, TCA, DCE[e]	NA	?	NA	?	NA	?	NA	?	?	?
Chloroform	NA	?	NA	ppb	NA	?	NA	?	?	?
Cyanide	NA	ppm	NA	?	?	ppb	NA	?	?	?
Methyl ethyl ketone	NA	?	NA	?	NA	?	?	?	?	?
Hydrocarbons	ppb	?	NA	ppb	NA	?	?	ppm	?	?
Inorganics										
Chromium(IV)	NA	ppm	?	?	ppb	ppb	NA	?	?	?
Fluoride	NA	NA	NA	?	?	ppb	NA	?	?	?
Nitrate	NA	?	NA	?	NA	?	NA	?	?	?
Uranium	NA	?	?	ppm	ppb	?	NA	?	?	?

[a] NA = Not applicable; ppm = parts per million; ppb = parts per billion; ? = Unknown.
[b] Fiber optic spectrochemical emission sensors
[c] Surface-modified
[d] Surface acoustic wave
[e] PCE = perchloroethylene; DCA = 1,1-dichloroethane; TCA = 1,1,1-trichloroethane; DCE = 1,2-dichloroethylene.

SOURCE: E.M. Murphy and D.D. Hostetler, "Evaluation of Chemical Sensors for In-Situ Ground-Water Monitoring at the Hanford Site," PNL-6854 DE89 011306 (Richland, WA: Pacific Northwest Laboratory), March 1989.

Table B-2—Relationship Between Remedial Technologies and Site Characterization

Technology	Specialized site/contaminant data
In situ vitrification of contaminants in soil	Soil electrical conduction and glassification properties, presence of groundwater, soil permeability, presence of metals
Soil washing to remove trace metals and radionuclides in soil	Distribution of contaminants as a function of soil particle size and density
In situ removal of gasoline in soil and groundwater by vacuum-induced venting	Clay content of soil, depth to groundwater
In situ destruction of 1,1,2-trichloroethylene and perchloroethylene in groundwater by using microbes	Soil nutrient content, soil ion-exchange capacity
Ultraviolet/ozone treatment of groundwater contaminated with 1,1,2-trichloroethylene	Iron and manganese content of groundwater; presence of long-chain organics
Reducing the natural rate of conversion of metallic mercury to organic mercury through biological processes	Characterizing the physical and chemical conditions in the environment that favor mercury-resistant microbes
Chemical extraction of contaminants from soil	Presence of refractory minerals in soil
Soil washing to remove organic contaminants	Amount of sand present in soil matrix
Ion-exchange processes to remove heavy metals from groundwater	Water hardness
In situ steam cleaning of soil contaminated with volatile organics	Vapor pressure of contaminant
In situ electroacoustical soil cleaning[a]	Clay content of soil

aThis system is an example of the application of coupled processes.

SOURCE: S. Cohen&Associates, 'Technologies for Identification, Characterization, and Remediation of Environmental Contamination at U.S. Department of Energy Defense Complex Sites," contractor report prepared for the OTA, unpublished, October 1989.

solution or vapor analysis. It is an on-site technique that requires that samples be extracted; therefore, it is subject to problems with sample integrity. Many compounds could be missed with this technique because it is not sensitive to high-molecular-weight organics, and it is difficult to interpret readings for complex mixtures of contaminants on the available field equipment. Specific conductance electrodes are useful for dissolved ionic contaminants and generic plume definition. Results reflect total concentration of metal salts in water, but the method is not specific and thus cannot distinguish between different sources of contaminants and natural background levels. Also, the technique does not give information on organics that may move through aquifers at different rates than dissolved metals. These limitations highlight the need for well-qualified people to use and interpret the results.

Predicting Fate and Transport

Predicting fate and transport of contaminants in groundwater is very site-specific and inherently uncertain. It depends on understanding the characteristics of the source of contamination, the nature of the geologic environment, the rate and direction of groundwater movement, and the behavior of contaminants in the subsurface.

Investigations of fate and transport performed in accordance with guidance documents and sound science are conducted to take full advantage of existing data and to incorporate many methodologies-including aquifer tests, modeling, treatability studies, and geophysical surveys--- prior to, and in conjunction with, drilling and sampling. Proper use of these methods requires a high level of expertise. Specific data requirements depend on the site, the nature of the problem, and remedial alternatives. Examples of data needs for specific remedial alternatives are shown in table B-2. Guidance from EPA describes strategies and methods for determining the hydrogeology, characterizing the contamination, evaluating plume movement and response, assessing design parameters for potential treatment technologies, and considering technical uncertainty (8).

Technical uncertainty is inherent in the prediction of the fate and transport of groundwater contaminants. It arises from inadequate knowledge in the following areas:

- the source of contamination (e.g., volume, concentration, and timing of contaminant release; physical, chemical, and biological characteristics of contaminants; contaminant dispersion and diffusion),
- the movement of contaminants through the unsaturated zone (e.g., hydraulic conductivity and potential moisture content of soil, chemical and biological characteristics of soil), and
- the rate and direction of groundwater flow (e.g., hydraulic conductivity; viscosity, density, permeability, anisotropy, and heterogeneity of hydrogeology; aquifer characteristics such as porosity and organic carbon content; aquifer stresses arising, for example, from groundwater pumping at other wells and natural or artificial recharge; seasonal variation in groundwater levels; tidal and pressure effects; storage characteristics of the aquifer; aquifer thickness, and areal extent) (9).

An example of these technical uncertainties that is directly applicable to several sites in the Nuclear Weapons Complex is poor understanding of the physical, chemical, and biological processes that affect contaminant movement. The mobility of certain radionuclides with colloidal organic material is poorly understood. Other parameters are impossible to measure with sufficient detail to provide accurate predictions of the magnitude and direction of contaminant transport, such as geologic heterogeneities (10). Because the long-term behavior of radionuclides can be highly dependent on local soil chemistry, which makes accurate prediction from generic models unlikely, radionuclide mobility is an active area of research for DOE and the Nuclear Regulatory Commission (NRC) (11). The use of innovative sampling methods, such as sampling vegetation to detect groundwater contamination in fractured or inhomogeneous media, is also an important area of research (12).

EPA guidance on technical uncertainty focuses on how to address it so that cost-effective decisions can be made about data collection to support cleanup decisions (13). EPA notes that reducing uncertainty should be weighed against time and resource limitations and that, often, remedy selection should move ahead by using the best professional judgment even if the level of uncertainty is high. Additional data are justified to the extent they can help distinguish the performance and uncertainty of remedial alternatives.

Recognition of uncertainty in both characterization and performance of remedial alternatives has led EPA to recommend modifying the Superfund approach to groundwater remediation (14). The major recommendation is to initiate early action on a small scale, while gathering more detailed data prior to committing to full-scale restoration. This approach is discussed in more detail under a following section, cleanup of groundwater contamination.

Geophysical and Remote Sensing Techniques

Geophysical and remote sensing techniques can potentially serve as a screening tool to describe the geological environment, identify areas of contamination, and monitor the performance of some remediation measures (15). Perhaps the greatest value of these methods is to characterize the heterogeneity of the environment, rather than to detect contamination (16). Box B-1 presents examples of the use of various techniques to characterize environmental contamination. These techniques can potentially provide continuous information on a site, and many can be applied remotely without exposing the operator to contamination. Most practitioners argue that drilling will always be necessary to interpret the resulting data accurately. However, these techniques can limit the number of wells required by helping to locate the wells so as to maximize information gained.

Different techniques are not applicable to all sites due to limitations such as rock and soil type, depth of penetration, and interference from natural or manmade features. Based on a relatively fast geophysical survey (completed in a matter of days), wells can be located to investigate anomalies, which can lead to more rapid identification of unknown or unexpected problems. The accessibility of these techniques, however, is constrained by the lack of qualified people and the availability of equipment.

Considerable basic research is needed to develop equipment and applications in this area. The greatest need, according to some practitioners, however, is to educate people to use available techniques in appropriate ways. The subject is highly complex, and each site presents its own challenges as to what approaches to use, in what sequence, and how to interpret the results. Flexibility is important in applying the techniques.

Some of the technology applied today was developed 30 to 40 years ago for the mining and oil industries. Applying this technology to environmental restoration problems in many cases requires reinventing old techniques, refining equipment for more portable field applications, making it feasible for use in contaminated areas, and modifying new computer imaging tools to aid in interpretation at the depths of interest.

Some geophysical techniques are widely used and accepted. Technologies that are sufficiently developed to be suggested by the U.S. Geological Survey as possible techniques for characterizing hazardous waste sites are described in box B-2. Borehole techniques are also widely used; these involve lowering a sensing device into a well or borehole to collect data that can provide information on the characteristics of geologic formations that affect the availability of water and the water quality. The use of borehole techniques is quite extensive in the petroleum industry. Hydrogeologic applications emphasize the use of electrical techniques (17).

Significant improvements continue to be made in the sensitivity and interpretative ability of geophysical techniques. Prospects for new geophysical technologies are good, although most will represent improvements on existing techniques and detection. The detection of organic compounds is problematic. Many remote sensing systems are rapidly being developed and improved for air, surface, and near-surface detection of contamination, including organics. New technologies being developed and identified by government experts as showing great promise for environmental restoration problems include infrared reflectance spectroscopy, complex resistivity, and geophysical diffraction tomography.

Computer Modeling

Modeling of groundwater flow and contaminant transport has a definite role to play in characterizing a contaminated site and in planning and implementing remedial activities. To play that role in an effective manner, users of the models must know their limitations,

Box B-1—Examples of Use of Geophysical Techniques in Site Characterization

1) Gravity and seismic methods to determine detailed bedrock structure and to identify buried bedrock channels filled with permeable deposits that provide a pathway for migration of contaminants. Helpful in selecting drilling sites.[1]

2) Seismic methods to define bedrock topography and terrain conductivity survey to locate possible leaching field or buried drums. Combination of two techniques was necessary to help interpret results.[2]

3) Seismic methods for investigating boundaries of glacial units.[3]

4) Ground-penetrating radar to map water table in glacial outwash. Accuracy was within 2 feet (would not meet EPA standards for accuracy under RCRA).[4]

5) Ground-penetrating radar to provide information on the scale of heterogeneity of the aquifer and to monitor plume position and movement from a municipal landfill in glaciolacustrine sand. The upper surface of the plume was readily monitored.[5]

6) Magnetic methods and computer mapping to design a program of excavation and drum removal. Analysis took 6 days to complete and resulted in reducing excavation area from 2.5 to 0.3 acres.[6]

7) Electromagnetic and resistivity methods to monitor groundwater at a sanitary landfill. To design monitoring program, various geophysical methods were tested, interferences were identified, and seasonal fluctuations were defined. Similar area with known contamination was compared, showing significant differences from uncontaminated areas.[7]

8) Surface electrical resistivity to map fractures in bedrock and identify areas open to movement of groundwater in a crystalline bedrock formation.[8]

9) Promising field tests on the use of geophysical diffraction tomography to identify buried waste such as drums or trenches and to detect and locate leaks in buried hazardous liquid storage facilities.[9]

[1] E.B. Rodriguez, "Application of Gravity and Seismic Methods in Hydrogeological Mapping at a Landfill Site in Ontario," *Proceedings of the First National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring and Geophysical Methods,* May 1987.

[2] D.W. Hall and D.L. Pasicznyk, "Application of Seismic Refraction and Terrain Conductivity Methods at a Ground Water Pollution Site in North-Central New Jersey," Ibid., pp. 505-524.

[3] A. Streitz, "Off-End Surface Seismic Reflection Sounding With Vertical Seismic Profiling in Glacial Terrain," Ibid., pp. 525-537.

[4] D.G. Johnson, "Use of Ground-Penetrating Radar for Determining Depth to the Water Table on Cape Cod," Ibid., May 1987, pp. 541-554.

[5] T.M. Cosgrave, J.P. Greenhouse, and J.F. Baker, "Shallow Statigraphic Reflection from Ground Penetrating Radar," Ibid., pp. 555-569.

[6] J.F. Blasting, "Characterization of an Abandoned Waste Site Using Proton Magnetometry and Computer Graphics," Ibid., pp. 573-584.

[7] J.O. Rumbaugh, III, J.A. Caldwell, and S.T. Shaw, "A Geophysical Ground Water Monitoring Program for a Sanitary Landfill: Implementation and Preliminary Analysis," Ibid., pp. 623-641.

[8] G.A. Johnson and T.E. Saylor, "Detailed Subsurface Mapping of Fracture Closure in a Crystalline Bedrock Formation," Ibid., pp. 643-657.

[9] A. Witten and W.C. King, "Sounding Out Buried Waste," *Civil Engineering,* May 1990, pp. 62-64.

apply them in appropriate situations, and interpret the results accordingly.

Models can be useful tools for understanding some elements of groundwater and contaminant transport at a site. Because of the complex nature of the subsurface, models can be used to evaluate data and to form and test hypotheses of subsurface behavior. For example, modeling studies at the Feed Materials Production Center in Femaid, OH, contributed to understanding the role of the storm sewer outfall and the waste storage pit area as sources of contamination; identified the possible presence of a previously unknown groundwater divide that could affect local contaminant transport; and helped to refine groundwater monitoring programs (18). Models have also been used to compare remedial alternatives.[3] However, modeling alone is not sufficiently refined to confidently predict the transport and fate of complex mixtures of contaminants, exposure pathways, and effectiveness of remediation technologies.

Moiels differ in purpose, complexity, data requirements, and level of skill required of the user. Screening models have minimal data requirements and are useful for

[3] For example, drains, a slurry wall, and a clay cap were evaluated by using models for a landfill, and pump and treat technology has been modeled at several sites. See P.F. Andersen, C.R. Faust, and J.W. Mercer, "Analysis of Conceptual Designs for Remedial Measures at Lipari Landfill, N.J.," *Ground Water*, vol. 22, No. 2, March-April 1984, pp. 176-190; D.S. Ward et al., "Evaluation of a Groundwater Corrective Action at the Chem-Dyne Hazardous Waste Site Using a Telescopic Mesh Refinement Modeling Approach," *Water Resources Research*, vol. 23, No. 4, April 1987, pp. 603-617; C.R. Faust et al., "Simulation of Three-Dimensional Flow of Immiscible Fluids Within and Below the Unsaturated Zone," *Water Resources Research*, vol. 25, No. 12, December 1989, pp. 2449-2464; and J.W. Mercer et al., "Modeling Ground-water Flow at Love Canal, New York," *Journal of Environmental Engineering*, vol. 109, No. 4, August 1983, pp. 924-941.

Box B-2—Geophysical Methods

Radiometric Methods—Radiometric techniques measure the radiation emitted from radioactive isotopes. Radioactive contaminants may be masked by high background levels of natural radioactivity or by roughly a meter of overlying soil cover (depending on the type and strength of the source). These are generally useful only at radioactive waste disposal sites. However, they may be useful in locating natural radioactive hazards (e.g., radon gas sources), early radium processing plants, mining mill tailings, and other similar sites.

Magnetic Methods—Magnetic techniques measure perturbations in the earth's natural magnetic field near magnetic objects such as iron drums or barrels. Large concentrations of iron or steel fences, utilities, culverts, vehicles, or buildings may interfere with the technique. Soils with high iron content (e.g., greensand, basalt, red hematitic soil) may be sufficiently magnetic to hide objects detectable under other soil conditions.

Electromagnetic Methods Induction (EMIs)—EMIs are electromagnetic techniques that induce currents in the earth. They measure the magnetic field generated by the induced currents. The electrical conductivity of the earth is proportional to the magnetic field generated from the induced currents. The depth of investigation is a function of the instrument coil spacing and orientation, the frequency of measurement, and the electrical conductivity of the ground. By measuring and mapping the changes in electrical conductivity, EMI may directly locate plumes of inorganic contaminants, clay lenses, metallic objects such as buried drums, and inhomogeneities in geology such as fractures. EMI techniques are ineffective in areas with many fences, pipelines, telephone cables, or other metallic interference. EMI requires topographic correction. EMI techniques are readily available commercially, relatively inexpensive, and require one- or two-worker crews. EMI methods gather data very quickly over large areas, whereas resistivity methods are preferred for sounding to acquire depth information

Soil Gas Methods—Soil gas techniques measure the variation in concentration of gaseous vapors collected just below the ground surface. Collected vapors are analyzed by portable gas chromatographs or mass spectrometers to identify particular compounds of interest. The sampling zone may be at or within a few meters of the surface. Airborne or near-surface contamination may bias interpretation of underground contaminants. Permeability variations at the site from utility corridors, clay layers, or fractures will modify the apparent contaminant patterns at the surface, requiring careful interpretation. Driving gas sampling probes into the ground to avoid surface or airborne contamination may pose a safety hazard if utilities or near-surface barrels are punctured. Soil gas sampling is insensitive to nonvolatile organics and cannot detect inorganic contaminants.

Complex Resistivity Methods—Resistivity techniques use electrodes in contact with the ground to measure electrical resistivity (the reciprocal of conductivity). The depth of investigation is a function of electrode spacing and geometry (larger spacings probe more deeply). By measuring and mapping the changes in electrical resistivity, these techniques may directly locate plumes of inorganic contaminants, clay lenses, metallic objects such as buried drums, and inhomogeneities in geology such as fractures. Resistivity techniques are ineffective in areas with many fences, pipelines, telephone cables, and other metallic interference. Resistivity techniques may require topographic correction, are readily available commercially, are relatively inexpensive, and require one- or two-worker crews. Resistivity measurements are preferred for sounding to acquire depth information, whereas EMI provides easier and faster areal mapping. Complex resistivity methods measure resistivity as a function of frequency, and may be able to detect organic contaminants when they react with clay minerals. However, this is much more time-consuming and expensive.

Ground-Penetrating Radar (GPR) Methods—GPR measures changes in the velocity and mode of propagation of electromagnetic energy in the ground. Such changes typically occur from changes in water content and bulk density. Thus, GPR is a sensitive indicator of soil stratigraphy and bedrock fracturing and is an excellent way to map the water table. GPR may sometimes directly detect organic contaminants, either by changes in scattering properties (the texture of the radar record) or by dielectric contrast (e.g., oil floating on water). GPR works well in high resistivity environments such as dry or freshwater saturated coarse sand or granite. Low-resistivity salt water and clays such as montmorillonite severely limit the depth of penetration and the effectiveness of GPR.

Gravity Methods—Gravity techniques measure changes in the gravitational field of the earth. These changes are interpreted in terms of changes in density and porosity in the ground. Gravity techniques require accurate location and topographical surveying, removal of regional gradients, and correction for tidal effects. They cannot directly detect contaminants. Microgravity techniques may be useful in locating trenches, voids, and incipient subsidence problems.

Seismic Methods—Seismic techniques measure changes in the propagation of elastic compressional or shear energy in the ground. They may be operated in reflection or refraction modes. They are sensitive to changes in density and water content. They are most useful in defining subsurface geological or hydrological structure. They cannot detect contaminants directly, although they may locate trenches or other disturbed burial zones in the ground. In urban environments, high noise or difficult coupling (through concrete or asphalt) may render them useless. Seismic and radar techniques are complementary because seismic methods work well in clay soils, whereas radar does not, and radar works well in loosely compacted sandy soil, whereas seismic techniques do not.

SOURCE: G.R. Olhoeft, "Geophysics Advisor Expert System," U.S. Geological Survey Open File Report 88-399, June 1988.

elucidating the role of specific processes in controlling system behavior and for providing guidance in early data collection efforts. More complex, data-intensive models can be used to test the validity of assumptions made about the site by a comparison of past and present system behavior with model predictions.

Before models can be used to predict the transport and fate of contaminants, exposure pathways, and effectiveness of remediation alternatives, a detailed understanding of the site is required. In particular, the processes controlling groundwater flow and contaminant transport must be identified. Mathematical modeling is not a substitute for data collection, and successful forecasting of detailed system behavior requires good quality, site-specific data.

Selection of an appropriate model requires consideration of the purpose for which the model is to be used, the characteristics of the site and the contaminants, the site-specific data available, the extent to which the model has been validated, the education and experience of the person using the model, and the computational facilities necessary. Selection and use of a model also requires training and experience. However, it is more important for the model user to have a good understanding of the basic geologic, hydrologic, physical, chemical, and biological processes that control groundwater flow and contaminant transport than to be a skilled mathematician or numerical analyst.

There are very definite limitations on the use of models to predict contaminant fate and transport and to plan site remediation. The extreme heterogeneity of the natural environment can make the use of models extremely difficult (19). Other limitations include the large amount of site-specific data required as a result of heterogeneity, incomplete understanding of some of the processes controlling contaminant transport and fate, an inability to solve the resulting mathematical equations in an efficient manner, and the unavailability of people with the ability to select, use, and interpret the models (20).

The effect of these limitations can vary with the characteristics of the site and the contaminants being modeled. Problems involving a small number of completely soluble, noninteracting contaminants in a relatively homogeneous subsurface environment can be modeled with a high degree of confidence. Most sites, however, do not meet such conditions. Deviations from these conditions will reduce the level of confidence that can be placed in model results, particularly if one is looking for a detailed description of system behavior.

Uncertainties in model predictions result largely from a lack of detailed information about the site. Research is currently underway on methods of characterizing this uncertainty in a useful manner and on techniques to combine modeling and data collection in order to reduce uncertainties in the most efficient way. Research is also being carried out on the use of stochastic modeling techniques as a possible means of dealing with uncertainties in model predictions, but their applicability to waste site remediation projects has not been tested (21). One of the most advanced approaches involves combining computer simulation techniques for predicting contaminant migration with advanced mathematical and statistical methods for determining the most effective and economical pumping locations and rates to withdraw water for treatment (22).

Flow and transport through fractured rock environments, problems involving multiphase fluid systems (nonaqueous liquids), and chemical reactions other than simple appearance or disappearance of a chemical are examples of conditions for which good models are not available and little successful experience exists. These are all active areas of research, and the situation is slowly improving (23).

Modeling will be most effective when used in an interactive manner with data collection and site cleanup activities. Modeling can be used *to* guide data collection activities; in this way, the additional data can be used to refine the model, which, in turn, can provide guidance for further data collection, until a good understanding of system behavior is obtained. Modeling can be used in a similar manner to guide the operation of a cleanup system at the site.

CLEANUP OF GROUNDWATER CONTAMINATION

Once contamination has reached groundwater, it may be very difficult, expensive, and time-consuming to clean up. In some cases, cleanup maybe an unrealistic goal, and alternatives such as containment or treatment at the point of use may be appropriate.

The first steps in remediating a groundwater contamination problem, after initial characterization, are to prevent the spread of the contamination plume with a containment system and to eliminate the source. In addition to eliminating the source of contamination, such as leaking tanks or a surface impoundment, contaminated soils must often be cleaned up or isolated so that water moving through a contaminated unsaturated zone does not carry contaminants to the groundwater.

The major difficulty in restoring groundwater quality is associated with gaining access to the contamination—either by extracting the groundwater for treatment at the surface or by reaching contamination with in situ methods.

Recognizing these difficulties, EPA has made several recommendations for modifying the Superfund approach to groundwater remediation (24). The primary goal of

Superfund-to return groundwater to its beneficial uses within a reasonable timeframe-is retained. Recommendations encourage data collection to allow the design of an efficient cleanup approach that more accurately estimates the time required for remediation and the practicability of achieving cleanup goals. This entails initiating staged action and collecting specific data to optimize design and performance. It also entails recognizing the uncertainties associated with remediating contaminated groundwater, informing the public of these uncertainties, and developing contingencies to respond to new information and performance problems. EPA rec--ommendations are described in box B-3.

The new recommendations are directed to responsible EPA regional officials. DOE headquarters has endorsed this basic approach, also known as the observational method, and now has consultants educating field office personnel on use of the observational method in remediation programs. The approach has been criticized for application to non-Federal Superfund sites as primarily an effort for cleanup contractors to minimize their liabilities (25). Contractors contest these criticisms by stating that the motivation for applying the observational approach is to avoid conducting studies and collecting data for no useful purpose, and to move ahead with remedial activities while recognizing the inherent technical uncertainties (26).

There is a need to be explicit with the public about the uncertainties posed by characterization and cleanup, to optimize resources for characterization and cleanup, and to recognize that cleanup efforts must be monitored for their effectiveness so that modifications to remedial activities can be implemented when problems are recognized.

Box B-3—EPA Recommendations To Modify the Superfund Approach to Groundwater Remediation

1. *Initiate Response Action Early*—"Response measures may be implemented to prevent further migration of contaminants if they will prevent the situation from getting worse, initiate risk reduction, and/or the operation of such a system would provide information useful to the design of the final remedy." EPA provides examples of when such an approach is warranted, e.g., when contamination is migrating rapidly and when sites are located near drinking water wells that can potentially be affected by the plume. Advice is also given on implementing remediation measures in a staged process when data collected during the remedial investigation/feasibility study were insufficient to optimize design. By monitoring the response of contamination to the staged remedy, the system can be modified to address the problem efficiently.
2. *Provide Flexibility in the Selected Remedy To Modify the System Based on Information Gained During Its Operation*—EPA's discussion of this recommendation focuses on the uncertainty associated with reducing groundwater contamination to specified levels. EPA emphasizes the importance of informing the public of these uncertainties, developing contingency plans within the framework of a record of decision (ROD), and recognizing when it may be necessary to modify a ROD. EPA also discusses the importance of continuing monitoring activities after remediation measures have been completed to ensure that contaminant levels do not recover. EPA plans to develop future guidance on when it is appropriate to terminate groundwater extraction activities if some portion of groundwater cannot be returned to its beneficial uses.
3. *Collect Data To Better Assess Contaminant Movement and Likely Response of Groundwater to Extraction*—EPA's discussion of this recommendation lists the types of data required to improve the design and predict the performance of groundwater pump and treat systems. Evaluation of ongoing systems has revealed many deficiencies.

SOURCE: U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, "Considerations in Ground Water Remediation at Superfund Sites," OSWER Directive 9355.4-03, Oct. 18, 1989.

Groundwater Extraction

Extraction of groundwater for treatment is currently the primary method of groundwater remediation. Technologies to extract contaminated groundwater for treatment have limitations that make it difficult to predict the amount of time required to remove sufficient concentrations of contaminants. Limitations include adsorptive partitioning of contaminants between the aquifer and aquifer materials, and diffusion of contaminants into the small pores of the aquifer materials, which increase the amount of time required for remediation; aquifer heterogeneity, which makes it difficult to control groundwater flow; and residual contaminant sources in the soil or in a nonaqueous phase, which replace the dissolved contaminants as they are removed. In some cases, when sources of contamination cannot be eliminated, it may be necessary to operate pump and treat systems for long periods to achieve the desired reductions in contaminant concentrations.

There are two basic methods for extracting groundwater: pumping systems and passive systems. Both are based on two assumptions: 1) that it is possible to design a system that will withdraw all the contaminated water (this can be a problem in aquifers of low transmissivity, which do not release much water to wells, or in aquifers that have zones of low permeability, such as clay lenses); and 2) that the contaminants will come out of the aquifer with the water (this can be a problem if contaminants are sorbed onto aquifer materials or are present in a nonaqueous phase). Nonaqueous-phase contaminants may be either more or less dense than the groundwater. When dense nonaqueous-phase liquids (e.g., TCE and some other solvents) are present, they may be difficult to locate, and aquifer restoration may be judged impossible (27). When less dense, nonaqueous phase liquids (e.g., many petroleum products) are present, prospects for cleanup are improved by the use of additional restoration techniques such as vapor extraction or bioremediation.

Pumping systems, or wells, can extract or divert groundwater at virtually any depth. The system should be optimized to remove contaminated groundwater while extracting only a limited volume of uncontaminated water. More information on the design of pumping systems is discussed under a following section, *Containment and Flow Control.*

Passive interceptor systems can be excavated to a depth below the water table with the possible placement of a pipe to collect contaminated water or to lower the water table beneath a contamination source. These systems are relatively inexpensive to install, have low operating costs because flow is by gravity, and provide a means for leachate collection without impermeable liners (28). Although these systems can be more effective than wells for extracting water from some lower permeability materials, they are not suited to all low permeability conditions. They are limited in depth to the capabilities of trenching equipment (about 100 feet) and require continuous and careful monitoring to ensure adequate leachate collection (29).

Treatment After Extraction

Surface treatment techniques developed for water or wastewater are available for most contaminants.[4] However, treatment systems for extracted water must be designed to deal specifically with the mixtures of contaminants and varying concentrations present at a site. Combinations of treatment processes may be required, and there is little experience designing systems to handle the mixtures of organics, radionuclides, and inorganics that may be present. Some processes are not applicable to the low concentrations of contaminants in question. Measures are required to discharge treated water back to the subsurface, to surface water, or to further treatment at a treatment plant. Some processes also generate residuals that must be handled as hazardous waste.

A description of various physical, chemical, and biological treatment techniques and some of their important limitations are presented in the EPA handbook on groundwater (30).

DOE has sponsored research on several technologies for groundwater treatment including supercritical water oxidation, solar destruction, and ultraviolet ozonation. Many of the new technologies are potentially applicable to a range of organic waste streams with a high destruction efficiency. The applicability of technology developed by DOE for waste treatment and minimization is also being tested for groundwater treatment.

In Situ Biological Treatment

Technologies to treat contaminated groundwater in situ are at an early stage of development and, for the most part, will face many of the same technical limitations as efforts to extract groundwater for treatment. There is little field experience with actually restoring groundwater quality using in situ biological methods. However, recent pilot-scale field studies have provided enough data to show that the approach is feasible for some contaminants (especially hydrocarbons) and sites, if proper site characterization and feasibility studies are carried out (31). Sites with complex hydrogeology will greatly reduce the chances of successful biorestoration, regardless of the nature of the contaminants.

In situ biorestoration usually involves stimulating microorganisms that are present in the environment so that they transform contaminants into (ideally) harmless compounds more rapidly than they would under natural conditions. The technique can potentially transform contaminants sorbed to the aquifer material, dissolved contaminants, and nonaqueous-phase liquids.[5] Stimulation involves injecting oxygen or nutrients into the environment, but the characteristics of the environment may make it impossible for the stimulants to reach the appropriate areas (32). Again because of variations in the environment, microorganisms, if they are present, may not be able to gain access to all the contaminants. Another problem associated with the technique is possible formation of byproducts that are more toxic or mobile than the original contaminants. For example, TCE has been shown to degrade into vinyl chloride, although it has been demonstrated that vinyl chloride can be oxidized by other organisms (33).

Implementing in situ biorestoration requires several factors: very detailed site characterization, laboratory feasibility tests to determine both the nutrient requirements of the microorganism and the compatibility of the nutrients with the subsurface environment, system design, and monitoring (34). Moving from the laboratory to the

[4]Although treatment techniques are not available for tritium, many scientists believe that this is not a problem because means can be used to Prevent its migration while it decays naturally. Others, however, are concerned that migration could be more serious than currently understood.

[5]Biorestoration also has the potential to remediate the unsaturated zone. 'f'his is necessary to prevent contaminants that are trapped in pore spaces above the water table from being continually leached into the groundwater below.

field is very difficult, and field conditions can vary significantly, changing expected results (35). Research by ERA has shown that laboratory experience can be extrapolated successfully to field scale if performed in conjunction with a thorough site characterization study (36). These steps require a high degree of expertise in both hydrogeology and microbiology.

To date, most experience within situ biorestoration has involved remediating hydrocarbon spills in aerobic environments. Often, in situ remedies are combined with groundwater extraction and surface treatment, and integration into a welldesigned treatment system is considered by some researchers to represent the greatest potential of the technique (37).

Research is underway to define and stimulate other mechanisms for biotransformation, including anaerobic environments; organisms that use methane, nitrogen, sulfur, or lactate compounds as terminal electron acceptors; cometabolism and cooxidation; and proprietary microbes or genetically engineered organisms. Research in these areas has begun to demonstrate that some chemicak previously thought not to biodegrade can be biotransformed under the proper conditions. Research has also shown that the use of anaerobic biodegradation may be effective for aromatic hydrocarbons and may overcome the difficulty of providing sufficient oxygen to contaminated areas (38). However, the management of mechanisms such as cometabolism that do not use the contaminant as a growth substrate is very complex and will require considerable research before it is ready for field application (39).

Models are also being developed to predict contaminant transport affected by biodegradation to help design treatment systems and predict the time required for operation (40).

DOE contends that bioremediation is potentially the least costly of all groundwater treatment technologies for the destruction of organic contaminants (41). Although some costs will probably be much lower for in situ bioremediation compared with technologies that require extraction, other costs incurred by testing and analysis, potentially long treatment times, and the need to use containment technologies make it difficult to bakmce remediation costs (42).

In Situ Chemical and Physical Treatment

In situ physical and chemical techniques require very detailed site-specific knowledge of the contaminants present, their concentration, and extent. Problems include controlling the contaminants, the reactions that occur, and any chemicals that might be injected or placed in the environment to react with contaminants. Experience with these approaches is limited.

In situ chemical techniques involve adding chemicals to the groundwater to treat specific contaminants. Examples include making metals insoluble and immobile with alkali or sulfides, oxidizing cyanides with sodium hypoehlorite, encapsulating contaminants in an insoluble matrix, precipitating cations by adding anions or oxygen, and using reducing agents to render hexavalent chromium insoluble (43). Chemicals are either injected into wells or placed in shallow, permeable treatment beds. The use of treatment beds provides opportunities to remove contaminants by adsorption on activated carbon, zeolites, and synthetic ion-exchange resins.

As with biological techniques, problems include access to the contaminants of concern and the potential formation of toxic byproducts. The process may also interfere with groundwater flow patterns, and contaminants can be diverted to other areas.

In situ physical techniques include thermal or steam flooding (used to recover hydrocarbons at shallow depths), alcohol flooding to dissolve hydrocarbons, radio-frequency in situ heating, and in situ vitrification (44). These approaches are primarily applicable to soil.

Containment and Flow Control

Technologies to control contaminated groundwater either by containing plume movement or by ensuring discharge to surface water to provide for the dilution of contamination are subject to many of the same problems associated with characterization. However, the data requirements are generally fewer for containment than for actual cleanup. The basic data required to implement a containment system are the horizontal and vertical locations of the contaminant plumes and the gradient and flow rate of the groundwater. It is not necessary to evaluate factors that tend to slow the movement of contaminants, such as sorption characteristics or diffusion Imitations of the contaminants in the subsurface. More detailed data may be required for dense, nonaqueous-phase liquid contaminants that, depending on the hydrogeologic environment, may move in a direction different from groundwater. Another reason more detailed information is required for effective containment is the occurrence of unexpected forms and mixtures of contaminants that are more mobile than anticipated-a factor at sites within the Nuclear Weapons Complex.

Examples of unexpected contaminant forms include plutonium and americium contamination of groundwater within a canyon at Los Alamos National Laboratory (45). Laboratory studies had predicted that these substances would *move* less than a few meters, but both have been detected in monitoring wells 1,000 feet downgradient from the point of discharge. Investigation has shown that most of these radionuclides moved in association with colloids. The portion of americium unassociated with colloids exists in a low molecular-weight form and appears to be a stable, anionic complex of unknown composition. Another example of unexpected contaminant mobility is cobalt-60 at Hanford. In this case, cobalt-60, which is usually immobile, has probably been chemically complexed and mobilized by cyanide (46).

Migration control relies on the use of hydrodynamic or other physical barriers to affect the movement of contaminated groundwater. To establish such control, the groundwater flow system and spatial distribution of the contamination must be well understood. Control may also depend on establishing institutional regulations on water use.

Relatively simple analytical methods are available for designing control systems where groundwater flow is uniform and unidirectional, but this is rarely the case. Other groundwater wells, seasonal changes in surface water levels, heterogeneity in aquifer properties-all increase the complexity. The heterogeneity of aquifer properties is most severe in fractured rock or karst aquifers. In such systems, the design of remedial measures may be reduced to trial and error (47). Although computer models may be useful in designing such systems, very thorough site investigations may be required, and there will still be uncertainty about the model's accuracy. Nevertheless, models can be valuable, if calibrated and verified with site-specific data and sensitivity analyses conducted to determine appropriate safety factors immigration control system design. Monitoring is needed to verify the effectiveness of containment and flow control measures.

Hydrodynamic barriers involve changing groundwater flow patterns either by extracting or by injecting water to prevent contaminants from moving in an undesirable direction (e.g., toward a well field, another aquifer, or surface water) or at an undesirable rate. Depending on conditions, different techniques might be used, including well points, deep wells, and pressure ridge systems.

Physical barriers to control contaminated groundwater must be designed to be impervious to the combinations of contaminants that may be present. In general, these techniques are not considered to be proven, long-term solutions. Barriers include slurry trench walls, grout curtains, vibrating beam walls, sheet piling, bottom sealing, block displacement, and membrane and synthetic sheet curtains (48). The approach and design used depend on site-specific conditions. Basically these barriers work by preventing contaminated groundwater from moving beyond the area that is already contaminated. In many cases, this improves the efficiency of groundwater extraction and treatment because it limits the volume of clean water that is drawn into treatment systems along with contaminated groundwater. The integrity of these techniques can be verified by geophysical methods.

These physical barriers are often designed in conjunction with surface water controls to minimize infiltration of water from the surface to the groundwater. Surface controls include changing the contour to divert surface water from the area, installing a cover barrier to prevent water from entering the site, and revegetating to stabilize soils and reduce infiltration.

DEPARTMENT OF ENERGY ACTIVITIES

DOE recognizes the diflicdties associated with characterizing and cleaning up contarninated groundwater (49,50). It places a great deal of emphasis ontheprospects for developing: 1) characterization techniques that are not dependent on drilling wells or boreholes and 2) in situ techniques to clean up contaminated soil and groundwater. Given general progress in the field of groundwater remediation, great strides in these areas are likely to be made within the next decade. In fact, new characterization and monitoring equipment is becoming available. For example, an infrared sensor to detect liquid contaminants such as fuel oil or solvents within soil has been developed by the Pacific Northwest Laboratory and is available for commercialization and manufacture.

Despite these plans and prospects for future technology development, contamination problems are being addressed now under the regulatory structure of RCRA and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and under agreements developed by DOE, EPA, and the States. According to EPA personnel, as of January 1990 all but the Nevada Test Site had completed the preliminary analyses under RCRA or CERCLA (51). Numerous solid waste management units continue to be identified as part of the ongoing effort to characterize problem areas. The regional site hydrogeology is reasonably well understood at all the sites. However, due to the size of the sites, complexity of the subsurface, complexity of the waste, or lack of sufficient reliable information, additional hydrogeologic characterization is required at all sites to understand the site-specific occurrence and use of groundwater and the movement of groundwater and contaminantts. This additional information will be collected as part of the RCRA facility investigation or CERCLA remedial investigation phase, which is expected to begin within the next 5 years. The status of groundwater investigations at each of the DOE weapons facilities is presented in appendix A.

Although characterization studies are underway, the extent of contamination, including potential off-site contamination, has not yet been identified at many sites. In most cases, the types and concentration of hazardous constituents have yet to be determined. Information on the fate and transport of contaminantts and the risks to human health and the environment will have to be developed under the continuing characterization process. Groundwater remediation has been initiated at a small number of sites by using either pump and treat systems, or pump and treat with French drains or interceptor trenches. Treatment consists of air stripping, ultraviolet light exposure, physical/chemical treatment, and ozonation.

Although the cleanup work is in its very early stages, investigations of ongoing efforts by both EPA and DOE reveal deficiencies in the handling of groundwater problems at DOE sites, as described below.

Groundwater Cleanup at the Savannah River Plant A/M Area

Groundwater remediation has been underway since 1983 at the Savannah River A/M Area. This is one of 19 pump and treat projects included in a recent EPA review of the effectiveness of pump and treat systems (52). The case study prepared for EPA on this project reveals many of the pitfalls common to pump and treat projects that must be overcome if this type of cleanup approach is to be successful.

The case study reveals numerous problems with the pump and treat system at the Savannah River Site. The site was not adequately characterized, and the system was not adequately designed to meet a goal that was set without consideration of health-based criteria. The study concluded that the pump and treat system would not achieve its goal of removing 99 percent of the estimated contamination dissolved in the groundwater within 30 years, nor was the system meeting its objectives of containing the spread of the plume and preventing the downward migration of contaminants (53). This is partly because the pump and treat system was not designed to account for contamination that was sorbed onto the soil. The pumping system was not adequately designed. Wells were not screened to capture contamination from lower permeability areas, and pumping rates were insufficient to prevent downward migration or to recover contamination except in areas close to the wells.

Despite these deficiencies, it is important to note that the pump and treat system has effectively treated significant quantities of contaminants, has been approved by the appropriate regulatory agencies, was put in place quickly, is reviewed on a regular basis, and is modified as required (54). It is also important to note that this project was initiated outside the RCRA/CERCLA regulatory framework (55). The goal of 99 percent removal within 30 years was never intended as the basis for a cleanup criterion or a deadline for turning off the system. Rather, it was intended as a simplified estimate for gauging performance. The final cleanup standards and overall system will be determined by periodic negotiations with regulators and by updating the system. Further study has revealed that the downward migration of contamination was caused by another source, and the remediation plan has been modified to address this problem. The technical deficiencies of the system have been recognized, and plans have been proposed to expand the system to include, forexarnple, vacuum extraction of the unsaturated zone to eliminate residual sources before they slowly leach into the groundwater. New remediation technologies will be tested in this area, including a process developed at the site-in situ air stripping by using horizontal wells; this represents the first application of directional drilling (frequently used in petroleum recovery) to environmental restoration activity.

This example of system implementation, evaluation, and modification including the use of new technologies, is typical of what is likely to be encountered as more efforts are made to clean up contaminated groundwater. As new information is obtained while the performance of remediation activities is being evaluated, it may be necessary to modify or expand system design and to modify agreements that have been reached about the level of cleanup or the time required to reach that level. To enhance the chances that these modifications will be accepted by the public, likely problems and deficiencies must be identified, along with possible contingencies, as early as possible when remedial measures are being planned.

Inadequate Performance on Groundwater Problems at Other Department of Energy Facilities

The problems identified at the Savannah River Site are not unique to that facility. The EPA study reveals similar problems at most of the pump and treat projects evaluated. Other investigations have revealed problems with groundwater monitoring programs at various DOE facilities, which include the following:

- Pantex Tiger Team---inadequate groundwater monitoring program and unknown integrity of underground storage tanks and pipes (56);
- Fernald-EPA inspection in August and October 1989 (57) found inadequate monitoring database (58);
- Rocky Flats Tiger Team inadequate characterization of soil and groundwater contamination at inactive waste sites, lack of adequate upgradient background monitoring wells, use of groundwater monitoring wells of unknown construction, lack of comprehensive organized groundwater database, deficiencies in groundwater sampling procedures, lack of adequate quality assurance/quality control of work products, deficiencies in well filter construction (59);
- Oak Ridge (Y-12) Tiger Team-inadequate monitoring of wells and sampling procedures, including access to wells, monitoring well conditions, ground-

water level measurement procedures; problems with alternate concentration limits program (60); and

. Mound Tiger Team inadequate monitoring wells and insufficient groundwater monitoring programs (61).

CONCLUSION

Given the limitations of current approaches to both characterization and cleanup of groundwater, it may be appropriate to consider a range of other methods for protecting this resource.

First, it is important to prevent contamination from occurring in the first place, by following best management practices and existing environmental regulations to avoid spills, accidents, or leaks and to identfy and address them when they occur. Efforts should be made to remove the sources of contamination to prevent further contamination from occurring.

Second, more people with sufficient expertise are needed to conduct and review any efforts to actively address groundwater contamination problems.

Third, characterizing the extent of contamination and preventing existing contamination from spreading by implementing containment measures early can provide useful information for the design and implementation of cleanup technologies. Cleanup should be approached in a realistic manner, by clearly communicating to the public the uncertainties associated with characterization and cleanup.

Fourth, it may be appropriate to consider treating groundwater at the point of use, rather than trying to restore some aquifers. Such an approach would require the development of low-cost water monitoring and treatment methods suitable for nonpublic water supplies, including private wells, irrigation wells, and wells used to obtain water for livestock. This approach may be inappropriate for radioactive contaminants but could be suitable for other hazardous contaminants. DOE could work together with EPA to develop appropriate point-of-use and point-of-entry water treatment technologies.

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Appendix C

Costs of Environmental Restoration at the Department of Energy Nuclear Weapons Complex

INTRODUCTION

Much attention has been devoted to budgetary matters of late, with the Department of Energy (DOE) environmental restoration budget being no exception. The prospect of a long-term environmental cleanup at the Nuclear Weapons Complex, given the experience of Superfund cost inflation, raises serious concerns about funding requirements. Because of DOE's lengthy budgetary process, costs must be projected years into the future. With weapons production and engineering construction projects, cost estimators are usually dealing with known technologies and well-defiied specifications. With environmental remediation, however, technologies and specifications are much less well-defined. The art of environmental cost estimating is just now leaving its infancy.

Initial estimates have been made by DOE for its environmental restoration program, but the validity of these estimates has been widely debated. The uncertainty regarding environmental cost estimates may necessitate some divergence from the traditional defense budget allocation process. At the same time, some efforts are needed to reduce the uncertainty.

This appendix examines DOE's environmental restoration cost estimates in an attempt to get a clearer picture of the uncertainties involved. The aim of this analysis is to determine the mechanisms by which DOE estimates environmental restoration costs, to examine the divergence between those estimates and actual costs incurred, and to assess the implications of those findings for policymakers.

The process of environmental restoration is in the very early stages of a long-term (at least 30-year) process. Cost estimates for such a project are bound to have a large margin of error. Nevertheless, important decisions are based on them. The experience on which existing DOE estimates are based is very limited. Most environmental restoration (ER) projects are only at the stage of site characterization, a process that can vary considerably from site to site. Some remediation work, however, has been undertaken at DOE facilities. To shed some light both on DOE's estimation track record and on the potential for current estimates to vary, these remediation projects were examined in detail.

REMEDIATION PROJECTS FOR WHICH COSTS HAVE BEEN ANALYZED

The Office of Technology Assessment (OTA) identified a list of remediation projects at Nuclear Weapons Complex facilities for which estimated and actual cost data would be requested. Because of the limited number of remediation projects that have been completed in the recent past, the list was short. In drawing up the list, projects were chosen according to the following criteria:

1. Work on the project was completed or underway as of FY 1990.
2. The work planned represented typical remediation activity, in terms of the work breakdown elements, that may be expected to occur in remedial action at any industrial site.
3. The work, for the most part, was carried out under the environmental restoration portion of the Five-Year Plan, in most cases excluding decontamination and decommissioning (D&D) projects (in several instances, D&D and corrective action projects were included because they were very similar to ER-type projects and because few ER projects had been completed or initiated).
4. The list was confined to remedial activities as described above, to the exclusion of remedial investigation/feasibility study (RI/FS) work.

The list of projects was drawn primarily from information in the 1989 Five-Year Plan and the attendant activity data sheets (ADSs) and supplemented by discussions with DOE. Remedial activities completed or underway were identified at nine facilities: The Feed Materials Production Center (Femald), the Hanford Reservation, the Idaho National Engineering Laboratory (lNEL), the Kansas City Plant, the Lawrence Livermore National Laboratory (LLNL), the Oak Ridge National Laboratory (ORNL), the Oak Ridge Y-12 Plant, the Pinellas Plant, and the Savannah River Site. OTA was unable to obtain any information indicating that other remedial activities had been completed in the recent past. For projects that have not been completed, actual cost data were requested for the portion of the project completed as of the end of 1989.

Projects at those sites for which cost data were requested are as follows:

Fernald

- Groundwater monitoring well installation
- pumping of contaminated groundwater

Hanford Reservation

- A-29 Ditch interim remediation (interim activity deemed irrelevant to study; no cost estimate available on final closure)
- B-Pond interim stabilization (interim activity deemed irrelevant to study; no cost estimate available on final closure)
- 183-H solar basins decontamination and decommissioning
- Groundwater monitoring well installation (only some costs provided)

Idaho National Engineering Laboratory

- Idaho Chemical Processing Plant (ICPP) gravel pit and tank farm cleanup (data not available)
- SPERT IV waste removal and remedial action (only some data received)
- Capping of CPP injection well
- Groundwater monitoring well installation (only some data received)

Kansas City Plant

- *Rernov~* of Polychkxinated biphenyl (PCB) contaminated soils and capping at outfall 002

Lawrence Livermore National Laboratory

- Groundwater remediation at LLNL (received data on proposed groundwater remediation)
- Groundwater monitoring well installation

Oak Ridge National Laboratory

- SWSA 6 dynamic compaction and grouting demonstration projects
- SWSA 6 interim capping
- Groundwater monitoring well installation

Oak Ridge Y-12 Plant

- *S-3* Pond closure
- Oil land farm closure
- Groundwater monitoring well installation

Pinellas Plant

- Groundwater remediation at 4.5-acre site

Savannah River Site

- Closure of M-Area settling basin/Lost Lake
- AIM Area groundwater remediation
- Mixed waste management facility closure
- Groundwater monitoring well installation

Letters requesting specific information, including estimated costs and actual costs incurred, were sent to all appropriate field offices on the dates noted above. The purpose of requesting this information was to identify variations in unit costs among facilities, to determine the ability of contractors to estimate actual costs, to evaluate the potential for incurring unexpected costs for specific remediations, and to determine the ability of DOE/ contractors to retrieve detailed cost and site characterization information.

The cost information that has been supplied, in many cases, is rounded, aggregated, or disaggregate from information available to field engineers. As such, it may not represent *exact* **costs** for the activities shown. However, after lengthy conversations with field engineers at all of the responding facilities, OTA believes that considerable effort was made to provide data that is as accurate as possible. *Great caution should be taken in using these data for any purpose other than that intended in this report. The* manner in which many of the environmental restoration activities described in this report are accounted for makes extraction of specific unit costs difficult. OTA believes that although field engineers made every effort to portray unit costs accurately, further use of the data by other researchers should be preceded by direct communication with field personnel to avoid misunderstanding.

COST DATA PROVIDED BY FIELD OPERATIONS

Fewer than one-half of the data originally requested was provided. In most cases, both estimated costs and actual costs were not available. DOE does not routinely collect detailed cost information on its remedial actions but rather entrusts this responsibility to its contractors and subcontractors. At the majority of sites, OTA research efforts became productive only when contact was made with contractor personnel. Following is a summary of the information provided. All relevant field offices were given the opportunity to review this report in draft form.

Albuquerque Operations Office

The Albuquerque Operations Office (AL) maintains administrative responsibility for two of the projects listed-the 002 outfall at Kansas City and the 4.5-acre site at Pinellas. AL's initial attempt to estimate costs of environmental restoration at its field oillce in a comprehensive manner was begun in 1987, although some facilities prepared separate cost estimates (including Roe@ Flats, no longer reporting to AL, and Kansas City). This effort was undertaken by Roy F. Weston under contract to AL. Given the remediation needs of each facility, Weston estimated aggregated costs for each field office. These costs were never verified by AL but were apparently based on EPA unit cost assumptions.

After implementation of the Environmental Restoration (ER) Program in FY 1988, a detailed list of environmental problems was created for each field office for the ER program implementation plan, which identified expected remediation needs at the task level. To facilitate the estimation of costs for these tasks, AL again contracted with Weston to prepare a cost estimation document that could be used by the field offices. This document was completed in November 1988.

The cost estimation guidelines were divided into two sections. The costs for RI/FSs were based on the perceived complexity of the task-a one-stage characterization effort for simple tasks and a two-stage effort for more complex tasks. For remedial action costs, generic remedial actions were created for five cases, and work breakdown schedules were outlined for each. Unit costs were then developed and adjusted for location. These unit costs provided the basis for estimating the cost of each task at the field offices. Unfortunately, the assumptions used at the field offices for defining the tasks were not recorded; only the results (i.e., total costs) were put into the implementation plan. Because of time constraints, AL performed only a limited review and revision of these cost estimates prior to including them in the first Five-Year Plan issued by DOE in the fall of 1989. All of the costs estimated in this way were assigned a low level of confidence. AL identified, in the 1989 Five-Year Plan, a total ER fimding need of $1,439.8 million for FY 1989 through FY 1995. This includes assessment, cleanup, D&D, and research and development (R&D) at all priority levels.

In December 1989, AL requested backup information on assumptions made by the field offices in preparing the implementation plan to allow for a higher leveI of confidence in the estimates. The revised costs are being entered into a time-line computer program to allow schedule and cost tracking as each task proceeds. AL plans to request that all field offices for which it has responsibility use this or a similar format to provide detailed reports on ER tasks. This system should allow for more consistent and comprehensive reporting on ER activities among all of AL's field offices.

Pinellas Plant (see table C-1)

The total ER funding identified for the Pinellas Plant for the FY 1989-95 period was reported as $23.117 million in the 1989 Five-Year Plan. The corresponding amount identified for the 4.5-acre site remediation was reported as $4.5 million (an additional $750,000 was spent on the site prior to FY 1989) in the ADS. The level of confidence of this estimate was reported as high in the ADS, based on definitive design.

Table C-l-Costs Reported for Pinellas Plant

Monitoring well costs

Monitoring wells were installed as part of the site characterization phase. Over the period 1986-89,38 wells were drilled to depths averaging 20 feet. Total cost of monitoring well installation was $115,000, or about $150/foot.

Soil excavation and removal **(1986 doliars)**

Gost of soii excavation
- Actual: $20,000 ($66/ton) (This was estimated as the applicable portion of an $80,000 contract for characterization and an emergency removal.)

Cost of soil transportation (using a completely enclosed containerized vehicle)
- Actual: $25,000 ($0.165/ton-mile)

Cost of soil disposal
- Actual: $33,400 ($110/ton)

Groundwater extraction and treatment **(1989 dollars)**

Cost of recovery well installation
- Actual: $40,000 ($228/foot for seven wells averaging 25-foot depth)

Cost of well sampling
- Estimated: $20,000/year ($192 per sample) (Samples will be taken once a week, both before and after the water enters the air stripper.)

Cost of well operation and maintenance
- Estimated: $15,000/year (includes operation and maintenance on the air stripper)

Treatment facility construction cost
- Estimated: $50,000 (based on 30-gallon/minute treatment capacity, operating 24 hours/day, with 4 to 6 hours maintenance per month; this equals about 15 million gallons/year; $3,333 per million gallons of annual capacity)

Water discharge costs
- Estimated: $2.25 per thousand gallons (costs of discharge to POTW)

Cost of decommissioning
- Estimated: $35,000 (Treatment will take an estimated 2 to 3 years.)

SOURCE: Office of Technology Assessment, 1990.

The 4.5-acre site is located on private property adjacent to Pinellas Plant property. The site was used as a disposal area for drums containing solvents. The site was first investigated in 1985, and a Feasibility Study was completed in November 1987. The drums and the contaminated soil were removed to an EPA-approved landfill in 1985. That soil was never analyzed to determine contaminant levels. Low levels of contamination remain in an estimated 35 million gallons of groundwater, which is less than 20 feet below the surface (1).

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DOE has agreed to clean up the groundwater under the guidance of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA); however, no consent orders have been issued, and the site is not considered a Superfund site. The Florida Department of Environmental Regulation (FDER) is the relevant regulatory authority.

The surficial aquifer is about 25 feet thick, approximately 1 to 4 feet below the surface, and separated from the Floridan Aquifer by the Hawthorn formation. The saturated zone consists of fine sand, silt, and clay. The closest populated area is 0.5 mile north of the site. The initial Interim Remedial Action Plan (approved by FDER) consisted of pumping the groundwater from seven extraction wells to a holding tank. The water was discharged to a publicly owned treatment works (POTW). This activity was carried out from December 1988 to January 1989. At that time, a high concentration of methylene chloride was encountered, causing a temporary halt to the interim action. A new treatment system is now being designed that will include air stripping.

A total of 303 tons of contaminated soil was removed from the site in 1986 and disposed at an Environmental Protection Agency (EPA) approved landfill 500 miles away in Pinewood, SC. To treat the contaminated groundwater, seven extraction wells were drilled, each with 4-inch diameter, to a depth of 25 feet. Cleanup goals have not yet been established because the primary aim of this interim action is to draw the contaminant plume back onsite from adjacent property. Engineering cost estimates for the 4.5-acre site were made by CH2M Hill and reviewed by GEND Engineering, as well as by DOE personnel. CH2M Hill is the prime contractor for engineering design; as of January 1990, construction had not been started on the air stripper.

According to AL personnel, experience so far on this and similar projects indicates that because of a lack of staff expertise, DOE was not able to assess the validity of contractor costs. To solve this problem, AL has hired a contractor whose sole responsibility is to review feasibility studies and costs for ER projects.

Kansas City Plant (see table C-2)

The total ER funding identified in the 1989 Five-Year Plan for the Kansas City Plant amounted to $36.0 million for FY 1989-95. The total cost of the 002 outfall remediation was reported at $637,458 (incurred in FY 1988 and FY 1989 in the ADS). The remediation cost (excluding concrete flume construction, engineering, site work, and removal of contaminated liquids) was reported at $385,169 or $255/ton of contaminated soil. The costs reported are actual, and the level of confidence is therefore high. Estimated costs were not provided by DOE and were calculated by OTA with assistance from DOE field staff.

Table C-2-Costs Reported for Kansas City Plant
(1988 dollars)

Cost of excavation	
Estimated:	$7,266 ($8.40/ton based on removal of an estimated 865 tons; $14.53/cubic yard based on estimated 500 cubic yards)
Actual:	$12,674 ($8.40/ton based on removal of 1,509 tons; $10.56/cubic yard based on 1,200 cubic yards)
Cost of transportation (a long-bed, open-top, soft-cover truck was used to transport the soil 795 miles to Emelle, AL)	
Estimated:	$83,500 (estimated by OTA based on reported combined transport and disposal cost of $183,000; cost per ton-mile is not calculated because the density of the estimated 500 cubic yards of soil was unknown at the time, although it was believed to be less than actual)
Actual:	$115,875 ($0.09/ton-mile based on transport of 1,633 tons)
Cost of disposal	
Estimated:	$99,500 (estimated by OTA based on $184 per cubic yard of disposal cost for estimated 541 cubic yards of soil and kiln dust, includes proportionally the same amount of kiln dust as actually added; plant engineers indicated that the disposal cost was known at the time of estimate)
Actual:	$238,480 ($146/ton; $184/cubic yard)
Combined transport and disposal cost	
Estimated:	$338/cubic yard
Actual:	$274/cubic yard
Other costs (includes backfill and topsoil "cover" and fly ash)	
Estimated:	$15,417 (based on estimated use of 650 tons of clay and 88 tons of topsoil)
Actual:	$18,140 (based on use of 750 tons of clay and 83 tons of topsoil)
Total cost of remediation	
Estimated:	$205,683
Actual:	$385.169

SOURCE: Office of Technology Assessment, 1990.

The 002 outfall contaminated area comprised less than 1 acre containing 1,200 cubic yards of soil (about 200 cubic yards was sediment of higher contamination) contaminated with PCBs, with concentrations as high as 792 parts per million (ppm)[1]. Approximately 1,509 tons (based on a soil density of 1.26 tons per cubic yard) of contaminated soil were excavated from the outfall to a level of 1 ppm, combined with 124 tons of kiln dust, and disposed offsite in Emelle, AL. Clean clay soil (750 tons) was used to refill the area, and a concrete flume was constructed from the storm sewer discharge point to the Indian Creek. A layer of topsoil (83 tons of material) was placed over the surrounding area. Work was completed under the Toxic Substances Control Act (TSCA), prior to signing a Consent Agreement. EPA Region VII had regulatory control of the cleanup. The remediation was

@ₑsample was 792 ppm; others ranged from 5 to 16 ppm.

required to comply with a National Pollution Discharge Elimination System (NPDES) permit. Soil removed amounted to 1,509 tons; it has been estimated that only 865 tons would have to be removed.[2] The difference between the estimated and the actual cost of remediation is in part due to this underestimation in the quantity of contaminated soil. Estimated unit costs were inflated to some extent to account for some expected increase. Initial quantities were estimated by IT Corp. and reviewed by Allied-Signal. IT Corp. was Allied Signal's subcontractor for the remedial design. Construction was subcontracted to ENSCO Environmental Services.

The total cost of the remedial action was 87 percent higher than estimated, partly because the amount of contaminated soil was 140 percent higher than estimated. As mentioned above, the estimated cost was inflated to account for an expected increase in the amount of soiI that would need to be excavated. Discussions with project engineers indicate that the underestimation in soil amounts was due to technical difficulties in characterizing the site. The decision was made to save money on detailed characterization and to proceed with remediation. Details of the contamination were well known, but to determine the extent would have entailed bringing a drilling rig to the site. Because of the configuration of the land, this would have been extremely expensive; a road would have been required to bring the rig into the are% and even then, only one side of the outfall could have been sampled because of the levee grade. A permit would also have been required to build the road Note that a road was eventually constructed for remediation, but not in the time frame allowed for investigation. It was not believed that further characterization would change the choice of remedy, so remedial action was begun. Site engineers doubt that determining the extent of contamination prior to cleanup would have reduced remediation costs significantly.

Richland Opertions Office (RL)

The Richland Operations Office has responsibility for operating the Hanford Reservation. Data for Hanford's 1989 Five-Year Plan were taken from existing plans and budgets as of April 1989. Responsibility for gathering cost information was given to the Westinghouse Hanford Company Environmental Division; the submittals were reviewed by DOE RL senior officials. Some preliminary cost estimation work was performed in 1987 by Science Applications International Corp. (SAIC) under contract to Westinghouse. According to SAIC, "the purpose of this work was to develop a strategy for the characterization and remediation of potential CERCLA and RCRA Resource Conservation and Recovery Act] section 3(X)4(U) inactive sites in sufficient detail to enable the development of costs and schedules" (2). Costs were addressed therein based on the type of unit to be remediated, not on the specific characteristics of each individual site (i.e., "generic Hanford units" were developed for which remediation costs were estimated for a variety of technologies). It is not known how strictly the 1989 Five-Year Plan cost estimates adhere to the SAIC cost estimates.[3] An examination of SAIC data indicate that comparison would be difficult.

According to RL's predecisional draft, a field office financial review board was formed to confirm the validity of the final cost estimates for inclusion in the 1989 Five-Year Plan. Each ADS was reviewed and assigned a level of confidence.[4] According to RL's Five-Year Plan, "The budget estimates tend to reflect a 'success oriented' approach to activity data sheet workscope completion, even though recent experience indicates the evolution of more stringent and costly regulatory requirements" (3). This statement is apparently an expression of the belief held by some Hanford personnel that, under the recently complekxi Federal Facilities Agreement with EPA and the State of Washington, Hanford will face increasingly stringent standards as new technologies are developed They attribute this in part to the inexperience of technical staff at the State level, which results in regulation "by the book" rather than by reasoned engineering judgment.[5]

The total ER budget identified in the 1989 Five-Year Plan for RL amounted to $1,127.4 million over the period FY 1989-95. This includes assessment, cleanup, D&D, and hazardous waste technology. No red remedial activities have been completed to date at Hanford. The A-29 Ditch and B-Pond interim remediation consists only of installing a bypass line for liquid effluent to B-Pond The ditch and unused areas of the pond will be covered with clean fill until an RI/FS can be completed. These activities are considered closures of treatment, storage, and disposal units and come under the regulatory authority of the Washington State Department of Ecology. Remedial action for these units is not expected until 1996 and beyond. These two activities were not considered relevant to this cost analysis, and further data were not requested.

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[2] By volume, the amount of contaminated soil was initially estimated at 500 cubic yards; the actual amount was 1,259 cubic yards. In addition, the soil was found to contain more rock than expected. This difference in soil density was not accounted for in the excavation unit cost estimate. Records were not kept for soil volume (cubic yards). However, a typical soil density for Kansas City (excluding rock) i100 pounds per cubic foot.

[3] The site numbers in the SAIC report do not correspond to the facility/waste area grouping numbers in the activity data sheets.

[4] The methods of estimation and levels of confidence were defined in the predecisional draft. No particular method of cost estimation was recommended.

[5] Paul Day, EPA Region X, indicated that the regional office is attempting to address this problem of ever-increasing costs by offering cooperation and technical assistance to the State and DOE.

183-H Solar Basins Decontamination and Decommissioning (see table C-3)

The 183-H solar basins were used for the treatment of cooling water from H Reactor and for the storage and evaporation of liquid chemical waste. A leak detected in one of the basins in 1977 resulted in groundwater contamination. The primary contaminants are chromium, nitrate, uranium, sodium, and technetium. The decontamination and decommissioning of the four basins consist of removing the liquids and solidified sludge and demolishing the enclosing structures. After this, the surrounding area will be sampled, and a cap will be installed. The total estimated cost of D&D on the basins, to be completed in FY 1992, of $21.4 million is based on conceptual engineering estimates and work done to date. The estimate has a medium level of confidence.

The basins comprise an area of 0.6 acre (26,332 square feet) and, as of early 1990, had an estimated 35,860 cubic feet of sludge containing solvents, heavy metals, and radioactive materials remains in place. A total of 7.8 million liters of contaminated water has been removed through evaporation or solidification from the basins, and an estimated 193 million liters of groundwater is believed to be contaminated. The basins are being closed as a RCRA treatment, storage, and disposal unit under the direction of the Washington State Department of Ecology.

The D&D activities consist of the following:

1, All liquids have been evaporated, transformed into a crystallized solid material, or solidified and removed from the basins.
2. Sludge was removed and packaged in 55-gallon drums, which are now stored in the 200 West Area Central Waste Complex, Retrievable Waste Storage Area.
3. Concrete surfaces within the basin were wet sandblasted, and spent grit was packaged in the same manner as sludge.
4. Concrete will be sampled and tested to determine residual contaminants.
5. The basins will be demolished by using standard practices, and the rubble will be disposed of according to the level of contamination. (The rubble is expected to have been adequately cleaned so that it can be classified as nonregulated waste.)
6, Soil below the concrete floors of the basins will be sampled to determine if any hot spots exist in the surrounding area.
7. A cap will be installed, and postclosure care and monfioring will be carried out for a minimum of 30 years.

Costs for the 183-H basin D&D were obtained only for the sludge removal, packaging, and storage phases (steps 1 through 3). This activity occurred from 1985 through early 1990. Included in reported costs are the removal of 61,583 cubic feet of solidified sludge, its packaging in 55-gallon drums and transport to the storage facility, groundwater monitoring over the 1985-90 period, and the costs of storage. All of the work was estimated and completed by Westinghouse and monitored through its D&D program office. Further detail on the actual costs and estimated costs were not available because cost accounting has not been done on a unit cost basis.

Table C-3-Cost Reported for Hanford 183-H Solar Basins (1989 dollars)

Cost of soraping, grit blasting, and packaging (includes transportation of paokaged waste 10 miles to on-site facility) Actual: $4,754,000 ($77.20/cubic foot)
Cost of storage (of 8,211 55-gallon drums) Actual: $1,813,000 ($29.44/cubic foot on average)
Cost of groundwater monitoring program (inoludes installation of some monitoring wells) Actual: $2,863,000
Total cost of sludge removal and storage, 1985-90 Actual: $9,430,000 ($153/cubic foot)
Cost of monitoring well installation at Hanford Actual: $125,000 per well ($417/foot)
Annual cost of sampling analysis Actual: $11,500 per well
Annual cost of well operation and maintenance (for 400 wells) Actual: $1.1 million ($2,750 per well)

SOURCE: Office of Technology Assessment, 1990.

Costs for the full 183-H solar basin D&D project are not yet available because work is expected to continue until 1992, preliminary estimates on waste volumes have changed as a result of rain and evaporation, and the costs of retrievable waste storage change annually. Preliminary cost estimates are therefore considered unreliable for projecting actual final costs.

Savannah River Operations Office (SR)

Attention to environmental problems at Savannah River began relatively early. The characterization of waste at SR started in 1981, with refinements in 1983. By 1984, the seven chemicals, metals, and pesticides (CMP) pits, covering approximately 2 acres, were closed at a cost of about $2.1 million. Closure consisted of excavation, capping, interim storage of excavated waste, installation of a leach field, and installation of monitoring wells. This closure was undertaken with no regulatory impetus, with verbal approval from the South Carolina Department of Health and Environmental Control (SCDHEC). Groundwater remediation began in the A/M Area at about the same time. As a result of this early work, SR and its current prime contractor, Westinghouse Savannah River Co., feel confident about their environmental restoration program plans and the associated cost estimates.

Prior to the formulation of the 1989 Five-Year Plan, remediation activities at SR were guided mainly by RCRA. However, development of an interagency agreement has shown that it would be prudent to ensure that remediation work will comply with both RCRA and CERCLA. EPA has been working with SR to integrate RCRA and CERCLA procedures, but this has been difficult. Despite this difficulty, SR personnel feel that the ER process has been running relatively smoothly.

At Savannah River, ER project details are identified by Westinghouse's Waste Management and Environmental Project Division staff.[6] Initial cost estimates for these projects are typically made by a full service design subcontractor, and then reviewed by Westinghouse. The final estimate is sent to Westinghouse's project management team and to SR. Most of SR's ER projects have not been ''line item'' activities and, therefore, have not had to be submitted for review to DOE headquarters. Such a review has been requested occasionally, when SR suspected that an estimate was controversial. The U.S. Army Corps of Engineers has also been asked to review some estimates.

Once remedial activity has begun, cost accounting is carried out by Westinghouse. Subcontractors submit a monthly cost report to Westinghouse, which then adds this to the total operations project cost. Westinghouse reports the monthly cost to SR. Apparently, the costs for ER activities are rolled into other project costs, so it is difficult to determine, at the monthly reporting level, what is actually being spent on remedial activities. When SR was asked for the costs of remedial actions, staff indicated that these were not readily available and would have to be provided by Westinghouse.

For the preparation of the 1989 Five-Year Plan, SR called on Westinghouse Savannah River Co.'s (WSRC) Environmental Restoration and Groundwater Protection Section, which monitors and assists all WSRC operating units with ER activities and interfaces with SR.[7] This group is responsible for the ER program, RCRA, RCRA facility investigations (RFIs), Federal facility agreements (FFAs), CERCLA, groundwater remediation, waste site closures, water use, and RCRA quarterly reports. The same group, under Du Pont's prime contractorship, also developed a generic program plan for conducting RFIs and site-specific plans.[8]

Cost estimates for the 1989 Five-Year Plan were made by assuming particular technologies at each site and using historical costs incurred in employing those technologies elsewhere at Savannah River. Characterization and assessment costs were based on EPA data on the costs of RI/FSs. The Westinghouse cost estimating group was not involved in making these estimates, and the people making the estimates were not cost estimators. To test the validity of the initial cost estimates, environmental coordinators in operating units were consulted and an informal complexwide survey was undertaken to collect comparable cost information. It was determined that the estimated costs for SR were within a reasonable range.

The ER cost estimates that appeared in the 1989 Five-Year Plan were often assigned a high level of confidence, based on SR's proven track record in remediation work and historical cost information. The validity of these estimates depends on the accuracy of the choice of technology for each site. The funding identified for SR for the period FY 1989-95 amounted to $466.1 million in the 1989 Five-Year Plan.

M-Area Settling Basin/Lost Lake Closure (see table C-4)

The M-Area settling basin received electroplating waste from M-Area operations, and the Lost Lake area acted as an overflow for the basin. The water and the sludge in the basin were contaminated with heavy metals and depleted uranium.

The basin and related seep area covered approximately 2 acres, and the adjacent Lost Lake is approximately 35 acres. The volume of contaminated soil (in and around the Lost Lake area) amounted to about 59,000 cubic yards, and the volume of contaminated sludge found in the basin amounted to about 5,000 cubic yards. Approximately 6 million gallons of contaminated water was present in the basin. During remedial action, heavy rainfall resulted in an additional 7 million gallons of water being deposited in Lost Lake, which had to be removed as part of the closure process.

The M-Area basin is being remediated under RCRA, with EPA and SCDHEC having regulatory authority. The RCRA closure plan was undertaken by Du Pont and Black & Veatch and was approved in July 1987. The physical closure, undertaken by OHM Corp., was about 98 percent complete as of February 1990 (completion had been scheduled for the end of FY 1989).

Closure of the area consisted first of dewatering the basin, treating the water, and discharging it to a surface stream under an NPDES discharge permit. The remaining sludge in the basin was treated via plate and frame filter

[6] These people are generally project engineers, not cost estimators. Westinghouse cost estimators have not been involved in estimating ER projects to date.

[7] Each operating unit also has an environmental coordinator, who reports to Westinghouse through the Manufacturing Division head.

[8] The RFI program plan, prepared by Du Pont for the Environmental Division, Savannah River Operations Office, U.S. DOE (revised November 1988).

Table C-4-Costs Reported for Savannah River M-Area Basin (In 1986 dollars)

Cost of basin water treatment (includes dewatering)	
Estimated:	$320,760 (8 cents/gallon for estimated 4 million gallons)
Actual:	$444,379 (6.6 cents/gallon for actual 6.747 million gallons)
Cost of soil excavation from Lost Lake and disposal in M-Area basin	
Estimated:	$350,000 ($7.78/cubic yard for estimated 45,000 cubic yards)
Actual:	$500,000 ($8.47/cubic yard for actual 59,000 cubic yards)
Cost of sludge treatment (inotudes dredging)	
Estimated:	$502,408 ($1.00/gallon for 500,000 gallons estimated)
Actual:	$1,893,342 ($1 .00/gallon for 1.9 million gallons actual)
Cost of dewatering Lost Lake	
Estimated:	$83,804 (6 oents/gallon for estimated 1 million gallons)
Actual:	$300,572 (4.3 centdgallon for actual 6.954 million gallons)
Cost of backfilling	
Estimated:	$68,000 (estimated amount of dean fill not available)
Actual:	$85,000 ($8.50/cubic yard for 10,000 cubic yards of dean fill)
Cost of cap installation (includes materials, see description above)	
Estimated:	$450,000 (estimated area unknown)
Actual:	$600,000 ($6.00/square foot)
Cost of cap operation and maintenance (annual)	
Estimated:	$10,000 (10 cents/square foot)

SOURCE: Office of Technology Assessment, 1990.

press, dredge, pugmill, cement silo, and conveyors. This treatment stabilized contaminants in the sludge, which was then returned to the basin. The Lost Lake area, which had filled with rainwater, was dewatered and the soil was excavated to background levels of contaminants. This contaminated soil was backfilled in the basin. About 10,000 cubic yards of clean fill material were used to backfill excavated areas and complete the closure. The basin bottom was not lined before the soil and stabilized sludge were redeposited.[9] The area was capped with local kaolin clay, a Hypalon cover, and topsoil, and a runoff control system was installed to meet RCRA requirements. The total cost of the project, 80 percent of which was attributed to the basin closure, is now estimated at $5.8 million (the total estimated cost in November 1989 was $5.3 million); $3.7 million was allocated for FY 1989 in the 1989 Five-Year Plan. A high level of confidence was associated with this estimate because the project was ongoing.

The total expected cost for the M-Area/Lost Lake closure is now $5.8 million; the project was originally authorized for $3 million. The main factors responsible for this 93 percent increase in costs are the higher than expected amount of sludge to be processed, the greater than average amount of rain that fell during the remedial action, and the unexpected requirement for a wastewater treatment facility. Unit costs appear to have been relatively well-estimated. Estimates were based on subcontractor bids provided in 1985-1986; the subcontractor was generally held to original unit prices, except for the factors mentioned above.

A/M Area Groundwater Remediation (see table C-5)

The A/M Area Groundwater Monitoring Program encompasses the A/M Area including the Savannah River Laboratory (SRL), an area comprising about 5,371 acres. The largest plume, in M Area, covers approximately 1,239 acres; SRL contamination covers an area of about 183 acres. The groundwater and soil under A/M Area are contaminated with trichloroethylene (TCE) and tetrachloroethylene (PCE) (concentration levels range from less than 1 to 100,000 parts per billion (ppb)), which were used as degreasing agents in the M-Area fuel fabrication facility. The performance of this project is described in appendix B.

Also under this task is the remediation of groundwater contamination in the northern sector of A/M Area under the SRL. Another investigation is underway in the southern sector of the A/M Area. A prototype air stripper from the Reactor Materials Department will be used for the northern sector remediation. Finally, this task includes a vadose zone program, which is a pilot program to remove residual contamination from the vadose zone by using horizontal wells. Cost estimates for these two pilot projects are not available, but characterization costs alone for the vadose zone project are estimated at $250,000. The total amount of funding identified in the 1989 Five-Year Plan for the A/M Area groundwater remediation project was $8.8 million for FY 1989-95.

Facility engineers indicate that the small increase in actual v. estimated cost was the result of several design changes required of the subcontractor during the construction period.

Mixed Waste Management Facility Closure (see table C-6)

The Mixed Waste Management Facility (MWMF) constitutes a 58-acre portion of a 200-acre radioactive waste burial ground (the remainder of the area will become a CERCLA site). The 200-acre area served as a burial ground and storage area for contaminated equipment, empty drums, tritium crucibles, reactor scrap, and containerized waste. The 58-acre site contains a wide

[9] The bottom liner was not required because the basin was considered a RCRA interim status facility.

Table C-5-Costs Reported for A/M Area Groundwater Remediation

M-Area monitoring well installation (1989 dollars)
- Estimated: deep wells (295-300 feet) $132/foot (includes stainless steel casing)
  - Shallow wells (130-270 feet): $103/foot
  - Oversight costs: $500/day per rig
  - Mobilization costs: $100 per rig (contractor A); $500 per rig (contractor B)

Well sampling costs
- Estimated: $200,000/year for 235 monitoring wells
- Annual sampling for 12 point of compliance wells: $2,600 per well
- Quarterly sampling for 12 point of compliance wells: $400 per well (three quarters only)
- Quarterly sampling for other monitoring wells: $160 per well

Cost of well operation and maintenance
- Estimated: $15 to $30 annually per well
- Actual: extremely variable

Groundwater treatment system
- Cost of recovery well installation (1985 dollars)
- Estimated: $350,000 ($1.59/foot for 11 wells averaging 200-foot depth)
- Actual: $350,000

Cost of sampling (1989 dollars)
- Estimated: $2,000 for two samples (influent and effluent sampled quarterly)

Cost of well and air stripper operation and maintenance (includes costs of disposal of treated water to NPDES outfall)
- Estimated: $110,000 ($550 per million gallons)
- Actual: unknown (This is treated as an overhead cost and is hidden in the total overhead cost of the raw materials operating budget.)

Treatment facility construction costs (200-million gallon per year air stripper)(1985 dollars)
- Estimated: $4.45 million ($22,250 per million gallons of annual capacity)
- Actual: $4.515 million (22,575 per million gallons of annual capacity)

SOURCE: Office of Technology Assessment, 1990.

variety of waste types, including boxes containing mixed debris, random mixed debris, containers of absorbed waste oil, containers of scintillation solution, waste lead, cadmium, and silver, as well as heavy equipment. The estimated volume of contaminated soil in the 58-acre area is 3.75 million cubic yards.

Groundwater at the site is at average depths of 30 to 40 feet below the surface; however, perched water conditions due to intermittent clay lenses exist 15 to 20 feet below the surface in some areas.

The MWMF will be closed by dynamic compaction and capping as a RCRA closure under SCDHEC. In dynamic compaction, a 20-ton weight is dropped by a crane onto old trenches identified by ground-penetrating radar. The compaction reduces settling of contaminated material and helps maintain cap integrity. The area will be covered with a 3-foot-thick kaolin clay cap and an additional 2 feet of soil and will be monitored. The total

Table C-6-Costs Reported for Savannah River Mixed Waste Management Facility (1989 dollars)

Cost of site preparation
- Actual: $4,189,850 ($72,239/acre; includes clearing, stripping,borrow site grading, and MWMF grading)

Cost of equipment mobilization
- Actual: $750,000

Additional construction costs
- Actual: $500,000 (to present)

Dynamic compaction operation and maintenance cost
- Actual: $2,990,000 ($51,551/acre)

Cost of cap installation
- Actual: $7,670,000 ($332,241/acre; $7.63/square foot)

Monitoring costs
- Unknown

NOTE: All costs are actual; estimated costs for the lump sum subcontract were not broken down into the increments above.)

SOURCE: Office of Technology Assessment, 1990.

baseline cost of design, procurement, and remediation was estimated at $52.8 million, with $37 million accounted for by an expected "lump sum" subcontractor bid for the dynamic compaction and capping procedure. The original estimate to close the site had been much higher ($118 million) because the contractor's estimate included a higher level of worker protection than ultimately deemed necessary (4). Once the lump-sum contract was let, the total cost was revised further downward to $35.029 million (the lump-sum subcontract was reduced to $24.44 million, including a 6 percent contingency). It now appears that the final actual cost of the dynamic compaction and capping will be less than $18 million-lower than expected due to a fewer number of drops required per acre than originally estimated.

Remedial design for the site, as well as cost estimation and cost review, was conducted by C.T. Main and reviewed by DOE SR; construction is being performed by Nello L. Teer. Testing on the project began in October 1987, and full-scale dynamic compaction began in February 1989. Closure is almost complete. The total funding allocated to the closure in the 1989 Five-Year Plan amounts to $42.7 million for FY 1989-91. The level of confidence associated with this estimate was high because SR is well into closure activities.

Oak Ridge Operations Office (OR)

The Oak Ridge Operations Office oversees the activities of the Y-12 Plant, ORNL, the former gaseous diffusion plant at K-25, and the Feed Materials Production Center at Femald, OH. Cost estimates for the environmental restoration and waste management activities for the 1989 Five-Year Plan were made by Martin Marietta field engineers. For activities at the conceptual design stage, estimates were based on that design and reviewed by DOE headquarters in its annual validation review. For activities with no conceptual design, estimates were based on the expected level of effort and best engineering judgment. These estimates were made without the use of any consistent methodology and underwent no formal review process prior to inclusion in the Five-Year Plan. OR staff were included in the decisionmaking process for these estimates, however. Estimated funding requirements for OR's ER program were reported at $3.397 million for FY 1989-95.

Environmental restoration cost estimates are being coordinated by OR for the 1990 Five-Year Plan. Both DOE and Martin Marietta have created a centralized ER division to conduct this effort.

Y-12 Plant (see table C-7)

Eight RCRA closures are among the remedial activities being carried out under the ER program at Y-12. The total cost of these closures, which cover a combined area of about 92 acres, has been estimated at $46.8 million. At least four of the closures were completed as of the end of 1989. The total estimated ER budget for Y-12 in the 1989 Five-Year Plan was $340 million for 1989-1995. Data were requested on two of the closures, the S-3 Ponds and the Oil Land Farm.

S-3 Ponds—The S-3 Ponds are four ponds covering an area of approximately 5.1 acres. The ponds were used from 1951 to 1984 as a disposal area for a variety of aqueous wastes, containing uranyl nitrate, nitric acid, and aluminum nitrate. Each pond contained about 2.5 million gallons of contaminated water, and the four combined contained a total of 26,900 cubic yards of contaminated soil and 26,900 cubic yards of contaminated sludge.

Contaminant ts included nitrates in a concentration as high as 10,620 ppm and, in general, exceeded 1,000 milligrams per liter in groundwater. Mercury contamination in excess of 0.002 milligram per liter was also found in the area of the ponds; volatile organic compounds in the groundwater ranged from 10 to 1,000 micrograms per liter. The saturated zone is comprised of silty clay, and the depth to groundwater is approximately 12 feet.

Prior to closure, pond water was neutralized with lime, treated with bacteria for denitrifying, pumped, and treated in a liquid treatment facility. Closure of the ponds consisted of stabilizing the remaining sludge by spreading dolomite shot rock over the bottom of the ponds and by installing an engineered cap consisting of compacted clay, a poly vinyl chloride liner, a geosynthetic drainage net, a filter fabric, and a vegetative layer. Pond water was treated from 1983 through 1986 by Martin Marietta under an operation and maintenance budget.

Remedial design and construction, conducted by Rust Engineering under contract to Martin Marietta, took place from November 1987 to November 1988. Cost estimates were made by Martin Marietta Energy Systems and Lockwood Greene Engineers and reviewed by Martin Marietta Energy Systems and Lee Wan & Associates.

The total cost of S-3 Pond closure, not including water treatment, was $2.283 million, about 3 percent less than the estimated cost of $2.346 million. Field engineers indicated that capping costs at the Y-12 Plant have declined since the S-3 Ponds were capped as a result of improvements in productivity. (S-3 Ponds were the first

Table C-7-Costs Reported for the Y-12 Plant

Total Cost of water treatment (1986 dollars)		
	Actual:	$5.5 million ($0.61/gallon) includes neutralization, biodenitrification, construction of a liquid treatment facility, pumping and treating 9 million gallons of pond water. Construction of the liquid treatment facility cost $1.5 million.
Cost of pond closure (1987 dollars)		
Cost of sludge excavation		
	Estimated:	$78,000
	Actual:	$78,000 ($260/cubic yard)
Cost of sludge stabilization		
Cost of dolomite shot rock		
	Estimated:	$395,000 ($8.78/ton of shot rock)
	Actual:	$347,000 ($7.70/ton of shot rock)
Total cost of stabilization (including dumping and spreading 45,000 tons of dolomite shot rock)		
	Estimated:	$500,000 ($98,000/acre)
	Actual:	$465,000 ($91,200/acre)
Cost of capping 5.1-acre area with 4.2-foot-thick cap (1989 dollars)		
Cost of cap construction		
	Estimated:	$1,325,000 ($259,000/acre; $5.96/square foot)
	Actual:	$1,290,000 ($252,940/acre; $5.81/square foot)
Total cost of cap installation (includes administration, engineering design, and testing)		
	Estimated:	$1,768,000 ($346,670/acre; $7.96/square foot)
	Actual:	$1,740,000 ($341,176/acre; $7.83/square foot)

SOURCE: Office of Technology Assessment, 1990.

area capped.) Cost estimates and cost breakdowns were not available for water treatment activities because the work was carried out by Martin Marietta under general operating and maintenance task, and was not recorded as environmental restoration. Estimates provided for the closure were based on the remedial action project description; the 30 percent, 60 percent, and 90 percent design reviews; and subcontractors' bids.

Oil Lund Farm (see table C-8)-The Oil Land Farm comprises a 13-acre area that received machine coolants and waste oil, some uranium-contaminated, from 1973 to 1982. (Other areas in the land farm are also undergoing closure, but they are not included in this analysis.) The land farm was designed to promote the biological degradation of this waste through the application of nutrient-adjusted soil. Prior to closure, the area contained contaminated soil and groundwater.

Closure of the site consisted of the removal of 390 cubic yards of PCB-contarninated soil, which constituted all of the soil with PCB concentrations in excess of 25 ppm. Other contaminants included solvents and radioactive materials, but no cleanup standard was specified for them. No information is available on the levels of these other contaminants. Soil is being stored in a vault for future disposal. The area was then covered with an engineered cap.

The remedial design and construction period extended from February 1988 through September 1989. Cost estimates were prepared by Martin Marietta Energy Systems and Lockwood Greene Engineers and reviewed by Martin Marietta Energy Systems and Lee Wan & Associates.

The total cost of closure amounted to $3.16 million, including the costs of administration, design, road construction, stream diversion, and vault construction. Cost breakdowns were provided only as shown.

Table C-8-Costs Reported for the Oil Land Farm (1988 dollars)

Cost of excavation	
Actual:	$18,000 ($46.15/cubic yard)
Cost of vault construction	
Actual:	$250,000 ($833/cubic yard capacity)
Cost of backfilling and contouring	
Cost of soil	
Actual:	$36,000 ($1 55/cubic yard)
Cost of contouring	
Actual:	$239,000 ($18,800/acre)
Cost of cap installation (including administration, design, etc.)	
Estimated:	$3,240,000 ($249,23/acre; $5.72square foot)
Actual:	$3,160,000 ($243,076/acre; $5.58/square foot)

SOURCE: Office of Technology Assessment, 1990.

Oak Ridge National Laboratory (ORNL)

Remediation work at ORNL has been minimal. However, a series of technology demonstration projects have been carried out at Solid Waste Storage Area 6 (SWSA 6) that are similar to activities carried out elsewhere. The total ER budget for ORNL in the 1989 Five-Year Plan was $601 million.

SWSA 6 (see table C-9)

SWSA 6 covers a 68-acre area, about 15 acres of which were used for waste disposal. The area has been in use since 1973 and contains waste in unlined trenches and auger holes. The waste includes low-level solid radioactive waste, solvents, scintillation liquids, Laboratory glassware and equipment, protective clothing, obsolete mechanical equipment, construction materials, asbestos, filter media and resins, animal remains, and contaminated earth. These disposal areas are now in the process of characterization; the total volume and nature of contamination are as yet unknown. Currently, SWSA 6 is used for the disposal of low-level radioactive waste in concrete silos and above-ground tumuli. Through May 1986, approximately 312,000 cubic feet of low-level waste containing more than 200,000 curies of radioactivity was buried at SWSA 6.

Groundwater in the area is very close to the surface, occurring in the lithologically heterogeneous Conasauga Group. The soil is generally characterized as strongly leached, low in organic matter, and silty, although considerable amounts of clay maybe present. In addition to the city of Oak Ridge, four communities are within 10 miles of the site. Public involvement in ER activities has been low to date but is expected to increase during the remedy selection process. The RFI of SWSA 6 was scheduled for completion in September 1990. Final closure is expected to be completed in FY 1993. An interim cap consisting of an 80-mile high-density polyethylene liner has been placed over the site until final closure is begun.

The Tennessee Department of Health and Environment has regulatory authority over the RCRA closure of SWSA 6; however, radioactive contamination will be covered by CERCLA under a pending FFA. Cleanup goals have not yet been determined but will be developed as part of the RFI.

Existing cost estimates for the closure of SWSA 6 are based on preliminary evaluations of potential remedies. These estimates were made by Martin Marietta, but they have not been reviewed or validated.

The final remedy for SWSA 6 has not yet been chosen. The grouting demonstration project indicated that the trench voids could be successfully filled, thereby eliminating subsidence. The dynamic compaction project indicated that compaction also reduced the void space considerably.

Table C-9-Costs Reported for SWSA 6 (1989 dollars)

Costs of groundwater monitoring wells	
Cost of well installation (shallow wells, 2-inoh diameter; deep wells, 4-inoh diameter)	
Estimated:	$22,500 to $25,000 per well
Actual:	$22,147 per well (about $340/foot for 65-footaverage depth)
Annual cost of sample analysis	
Estimated:	$1,740 per well
Annual operating and maintenance oost	
Estimated:	$320 per well
Cost of interim capping	
Cost of cap installation (includes planning, management, design, and construction; health, safety, and environmental monitoring)	
Estimated:	$3 million
Actual:	$3 million ($288,461 /acre; $6.62/square foot) (construction only $1.4 million; $3.09/square foot)
Annual cost of cap operation and maintenance	
Estimated:	$104,000 ($0.23/square foot)
Annual monitoring cost	
Estimated:	$150,000 ($0.33/square foot)
Cost of grouting demonstration project (The voids in Trench 150 were grouted using 30% Portland cement, 55.5% eastern class C fly ash,5.5% sodium bentonite, and 0.02% glucono-delta-lactone at 12.5 pounds/gallon of water. Total injected= 8,081 gallons.)	
Cost of materials	
Estimated:	$2,000
Actual:	$1,697
Cost of equipment mobilization	
Estimated:	$10,000
Cost of grouting process	
Actual:	$48,680 ($6.05/gallon)
Cost of scientific evaluations	
Estimated:	$100,000
Cost of commercial grout application	
Estimated:	$2.60/gallon of grout emplacement
Cost of dynamic compaction demonstration project (test on Trench 271; 64 square meters (690 square feet), 4.06 meters deep (13 feet), consisting of low-level radioactive solid waste components; compaction achieved with a 60-ton crane)	
Cost of site preparation	
Estimated:	$1,000
Cost of equipment mobilization	
Estimated:	$3,500
Dynamic compaction operation and maintenance cost	
Estimated:	$3,000 ($4.35/square foot)
Cost of scientific evaluation	
Estimated:	$100,000

SOURCE: Office of Technology Assessment, 1990.

Idaho Operations Office (ID) (see table C-10)

The Idaho Operations Office oversees the activities at INEL and the Grand Junction Projects Office. According to ID and EG&G Idaho personnel, the only completed remedial action at their facility is the capping of a waste injection well. Information was requested, but not available, on the Chemical Processing Plant gravel pit and tank farm closing and the SPERT IV waste removal and remedial action.

The initial 1989 Five-Year Plan estimates for ID were made by EG&G personnel (including a financial manager and an environmental engineer). These estimates were reviewed and amended by DOE and EG&G reviewers, but no documentation is available for either the initial or the amended estimates. The total ER funding identifkd for ID for FY 1989-95 was $707.9 million, according to the 1989 Five-Year Plan.

The capping of the CPP injection well was initiated in October 1989 and completed in November 1989. Remediation was designed by EG&G and WINCO in February 1989 and undertaken by M&K with the supervision of WINCO. The 468-foot injection well had been used for the disposal of liquid waste. Remediation consisted of perforating the well casing with explosives and tilling the well with cement in stages. The total actual cost of the

Table C-IO-Costs Reported for the Idaho Chemical Processing Plant

Monitoring well installation

Cost of well installation (two monitoring wells at the CFA landfill, both 8-inch diameter with stainless steel casings in saturated zone—combined depth 1,186 feet); (1989 dollars)
Estimated: $257,000 ($217/foot)
Actual: $331,000 ($279/foot)

Cost of well installation (four 8-inch diameter wells 500 to 700 feet deep to be drilled at the central landfills) (1990 dollars)
Estimated: $200,000 per well ($286 to $400/foot)

Cost of sample analysis (quarterly sampling for four wells); (1989 dollars)
Estimated: $75,000 per year ($4,687 per sample)
Actual: $82,000 per year ($5,125 per sample)

Cost of well operation and maintenance (1989 dollars)
Estimated: $5,000/year

Additional costs (including health and safety plans, quality assurance/quality control, and technical work plan; 1989 dollars)
Estimated: $40,000
Actual: $60,000

SOURCE: Office of Technology Assessment, 1990.

remediation was reported at $558,278, including design and construction but excluding the salaries of supervising WINCO personnel.

Increases in monitoring well costs resulted from problems encountered during drilling, including heaving sand, grouting of wells, and use of bentonite seals. Sampling costs have been steadily increasing due to the limited availability of qualified laboratories. Samples are sent from Idaho to St. Louis for analysis and often require at least 8 weeks for results.

Lawrence Livermore National Laboratory (LLNL)

LLNL (see table C-n) is managed by DOE's San Francisco Operations Office (SAN), along with a number of other facilities. The total ER funding identified for SAN in the 1989 Five-Year Plan for FY 1989-95 was $218.2 million. LLNL contains two general areas of contamination: 1) the main Livermore site, which is now listed on the National Priorities List (NPL), and 2) Site 300. The 1989 Five-Year Plan estimate amounted to $55.9 million for the Livermore site cleanup over FY 1989-95 and to $30.75 million for the Site 300 cleanup during that same period (not including an additional $12.2 million for Site 300 environmental assessment activities during that same period). The level of confidence for both estimates was reported as moderate or at the conceptual design stage. Environmental investigation and remediation efforts have been underway at LLNL, under the direction of the California Regional Water Quality Control Board (RWQCB) San Francisco Bay Region and the California Department of Health Services (DHS) since 1983. Activities at LLNL are now coordinated under an FFA with EPA, RWQCB, and the California DHS. Information is not available on the methodology used by LLNL to estimate ER costs.

Livermore Site

The Livermore site comprises about 700 acres (1.1 square miles), beneath which the groundwater is contaminated with volatile organic compounds (VOCs). Contamination is the result of leaking tanks and drums that had been disposed of in the area and from use of the area as an aircraft maintenance facility by the U.S. Navy. Between 1983 and 1989, $25.2 million was spent on characterizing and cleaning up the site (5). It is now believed that about 2 billion gallons (7.5 billion liters) of groundwater is contaminated above the 1-ppb level with VOCs; the amount of contaminated soil, in "hot spots" around former leaking tanks and drums, has not been calculated. The depth to groundwater at the site ranges from about 30 feet in the northwest to about 110 feet in the southeast. Perchloroethylene and lower concentrations of other VOCs have been detected in offsite monitoring wells. A groundwater plume containing VOCs appears to be migrating from the southwest corner of the site to the west-northwest, at a rate of about 100 feet per year. A public water well system serving 10,000 people is within 3 miles of the contaminated groundwater.

The saturated zone can be described as alluvium, consisting of sandy silt to silty sand with some gravel layers. Fault zones are present several hundred to several thousand feet to the south and east of LLNL. The closest populated area is about 0.1 mile from LLNL.

Prior to groundwater remediation, two cleanups were done at the Livermore site: 1) removal of a former landfill at East Traffic Circle in 1984-85 and 2) excavation of former waste pits and evaporation ponds in the Taxi Strip Area in 1982-83. Engineering design for groundwater remediation is not expected to be completed until FY 1992; planned remediation will consist of extraction and treatment by an ultraviolet/peroxide process combined with air stripping polish. Cleanup goals will be the maximum contaminant levels (MCLs) for individual VOCs and fuel hydrocarbons, and below MCLs for tritium (20,000 picocuries per liter), chromium (50 ppb), and lead (50 ppb). Cost estimates for groundwater remediation have been provided through LLNL by Weiss Associates and are based on two pilot groundwater remediation projects undertaken at the site. Remediation is expected to take 20 to 30 years to complete.

Summary

From the above descriptions of cost estimating methodologies, it seems clear that the cost estimates in the 1989 Five-Year Plan were inconsistent and difficult to compare among facilities. Although steps are being taken by both

Table C-n-Costs Reported for LLNL (1989 dollars)

Groundwater monitoring wells (No actual costs were provided, only estimates, although 300 monitoring wells have been completed.)

Cost of installation (50 to 300 feet deep, 4.5 inch diameter)
Estimated: $20,000 per well plus $2,000 for soil and drilling mudsamples (additional mobilization/demobilization costs estimated at $1,200 per well)

Annual cost of water sample analyses
Estimated: $400,000 for 300 wells ($1,333 per well)

Annual cost of well operation and maintenance
Estimated: $50,000 for 300 wells ($167 per well)

Groundwater remedlation (planned; all rests estimated)

Number of wells planned, by type
Extraction: 20
Recharge: 2 to 3
Piezometers: 100

Cost of well installation, by type
Extraction: $50,000 per well (50 to 200-foot depth; 6-inch diameter)
Recharge: $65,000 per well (400 to 500-foot depth; 8-inch diameter)
Piezometers: $10,000 per well (50 to 200-foot depth; 2-4-inch diameter)

Annual cost of sample analysis
Total: $275,000 (about $2,200 per well); (Frequency of water sampling is generally quarterly; various clean wells and wells well within the margins of the plume are sampled on a semiannual or annual basis.)

Annual well operation and maintenance cost, by type
Extraction: $10,000 per well
Recharge: $15,000 per well
Piezometers: $1,000

Cost of treatment tacilities (Total volume treated will be about 400 gallons/minute for the site; the number of treatment facilities is estimated at seven.)

Treatment facility instruction cost
Per facility: $400,000

Treatment facility annual operation and maintenance cost
Total: $75,000

Method of wastewater disposal (recharge via recharge basin and recharge wells; infiltration in arroyos; total of 400 gallons/minute)

Cost of disposal: $1,150,000

Cost of decommissioning wells and treatment facility
Wells: $7,000 each
Treatment facilities: $300,000 ($400,000 if underground piping removed)

SOURCE: Office of Technology Assessment, 1990.

DOE and its prime contractors to address this inconsistency, the costs in the 1990 Five-Year Plan are also of a very tenuous nature. As the above case studies show, costs for similar activities, both estimated and actual, can vary significantly from facility to facility, and even from site to site (see table C-12).

Because data are extremely limited and so few remedial actions have actually been completed, it is difficult to draw any valid conclusions from this variation. Variations in costs may be the result of legitimate differences in circumstances at each facility. The experience with unit costs of remedial action in the Superfund program has been similar. The implications are that it is very important to keep good records of costs, project characteristics, implementation, problems encountered, and other factors impacting costs to assess the efficiency and effectiveness of DOE's Environmental Restoration Program. Such careful attention to costs appears to have been lacking in the early years of the Superfund program (and may even continue), making it extremely difficult to determine its success and opening EPA to a barrage of criticism. Careful attention to unit costs can be most valuable if initiated early in a program.

With respect to the ability of DOE and its contractors to estimate costs of remedial action, no conclusions can be drawn from the above information. The availability of both estimated and actual costs has been limited to some extent because of the way in which some of the remedial activities were funded In many cases, cleanup or operation and maintenance work was done under an operating or central services budget (for example, water treatment of the S-3 Ponds at Oak Ridge). When this

Table C-12—Unit Cost Comparison: 11 DOE Case Studies (costs in 1989 dollars unless otherwise noted)

Activity/site	Groundwater monitoring well installation per foot	Sample analysis per well, annual	Monitoring well annual operation and maintenance per well	Soil/sludge excavation	Soil transportation per ton-mile	Soil disposal	Groundwater recovery well installation per foot	Sample analysis, per sample	Recovery well operation and maintenance per well, annual	Treatment facility construction, total	Cap installation, per square foot	Cap operation maintenance per square foot per year
4.5-acre site (Pinellas-AL)	$150	—	—	$66/ton (1986 dollars)	16.5 cents (1986 dollars)	$110/ton offsite (1986 dollars)	$228	$192 (e)	$1,875 (e)	$50,000 (e) ($3,333 per million gallons annual capacity)	—	—
002 outfall (Kansas City-AL) .	—	—	—	$8/ton; $11/cubic yard (1988 dollars)	9 cents (1988 dollars)	$146/ton; $184/cubic yard offsite (1988 dollars)	—	—	—	—	$0.42 (top soil and clay) (1988 dollars)	—
183-H solar basins (RL)	$417	$11,500	$2,750	$2,084/cubic yard (includes packaging)	—	$795/cubic yard (shortage)	—	—	—	—	—	—
M-Area settling basin (SR)	—	—	—	—	—	—	$8.47/cubic yard (1986 dollars)	—	—	—	$6.85 (with backfill) (1986 dollars)	$0.10 (e) (1986 dollars)
A/M Area ground-water remediation (SR) ...	$132 (e)	$2,600 (e)	$15-30 (e)	—	—	—	$159 (1985 dollars)	$1,000 (e)	$9,000 (e)	$4.865 million (1985 dollars)	—	—
Mixed waste management facility closure (SR) ...... —	—	—	—	—	—	—	—	—	—	—	$7.63	—
S-3 Ponds closure (Y-12, OR)	—	—	—	$260/cubic yard (1987 dollars)	—	—	—	—	—	$1.5 million (1986 dollars) $7.83	—	—
Oil landfill closure (Y-12, OR)	—	—	—	$46/cubic yard (1988 dollars)	—	—	—	—	—	—	$5.58 (1988 dollars)	—
SWSA 6 closure (ORNL, OR)	$340	$1,740 (e)	$320 (e)	—	—	—	—	—	—	—	$6.62	$0.56
INEL (ID)	$286-$400 (1990 dollars) (e)	$20,500	$1,250 (e)	—	—	—	—	—	—	$2.8 million	—	—
LLNL (SAN)	—	1,333 (e)	$167 (e)	—	—	—	$400 (e)	$2,200/well/year (e)	$10,000 (e)	$400,000/facility (e)	—	—

(e) = estimated costs

NOTE: All of these costs were submitted for DOE review at each applicable facility; no comments were received from the Richland Operations Office.

SOURCE: Office of Technology Assessment, 1990.

occurred, it was impossible to separate the costs of remedial activities from normal operating costs of the facility. With accounting procedures for waste management and environmental restoration still in an apparent state of flux, it is not possible to determine if this situation will change. For some activities, it may be very difficult to separate the costs of environmental restoration, waste management, and defense production activities.

From the limited information obtained in this analysis, no consistent relationship between estimated and actual costs has become apparent.[10] Cost overruns have apparently been due primarily to lack of detailed characterization of the contamination, especially with respect to volume, or to unforeseen circumstances, such as unusually high rainfall. Costs were also overestimated (for Savannah River's MWMF) and estimated accurately (A/M area groundwater remediation).[11] Based on EPA Superfund experience, cost overruns of as much as 100 percent for remedial action have not been unusual (6). Closer attention to the details of current remedial action costs may help in estimating future costs, but wide variation can still be expected due to the uncertainties inherently associated with contaminated waste sites.

OVERVIEW OF THE DEPARTMENT OF ENERGY COST ESTIMATION PROCESS

Past Estimation Practices and Consistency of Five-Year Plan Estimates

DOE has a well-established process for the estimation and review of cost for major construction contracts. (This process is regularly applied to "line item" projects and is generally followed, with more limited review, for smaller construction projects.) All requests for proposals for construction work include detailed instructions specifying how cost estimates are to be provided for specific types of contracts and services. These guidelines are set out in DOE orders and supplemented by field office guidelines and orders based on Federal Acquisition Regulations, which include basic cost accounting principles in sections 30 and 31, and on the DOE Supplemental Acquisition Regulations.

Each DOE operations office has access to its own cost estimators, who are usually employed by the management and operations contractor. These estimators all follow the same basic cost guidelines. However, because of the uncertain nature of cost estimation and the flexibility of the guidelines (which is necessary to allow for this uncertainty and the variability among sites), different cost engineers/estirnators may interpret the guidelines differently.

DOE headquarters has an independent cost estimators group, which reviews cost proposals to determine the probable costs of services and reviews mod.iilcations to contracts both for headquarters and for field offices. Line item project costs are regularly submitted to the independent cost estimators at DOE headquarters. In the event of a disagreement or large discrepancy, management makes a determination based on the evidence.

It must be emphasized that this procedure has been used for all projects in the past with regularity, except ER projects. The cost guidelines used for typical construction/service contracts are not fully compatible with environmental remediation projects. This incompatibility arises for two major reasons. First, the work breakdown structure for construction projects is not entirely transferable to environmental restoration projects because of the differences in the kind of work being done. Second, regulatory requirements for ER projects include a number of items, such as public involvement, that might not normally appear in a construction contract and are not accurately reflected in construction work breakdown structures.

Partially for these reasons, DOE cost estimators have not routinely been involved in estimating costs for ER projects and have generally been excluded from estimating costs that appear in the Five-Year Plan. Estimates in the 1989 Five-Year Plan were often prepared by contractors, or subcontractors, and compiled by DOE engineering or environmental staff in what has been described by some as a "seat of the pants" manner.

According to information gathered on the methodologies used to prepare cost estimates for the 1989 Five-Year Plan, no degree of consistency appears to exist among estimates for the various field offices, and little may even exist among estimates for different sites within each field office's area of responsibility. Field offices were given limited time to prepare the initial estimates, and these were often done on an ad hoc basis. Several field offices attempted to develop a more methodological approach. One example of such an attempt is the Albuquerque Operations Office, whose estimation strategy is described above. Even there, however, some facilities (i.e., Rocky Flats and Kansas City) opted to prepare their own estimates for the 1989 Five-Year Plan. The precise methods used at those facilities have not been documented. Apparently, DOE headquarters issued no

[10]Cost variation has been studied for environmental remediation projects by IPA, Inc., under contract to DOE. The studies conclude that about 75 percent of the variation can be explained by project definition, site complexity, and level of sophistication of cleanup technology.

[11]Although cost estimates for the A/M groundwater project accurately reflect expenditures for the plant equipment installed, the initial design was insufficient because of incomplete characterization and additional equipment was required (see app. B).

guidance for the estimation of costs for the 1989 Five-Year Plan.

In the 1990 Five-Year Plan, some further attempts have been made by individual field offices to develop a more consistent approach to cost estimation. Greater effort has been devoted to providing estimates that can be better justified with supporting data. This increased attention has arisen from realization that the Five-Year Plan estimates will be used for budgeting purposes. Conversations with field office personnel throughout the DOE Nuclear Weapons Complex indicate that the original estimates were made without this understanding. In many cases, the 1990 cost estimates, particularly for site characterization, are higher than those that appeared in the 1989 document. Field office personnel claim that this is the result of more information about characterization needs and more detailed analysis. Field offices have been pressured by DOE headquarters to reduce their 1990 cost estimates to the lower, less carefully constructed 1989 estimates.

Some field office personnel have also indicated that pressure is being exerted to reduce time and expenditure on characterization and to hasten the start of remediation. This pressure appears to be coming both from public interest groups and from DOE headquarters.

With regard to the 1990 Five-Year Plan, it should be pointed out that many of the reporting codes have been changed. In the development of budget numbers, there was some confusion regarding the designation of activities as waste management or environmental restoration. This confusion appears to result from conflicting and changing guidance from DOE headquarters, which may make comparison of aggregate budget numbers difficult.

Current Efforts To Standardize Environmental Restoration Cost Estimation Practices

The need to create consistency among cost estimates for environmental restoration has been recognized by some DOE staff, both at headquarters and at field offices. The Environmental Restoration and Waste Management Cost Assessment Team (EM-CAT) has been meeting since about mid-1988 in an effort to develop standardized cost estimation tools and techniques. Members of the team are primarily cost engineers, but environmental engineers and other related professionals have also attended meetings on an ad hoc basis. EM-CAT's goal is to provide a focal point for the dissemination of costing data, methodologies, and techniques (7).

The CAT guidelines provide work breakdown structures for remedial activities, including RIs, FSS, remedial design, and remedial action. The attitude of the cost engineers is rather conservative, in that they seem reluctant to diverge from past practices, but they also recognize the need for new guidance for environmental projects. Some disagreement exists among team members about how close the connection should be between past estimating practices and newly developed guidelines. In addition, from the comments made by some CAT members, it is evident that not all members are in agreement about the degree of importance of this effort. Apparently, the issue of consistent cost estimates is receiving some increased attention at DOE headquarters.

In the course of designing new cost estimation guidelines, DOE headquarters contracted with IPA, Inc., to prepare a database of environmental cleanup costs to help determine the level of economic risk associated with these activities (i.e., the probability that actual costs will differ significantly from estimated costs).

One of the difficulties in estimating remediation costs is that a historical database, similar to that which exists for construction projects, is not available. As far as can be determined, this database is the only concerted effort by DOE to develop a historical database for its remediation activities. Even then, the contractor (IPA) apparently has had difficulty collecting data on recent DOE remediation. Cost accounting methods for these DOE projects have not lent themselves to the creation of such a data base. Several interested parties suggested that the creation of a unit cost accounting system for environmental activities would prove extremely useful for future cost estimation efforts. (Interestingly, EPA also has no standardized unit cost accounting method for CERCLA or RCRA cleanups. It was claimed by a member of the EPA staff present at the La Jolla CAT meeting that no one can agree on the standard elements of cost that should be collected, so no effort is being made.)

Other work performed by EM-CAT has included a review of currently available data bases and cost estimation models used for estimating costs of remediation by other entities. Several such models have been identified, although none address radioactive and mixed waste. Two Federal agencies have developed or are developing remediation cost estimation models. The Army Corps of Engineers, motivated by its responsibilities related to CERCLA sites, is in the process of developing a model and database patterned after its construction cost estimation model, the most recent version of which has been in use for about 8 years. The Corps is developing a CERCLA estimating manual, a standard code of accounts (it reiterated that standard construction codes do not work for CERCLA), and a cost estimation checklist. This guidance will be used at the final engineering design phase of the projects (i.e., after feasibility studies have been done and remedial technologies have been selected). This model does not include radioactive and mixed waste and requires very detailed information.

EPA has two models for cost estimation. The Cost of Remedial Action (CORA) model was developed for EPA headquarters to estimate costs for CERCLA out-year budgeting and is applied at relatively early stages of site investigation (8). The model, developed at a cost of $2.5 million, consists of an expert system module, which asks questions about the site characteristics and identifies appropriate remediation technologies, and a cost estimation module, which develops a cost estimate for the selected technologies from its built-in cost database. Again, this model is not designed to address radioactive and mixed waste. IPA, in cooperation with the Los Alamos National Laboratory (LANL), under contract to DOE, performed a validation of the CORA model and found that it chose the technologies ultimately selected for the site at least 73 percent of the time and performed best for removals (9). In general, CORA overestimates costs and has an accuracy of from +50 percent to -30 percent. LANL staff have proposed building a similar model to include radioactive and mixed waste remediation. That effort has not been funded by DOE.

EPA's Cincinnati research office is in the process of developing the Remedial Response Construction Cost Estimating System, called PRACES, to be used as a tool for cost estimation at CERCLA sites (10). The model can calculate costs at early investigation stages up to the final engineering design phase. The model can develop budget estimates for planning purposes, compare costs of alternative remediation technologies, calculate specific site cleanup costs, check cost estimates prepared by others, and conduct present-worth analyses.[12] The model has been in development for about 3 1/2 years at a cost of about $400,000. Limited resources have been devoted to development of the model, thus slowing progress. The model has apparently never been validated; although EPA sent out copies for testing, it did not receive any feedback.[13] Early in 1990, the model developers began communications with the Corps of Engineers concerning a cooperative effort to exchange cost information. Discussions have also begun between EPA and DOE to address the costs of radioactive and mixed waste, but DOE has not been willing to sponsor this effort.

POTENTIAL FOR FUTURE COST SAVINGS FROM RESEARCH AND DEVELOPMENT

DOE has stated that new technologies on the horizon for environmental restoration have the potential to reduce estimated costs considerably. Inquiry into the justification for this statement indicates that the only attempt to quantify the potential cost saving specifically for DOE exists in the 1989 Draft Applied Research, Development, Demonstration, Testing and Evaluation (RDDT&E) Plan. This was done through an examination of the cost saving potential of new technologies both for remediation and for waste minimization.

The cost savings analysis resulted in the conclusion that "[i]mplementation of new technologies developed under the RDDT&E program can significantly reduce future expenditures, especially in situ treatment and waste minimization" (11). This conclusion is based on three cost savings analyses: in situ treatment of a waste site at the Hanford Reservation, a CORA model comparison of remediation of a low-level waste burial site by excavation/disposal and in situ measures, and waste minimization technologies for low-level, transuranic, and high-level waste. The plan indicates the key nature of benefit-cost information in technology selection and calls for additional studies to collect this type of information. It does not appear that any such studies have yet been initiated by the newly formed Technology Development Division.

Review of RDDT&E Plan Cost Savings Analyses

The first cost savings analysis was based in part on a study done for Westinghouse Hanford Co. by Science Applications International Corp. (SAIC) in 1987 (12). The analysis indicates an estimated savings of $44 million per site by using in situ vitrification (ISV) rather than excavation, treatment (incineration), and redisposal for the cleanup of an unspecified 100 contaminated sites at Hanford. Thus the total savings estimated at Hanford by using ISV was calculated as $4.4 billion in the RDDT&E Plan. This, of course, assumes that each of the sites is the same size, with similar contaminants, geological characteristics, and moisture content (an important factor in estimating the amount of electricity needed for ISV).

The SAIC cost estimates for ISV were based on applying the technology to a trench 35 feet by 35 feet by 30 feet deep (about 1,361 cubic yards). The estimated cost of $389 per cubic yard "does not include health and safety costs associated with working on radiological sites or the cost of backfilling the depression" (13). For the excavation, treatment, and redisposal cost estimate, SAIC estimated costs on an annual basis and assumed that a total of 163,800 cubic yards of soil would be removed per year. SAIC also assumed that the nature of the contamination would require the construction of a building over the excavation area, equipped with an air ventilation system to maintain negative pressure. Contaminated soil is

[12]According to a brief description of the model provided by H. Goddard, U.S. Environmental Protection Agency, Cincinnati, OH.

[13]EPA is apparently contracting with IPA, Inc., to validate the model and to distribute it to EPA regional offices some time this summer (H. Goddard, personal communication, January 1990).

loaded in drums by using remote handling equipment is disposed of at an approved site at a cost of $60 per dr Treatment consists of thermal destruction in a rotary k incinerator. SAIC estimated the cost at $365 per cu yard for excavation and disposal only and at $689 cubic yard if treatment is included.

According to Geosafe Corp., it is difficult to general about the cost of ISV, but Geosafe estimates it $250-$350 per ton for hazardous waste and up to $1,(per ton for radioactive waste (at SAIC's estimated density of 120 pounds per cubic foot, the latter estim converts to $1,620 per cubic yard).[14] An additional c of $35,000-$45,000 for treatability tests must be added well as mobilization/demobilization costs of ab $50,000-$60,000, plus $50-$60 for each mile that equipment must travel to the site (14). Electricity costs assumed to be about $0.07 per kilowatt-hour. At th costs, ISV is particularly competitive with incineratio large sites because of the latter's high fixed costs. T long-term stability of ISV is yet to be proved. ISV will tested in mid-1990 at several hazardous waste sites in United States under the Superfund Innovative Techn ogy Evaluation (SITE) program (Rocky Mountain Ar nal in Colorado is one of these sites). Given the abo information, the generalized estimate of $4.4 billion savings for the use of ISV at Hanford should be view with caution and should not be applied directly to ot sites outside the Hanford Reservation. (The plan does attempt to do this.)

The second cost savings analysis uses the CO model to estimate the cost of remediating a waste contaminated with low-level radioactivity and VOCs. T analysis compares excavation and disposal with in s treatment and confinement, yielding a cost ratio of 10 1. The in situ treatment and confinement meth examined in the analysis were soil vapor extraction, s flushing, and a protective cap. As is mentioned in RDDT&E Plan, CORA was not designed to incl radioactive or mixed waste and the treatment meth examined do not address these kinds of contaminants. addition, the plan indicates that the estimated cost for s flushing does not include wastewater treatment, wh would increase the cost (and reduce the ratio). T analysis, too, should be interpreted with caution.

These analyses highlight the fact that a limited amo of information is available concerning the cost savi potential of innovative or alternative technologies DOE-type contaminated sites. Some work is in progr throughout the complex, but demonstration of su technologies has been limited. In a 1988 report, E examined the application of treatment technologies

> ***Box C-1—How Does the Choice of Cleanup Le Affect Costs?***
>
> It is intuitively obvious that the cost of cleaning contaminated soil or water will increase as the clea standard decreases. As the contaminant dispe throughout the contaminated medium, it will bec more extensive, but less concentrated. More soil will h to be excavated, or more water will have to be pum as the cleanup standard decreases. What is not obvi however, is that the cost of cleaning up a given *uni* contaminant increases as the cleanup standard beco more stringent. This relationship was shown by Canc Engineers in their cost estimates to clean up trichloro ylene (TCE) contaminated soils at the McKin Superfi site in Maine. For a TCE standard of 1.0 ppm, the cos remove a pound of TCE was estimated at $880; fo standard of 0.5 ppm, the cost was $1,340; and fo standard of 0.1 ppm, the cost was $2,480. In gene because of the way contaminants disperse in soil groundwater, it is believed that the relationship betw cleanup cost and cleanup standard may be geome (although this was not the case for the McKin site).[1]
>
> [1]P. Schumann, "Options for Management of Soil Conta nation Problems at Superfund Sites: A Proposed Approach Setting Soil Cleanup Levels," doctoral thesis, University California-Berkeley, 1989.

radiologically contaminated Superfund sites and c cluded that:

> . . . the costs [of onsite treatment technologies] cannot b estimated reliably for any technology and for any site a this stage, because most of the prerequisite information i not available It also must be cautioned that many, if no most, of the controlling factors will be site-specific (15)

Despite this caution and the lack of substantive dat general belief exists among some of the scient involved that new technologies on the horizon characterizing and treating radioactive and mixed wa sites will ultimately save money. This optimism may based in part on the cost information that exists on the of innovative technologies for hazardous waste s through EPA's SITE program, among other sour Whether this experience will be duplicated in the radic tive and mixed waste arena remains to be seen. Alm every description of the costs of alternative technolog used on hazardous waste sites is prefaced with statement that it is very difficult to generalize about costs of relatively new technologies because they can v considerably depending on the specific characteristic a particular site. One disadvantage of using new techn gies is their relative uncertainty with regard to perfo ance. As is shown in box C-1, the level of clea

[14]Presentation given by D. Timmons at an EPA sponsored training course on solidification and stabilization technologies in Denver, CO, Jan. 10-11, 1990.

performance required for a site can greatly affect costs. Also, one study of the costs of megaprojects found that the use of new technologies in such projects resulted in 'cost growth, schedule slippage, and performance shortfalls" (16). Although this may not be directly comparable to environmental restoration, it does provide a reminder that the benefits of new technologies may not always be manifested in cost savings, particularly at the outset.

It seems premature, at this point, to try to quantify the potential for innovative technologies to reduce the cost of environmental restoration for DOE waste sites. As one scientist at Hanford said, "there's no silver bullet on the horizon for radioactive and mixed waste" (17).

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Appendix D
Attention to Ecological Issues

Despite statutory mandates to protect human health and the environment, ecological issues typically have not received significant consideration in the design or execution of remedial action plans either at Department of Energy (DOE) facilities or at other contaminated sites. It was not until March 1989 that the Environmental Protection Agency (EPA) issued a Superfund guidance document whose purpose was "to provide a scientific framework for designing studies. . that will evaluate pertinent ecological aspects of a site for the Remedial and Removal process. " Among the important ecological considerations, according to the guidance document, are the following:

- living resources at or near the site that require protection,
- effects of site contaminants on those resources, and
- effects of remedial actions (1).

More recently, the EPA Scientific Advisory Board (SAB) recommended that EPA direct as much attention to reducing ecological risks as to reducing health risks because of the inherent value of ecological systems and their strong links to human health (2). The SAB also recommended that EPA should improve the data and analytical methodologies that support the assessment, comparison, and reduction of different environmental risks.

Nine of the ten EPA regions have organized interagency ecological technical assistance groups to help project managers at Superfund sites consider relevant ecological issues during cleanup. In EPA Region III, the group is involved with every Superfund site. In other regions, the programs are just beginning. Groups such as these are necessary because ecological issues are often ignored in the initial planning activities at Superfund sites. According to one group coordinator, it is often impossible to tell from the initial characterization report whether a site is in "a desert or a tropical forest" (3).

Although such comments pertain to Superfund sites in general, not just DOE sites, several ecologists working with DOE facilities have expressed similar concerns. A common fear is that remedial action may do more harm than good because ecologists are not given sufficient input into the decisionmaking process. These ecologists offer several possible explanations for the failure to adequately consider ecological issues in the cleanup process at DOE facilities.

One contributing factor is that, historically, those in management positions at DOE facilities have not given substantial attention to biological issues. In addition, some facilities have been under great pressure from the public and individual States to "do something." Thus, some claim that remedial action is often advocated to quell criticism, without sufficient consideration of how much good it will actually do (4). A third reason that the ecological effects of contamination and remediation have tended to be ignored is that regulations have not usually been interpreted as requiring their consideration (5). Because it is very difficult to obtain remedial action money for projects not mandated by regulations (6), studies in basic ecology are generally not well-tided.

The amount of research being done on the ecological effects of contamination and remediation varies significantly from facility to facility. At Mound Plant, for example, no ecological research is being conducted (7). At Oak Ridge, on the other hand, the effort to study ecological effects related to the cleanup includes a well-established biological monitoring program, as well as ecological risk assessment. Even at Oak Ridge, however, ecologists have had to struggle to be heard (8). Some scientists believe that if the Environmental Sciences Division (ESD) at Oak Ridge had been utilized in the past as it is now, DOE could have avoided many of the credibility problems it faces today (9).

In-depth consideration of the situation at Oak Ridge is useful to provide examples of instances in which ecologists have been heeded and instances in which they have been ignored. It illustrates how the cleanup process is essentially regulation-driven but shows how doing more than is strictly required by regulations can be beneficial in the long run for both economic and environmental reasons.

The cooperative attitude that exists between ESD and the three Oak Ridge facilities with which it works (the Oak Ridge National Laboratory (ORNL), the Y-12 Plant, and K-25) has roots in a 1983 complainant order issued by the Tennessee Office of Health and Environment. The order required the Y-12 Plant to terminate discharges to the S-3 Ponds and close the ponds by March 1984. Although neither the order itself nor existing regulations required biological monitoring, management at the Y-12 Plant anticipated that massive cleanup would soon be required and approached ESD for help. As a result of that request for assistance, a monitoring program was begun to determine the effectiveness of remedial actions taken pursuant to the complainant order (i.e., neutralization and termination of discharges to the S-3 Ponds).

Over the years, monitoring has indicated the effectiveness of those remedial action measures from an ecological standpoint. Although a contaminated groundwater plume remains, the fish population in the upper reaches of Bear

Creek has recovered from a low of zero in 1984 to a high of several hundred in the sampling site nearest the S-3 Ponds in spring 1990. Monitoring has also proved that the main ecological problems in Bear Creek were a result of metal toxicity from the S-3 Ponds. Contamination from the oil landfarm and burial grounds further downstream appear to be ecologically insignificant. A 1985 ESD report advised that a planned 20-acre cap on the oil landfarrn and burial grounds would not improve ecological conditions in Bear Creek and would, in fact, have harmful effects on the terrestrial ecosystem of a ridge that had to be excavated to install the cap. Nevertheless, the cap was installed.

There are instances, however, in which the advice of ESD ecologists appears to have been heeded. They have pointed out the likely adverse ecological effects of pumping and treating groundwater at various sites along Bear Creek. Thus far, although it has been considered, no pumping and treating is planned. ESD scientists note that whereas human health considerations might make pumping and treating desirable, ecological considerations alone would discourage it.

In 1985, ORNL was required to initiate a biological monitoring and abatement program (BMAP) in order to receive a National Pollutant Discharge Elimination System (NPDES) permit. ESD scientists were able to implement a more extensive program than strictly required, by convincing DOE that in view of the impending cleanup, it would be more economical to undertake a program that could both meet NPDES requirements and inform the remedial action process. For example, although compliance with NPDES does not require monitoring of terrestrial ecosystems, data from such monitoring will be important in selecting remedial actions. ESD was able to obtain funds from both the NPDES compliance division and the remedial action division within ORNL. This initial commitment to an extensive monitoring program has been essential to the success of BMAP for two reasons. First, it is much easier to maintain existing funding levels than to obtain new funding. Second, it is impossible to compile adequate information about ecological impacts with 1-to 2-year studies.

One important result of BMAP has been the determination that chlorine is a problem at all Oak Ridge facilities. The large number of chlorinated point source discharges make this a difficult problem to remediate, but it is being addressed. Although 4 years elapsed between documentation of the chlorine problem and initiation of a search for solutions, in this case research on ecological effects informed the cleanup process (10).

The opinions of biological scientists are more highly valued at Oak Ridge now than in the past. The majority of biological research with potential relevance to the cleanup at Oak Ridge is performed by ESD. Of 200 staff scientists in the division, approximately 130 have master's or doctoral degrees, and about 40 percent of the latter are biologists. The staff is supplemented by about 250 visiting researchers (11). The State of Tennessee has acknowledged the ecological expertise that exists in ESD. Recommendations from the State that ESD be utilized more fully gave these environmental scientists the opportunity to be heard at Oak Ridge (12).

Ecological research with potential for informing the cleanup effort is also being done at the Savannah River Site (SRS). The Savannah River Ecology Laboratory (SREL) was officially established in 1961, but its roots go back to the beginning of SRS in 1951:

> At that time, interest in the kinds and numbers of plants and animals that may be affected by local operations spurred the Atomic Energy Commission to request "pre-installation" biological inventories. Scientists from UGA [University of Georgia] conducted censuses that might serve as indicators of future impacts of nuclear production facilities and examined basic ecological principles such as old-field succession, competition in animal and plant communities, and the use of radioactive tracers to chart food chains (13).

Today, 35 doctoral-level biological scientists are permanently employed by SREL; all of them in one way or another are studying the impacts of SRS operations on the environment (14). Approximately 20 of these researchers are also on the faculty at the University of Georgia (13).

The National Research Council's (NRC) Committee to Provide Interim Oversight of the DOE Nuclear Weapons Complex made the following comment in its 1989 report:

> The SRS is a model example of a DOE facility where an ecological culture has been adopted by many managers. Basic ecological research by the Savannah River Ecology Laboratory (SREL), as well as the Savannah River Laboratory, seems well appreciated by DOE and the site contractor management. Long-term, high-quality research along with popular writing and public lectures on the SRS wildlife and environment have obviously had a positive effect not only on plant management but also on public opinion (15).

According to a member of the NRC committee, science is being brought into the decisionmaking process at SRS, and managers there are less likely than those at other facilities to blindly perform remedial actions (16).

Like their counterparts at Oak Ridge National Laboratory, SREL scientists are concerned about the emphasis placed on engineering to the exclusion of biology in preliminary cleanup plans (14). However, more ecological research is being conducted at Savannah River than at most other facilities in the Weapons Complex, and SREL is confident that it will be able to influence the remedial action process there. Although SREL could provide important input into the development of cleanup plans for the entire DOE Weapons Complex, it is doubtful that SREL will be allowed to have a significant impact on cleanup decisions at the national level.

Oak Ridge and Savannah River are exceptions among DOE facilities in the effort they devote to ecological research. As mentioned earlier, Mound Plant does no such research. No ecologists are employed at the facility, and no ecological studies are being done in conjunction with the decommissioning of several plants there. The Mound Plant, however, covers slightly more than 300 acres, only half of which is used in operations (7). This is a fraction of the size of the Oak Ridge Reservation (about 60 square miles) (17) or the Savannah River Site (about 300 square miles) (18). Other large sites, however, are concerned much less about ecological effects than Savannah River or Oak Ridge. Neither Hanford nor the Idaho National Engineering Laboratory (INEL), both of which are substantially larger in area than SRS (19), has attempted extensive ecological site characterization.

DOE's Ecology and Radioecology Program at INEL is responsible for most of the ecological research done there, although contractors such as EG&G do some work in conjunction with specific remedial action projects (20). The Ecology and Radioecology Program consists of 3 DOE ecologists and about 20 associated university scientists (21). Although selected studies have been done on effects with potential relevance to the cleanup, there appears to be no systematic attempt to inform the cleanup process through ecological studies at INEL (20, 22). The routine monitoring program there is designed primarily to determine radionuclide pathways to human receptors and includes very little biological monitoring. Routine contaminant-level monitoring in animals is limited to game animals obtained from road kills (23).

The research on ecological effects at Hanford is confined to studies of individual operable units, which range in size from roughly 10 to 300 acres. Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedial investigation/feasibility studies are currently underway at about five of the smaller units, all of which are old reactor sites along the Columbia River. Ecological studies at these units consist primarily of monitoring contaminants in deep-rooted plants, small mammals, aquatic plants, and relatively stationary aquatic organisms such as clams and snails. Fish are not studied extensively because their mobility limits their usefulness in characterizing centamination at any particular operable unit. The studies are designed to establish baseline information with which data obtained during remedial action can be compared. Although a sitewide study would be useful, funding is limited to that necessary for the study of individual operable units. Ecological monitoring by Battelle Pacific Northwest Laboratories (PNL) currently involves about one person-year of activity (24).

There are approximately 15 master's or doctoral level ecologists on staff at Battelle PNL, a major DOE contractor at Hanford (25). Most of the research is devoted to using ecological principles to design remediation methods (26). For example, ecologists are involved in a multidisciplinary effort to develop protective baniers for waste sites. As part of the project, ecologists study how plants and animals can interfere with barriers by root intrusion or burrowing and how they can be used to prevent water infiltration into waste sites (27). Other major ecological research at Hanford includes revegetation of salt waste isolation sites and the development of a herbicide that prevents plant root intrusion into waste sites.

Related utility-oriented ecological research is being conducted at Los Alamos National Laboratory (LANL), but virtually no research is going on there. The major ecological research related to the cleanup at LANL involves nonengineering approaches to remediation, such as using evergreens as landfill caps. Native juniper pinions are replacing grass as a means of preventing erosion and controlling water flow because they are very effective in taking up water at the time of the spring snow reek. This helps minimize the amount of water that flows through a waste site and is much less expensive than traditional engineering solutions such as clay caps. In the course of this research at Los Alamos, there has been cooperation with ecologists at Hanford and INEL because of the similar ecology at the three sites (28).

Although great variation exists from facility to facility, it is perhaps not surprising for complexwide managers to be more interested in research that contributes to remedial action than in research that focuses on determining ecological effects. This appears to be true at Savannah River and Oak Ridge as well. Of the four major areas of research in ESD-bioremediation, biological monitoring, biomarkers, and burial ground restoration-the biggest emphasis is on bioremediation. Bioremediation involves the use of microbes to process waste, either in situ or in an above-ground reactor. Within ESD, a significant portion of available funds is spent on engineering sciences because of the expense of building bioremediation reactors (11).

One project being funded with remedial action money was selected from among a series of proposals submitted by SREL and is directed toward restoring an area in which vegetation has been destroyed by thermal discharges. About six ecologists are working on this. SREL hopes to have more projects funded with remedial action money in the coming year (14).

Although research on using ecological principles in remediation is essential, DOE must guard against focusing on methodology and ignoring the consideration of where remedial action is most necessary and where it might do more harm than good. One way to ensure effective remedial action is to devote sufficient ecological talent to determining where and what the problems are. Ecological information alone cannot determine priorities, but it must be a part of the priority-setting process. Comprehensive studies to identify the ecological effects of contamination or remedial action do cost money, but remedial action itself tends to cost far more. Money spent to determine where problems exist and whether proposed solutions are appropriate, given the alternatives, is well spent if it prevents ineffective (or even detrimental) and expensive "remedial" actions from being undertaken.

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Appendix E
Acronyms and Glossary

Acronyms

ACGIH —American Conference of Governmental Industrial Hygienists
ACLs —Alternative Concentration Limits
ADSs —Activities Data Sheets
AEA —Atomic Energy Act
AEC —Atomic Energy Commission
AIP —Agreement in Principle
AL —Albuquerque Operations Office
ALARA —As low as reasonably achievable
ARAR —Applicable or relevant and appropriate requirement
ATSDR —Agency for Toxic Substances and Disease Registry
BMAP —Biological Monitoring and Abatement Program
CDC —Centers for Disease Control
CEARP —ComprehensiveEnvironmentalAssessment and Response Program
CEDR —Comprehensive Epidemiologic Data Resource
CEHIC —Center for Environmental Health and Injury Control of the Centers for Disease Control
CERCLA —Comprehensive Environmental Response, Compensation, and Liability Act
CFR —Code of Federal Regulations
CMS —RCRA Corrective Measures Study
COCA -Consent Order and Compliance Agreement
CORA -Cost of Remedial Action
D&D —Decontamination and decommissioning
DHS —Department of Health Services (California)
DOE —Department of Energy
DWPF —Defense Waste Processing Facility
EIS —Environmental Impact Statement
EM-CAT —EnvironmentalRestoration and Waste Nkmagement Cost Assessment Team
EP —Extraction Procedure
EPA —Environmental Protection Agency
ER —Environmental restoration
ERG —External Review Group for the Department of Energy's Priority System
ESD —Environmental Sciences Division at Oak Ridge National Laboratory
ES&H —Environmental Safety and Health
FDA —Food and Drug Administration
FDER —Florida Department of Environmental Restoration
FEA —Federal Facility Agreement
FFCA —Federal Facility Compliance Agreement
FMPc —Feed Materials Production Center (Fernald)
FS —Feasibility Study
FTE —Full-time equivalent
FY —Fiscal year
GAO —General Accounting Office
HA —Health assessment
HAZWRAP —Hazardous Waste Remedial Action Program (in the Department of Energy)
HEDRP —Hanford Environmental Dose Reconstruction Project
HHS —Department of Health and Human Services
HLW —High-level waste
HRS —Hazard Ranking System
HSWA —Hazardous and Solid Waste Amendments
IAG —Interagency Agreement
ICPP —Idaho Chemical Processing Plant
ICRP —International Commission on Radiological Protection
INEL —Idaho National Engineering Laboratory
ISV —In situ vitrification
LANL —Los Alamos National Laboratory
LDR —Land-disposal restrictions
LLNL —Lawrence Livermore National Laboratory
LLW —Low-level waste
MCL —Maximum contaminant level
MEPAS —Multimedia Environmental Pollutant Assessment System
MOU —Memorandum of Understanding
NEPA —National Environmental Policy Act
NESHAPS —National Emission Standards for Hazardous Air Pollutants
NIEHS —National Institute for Environmental Health Science
NIOSH —National Institute of Occupational Safety and Health
NPDES —National Pollutant Discharge Elimination System
NPL —National Priorities List
NRC —Nuclear Regulatory Commission
NRDC —Natural Resources Defense Council
NTS —Nevada Test Site
NWC —Nuclear Weapons Complex
OMB --Office of Management and Budget
ORNL --Oak Ridge National Laboratory
ORR -Oak Ridge Reservation
OSHA -Occupational Safety and Health Administration
OTA -Office of Technology Assessment
OTD -Office of Technology Development (in the Department of Energy)
OU --Operable unit
PA —Preliminary Assessment

PA/SI	—Preliminary Assessment/Site Inspection
PCBs	—Polychlorinated biphenyls
PEIS	—Programmatic Environmental Impact Statement
PEL	—Permissible Exposure Limit
PNL	—Pacific Northwest Laboratory
POTW	—Publicly Owned Treatment Works
PUREX	—Plutonium and Uranium Extraction Facility
QRA	—Quantitative Risk Assessment
RCRA	—Resource Conservation and Recovery Act
R&D	—Research and development
RDDT&E	—Research, development, demonstration, testing, and evaluation
RFA	—RCRA Facility Assessment
RFA/VSI	—RCRA Facility Assessment/Visual Site Inspection
RFI	—RCRA Facility Investigation
RFI/RI	—RCRA Facility Investigation/Remedial Investigation
RI	—Remedial Investigation
RI/FS	—Remedial Investigation/Feasibility Study
RL	—Richland Operations Office
RMW	—Radioactive mixed waste
ROD	—Record of Decision
RRACES	—Remedial Response Construction Cost Estimation System
RWQCB	—Regional Water Quality Control Board (California)
SARA	—Superfund Amendments and Reauthorization Act
SCDHEC	—South Carolina Department of Health and Environmental Control
SDWA	—Safe Drinking Water Act
SEIS	—Supplemental Environmental Impact Statement
SI	—Site inspection
SITE	—Superfund Innovative Technology Evaluation
SPEERA	—Secretarial Panel for the Evaluation of Epidemiologic Research Activities for the U.S. Department of Energy
SREL	—Savannah River Ecology Laboratory
SRL	—Savannah River Laboratory
SR	—Savannah River Operations Office
SRS	—Savannah River Site
SWMU	—Solid Waste Management Unit
SWSA	—Solid Waste Storage Areas
TCE	—Trichloroethylene
TDHE	—Tennessee Department of Health and Environment
TLV	—Threshold Limit Value
TPA	—Tri-party agreement
TRU	—Transuranic
TSD	—Treatment, storage, and disposal
U.S.C.	—U.S. Code
U.S.C.A.	—U.S. Code Annotated
VOCs	—Volatile organic compounds
VSI	—Visual Site Inspection
WDOE	—Washington (State) Department of Ecology
WIPP	—Waste Isolation Pilot Plant
WSRC	—Westinghouse Savannah River Co.
WVDP	—West Vally Demonstration Project
Y-12	-Oak Ridge Y-12 Plant

Glossary

Bioremediation—Techniques using biological processes to treat contaminated soil or groundwater. Bioremediation can occur either in situ or in bioreactors where contaminated media are placed in contact with organisms to degrade the contaminants in a controlled environment. Generally, the technique involves stimulating organisms by adding materials such as nutrients or oxygen to increase the rate of biodegradation.

CERCLA Remedial Investigation—Investigation(s) under CERCLA for locating, identifying, and evaluating the nature and extent of contamination from hazardous waste that has migrated on or from a site. It currently involves drilling wells, collecting and analyzing samples, modeling contaminant migration, and other activities necessary to gather site-specific information for the Feasibility Study.

Certificate of Compliance—Certificate granted by the Nuclear Regulatory Commission certifying that a prototype of DOE's TRUPAC-II radioactive waste transport containers has passed its review and testing for "normal" and "hypothetical" accident conditions.

Characterization—Site sampling, monitoring, and analysis to determine the extent and nature of releases. Characterization provides the basis for acquiring the necessary technical information to develop, screen, analyze, and select appropriate cleanup techniques.

Compliance Agreements—Agreements between regulatory agencies and regulated parties setting standards and schedules for compliance with environmental laws. These agreements are legally binding and include Consent Order and Compliance Agreements, Federal Facilities Agreements, and Federal Facilities Compliance Agreements.

Compliance Order and Consent Agreement—*See* Compliance Agreements.

Corrective Action Order—Actions under RCRA that require a permitted facility to correct the release(s) of hazardous waste or constituents from a hazardous waste management unit. A Corrective Action Order can suspend or revoke the authority to operate a treatment, storage, or disposal facility, or seek appropriate relief (including an injunction) from a U.S. district court.

Corrective Measures Study—Study conducted to identify, evaluate, and recommend measures required to correct the release(s) identified in the RCRA Facility Investigation phase.

Curie—The amount of radiation emitted from 1 gram of Radium, equal to 37 billion decays per second. Curie (abbreviated as Ci) is used to measure the amount of material present, and does not express the quantity of radiation given off, nor the biological hazards involved, and is of limited use in measuring biological effects. A replacement measure in more common use in science today is the becquerel (Bq). 1 Bq = 2.7 x 10^{-11} Ci.

Decommissioning—Process of removing a facility from operation.

Decontamination—Removal of unwanted radioactive material from plants, soil, or equipment by chemical or mechanical processes or other techniques.

Deep Geologic Repository—Subterranean mined facility for the disposal of radioactive waste that employs natural geologic barriers to contain the waste over geological time scales.

DOE Orders—Internal DOE agency requirements establishing policy and procedures for compliance with applicable laws and regulations.

Environmental Characterization—*See* Site Characterization.

Environmental Impact Statements—A study prepared in accordance with the National Environmental Policy Act which evaluates and compares the environmental consequences of a proposed major action, such as the construction of a new facility, and other alternatives to that action. The conclusion of an environmental impact statement is usually a record of decision to select the preferred alternative.

Environmental Restoration—Cleaning up and restoring of sites contaminated with hazardous substances.

Epidemiology—Study of the distribution and determinants of diseases and injuries in human populations.

Feasibility Study—A phase of the CERCLA remedial process designed to develop, screen, and evaluate remedial action alternatives to correct or prevent the migration of contaminants from a site. Often, the Feasibility Study is conducted concurrently with the Remedial Investigation.

Federal Facility Agreement—*See* Compliance Agreements.

Five-Year Plan—U.S. Department of Energy, Environmental Restoration and Waste Management Five-Year Plan. DOE's yearly budget planning process and action plans for its activities in waste management and environmental restoration.

French Drain—A system of trenches excavated to a depth below the water table with the possible placement of a collection pipe in the bottom of the trench. Drains are generally used either to lower the water table beneath a contamination source or to collect groundwater from an up gradient source in order to prevent leachate from reaching uncontaminated wells or surface water.

Groundwater—Water occurring beneath the earth's surface that supplies wells and springs.

Hazardous Waste—As defined in the Resource Conservation and Recovery Act, a solid waste, or combination of solid wastes, that because of its quantity, concentration, or physical, chemical, or infectious characteristics, may cause or significantly contribute to an increase in mortality or an increase in serious, irreversible, or incapacitating reversible illness or pose a substantial present or potential hazard to human health or the environment when improperly treated stored, transported, or disposed of, or otherwise managed. Hazardous wastes may be listed or characteristic.

Hazard Ranking System—A computer model designed to aid EPA in determining a waste site's eligibility for placement on the National Priorities List. It includes an evaluation of the dangers determined at a particular site. The current system is undergoing revisions to incorporate further refinements.

High-Level Waste—The highly radioactive waste material that results from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid waste derived from the liquid, that contains a combination of transuranic waste and fission products in concentrations requiring permanent isolation.

Interagency Agreement (IAG)—Doeument in which two or more government agencies agree to cooperate.

Interim Status—Temporary permit condition that allows hazardous waste management facilities seeking a RCRA permit to continue operating until a final decision is made by EPA or the State to approve or deny the facility permit request.

Land Disposal Restrictions (LDRs)—Provisions of Hazardous and Solid Waste Amendments that require treatment of hazardous waste before disposal.

Low-Level Waste—Radioactive waste not classified as high-level waste, transuranic waste, spent nuclear fuel, or byproduct material.

Memorandum of Understanding—Document stating the terms of agreement between two agencies.

Mixed Waste—Waste containing both radioactive and hazardous components, as defined by the Atomic Energy Act and the Resource Conservation and Recovery Act, respectively.

Most Exposed Individual—An exposure component sometimes used in risk assessment calculation to identify individuals at greatest risk from a given hazard.

Multiattribute Utility Analysis—A mathematical algorithm designed to aid in the selection of choices with multiple and sometimes conflicting objectives. Through the assignation of different values to the objectives, the algorithm selects the choice that can satisfy the most objectives at the same time. It is the basis of DOE's priority system.

National Capacity Variance—EPA determination that extends the effective date of certain Land Disposal Restrictions and allows continued land disposal of wastes known to contain constituents that: 1) exhibit RCRA defined hazardous characteristics, or 2) are prohibited from land disposal. Granting of a National Capacity Variance is primarily triggered by the unavailability of either treatment capacity or treatment technology to render such waste nonhazardous.

National Priorities List—Listing of the nation's worst hazardous waste sites requiring cleanup, as established by CERCLA.

No-Migration Variance Petition—Petition filed by a hazardous waste management facility to be exempted from Land Disposal Restrictions established under RCRA. In general, the facility operator must successfully demonstrate that hazardous waste will not migrate from the proposed disposal area as long as such waste is considered hazardous under RCRA. Prior to final EPA approval, no-migration petitions must be subjected to public comment.

Nuclear Weapons Complex—Major facilities involved in the production and testing of nuclear weapons, operating under Department of Energy Defense Programs.

Operable Unit—Discrete area consisting of one to many release sites grouped together for purposes of assessment and cleanup. The primary criteria for placement of release sites into an operable unit include geographic proximity, similarity of waste characteristics and site type, and the possibilities for economy of scale.

Polychlorinated Biphenyls—A group of commercially produced organic compounds used since the 1940s in industrial applications, most notably as the dielectric material for large transformers and capacitors. Their toxicity has been documented in laboratory animals as well as humans, and they have been listed as hazardous wastes by the EPA.

Preliminary Assessment—Phase of CERCLA process used to determine whether a site has contaminated, or has the potential to contaminate the environment.

Pump and Treat—Groundwater remediation technique involving the extraction of contaminated groundwater from the subsurface to remove contaminants and subsequent return of the treated water to its source.

Quantitative Risk Assessment—A methodology to evaluate the extent of human exposure to environmental contaminants with potential health effects, in the face of incomplete knowledge of the molecular mechanisms that lead to disease. Quantitative risk assessments quantify the hazards associated with a particular pollutant under specific conditions of exposure, the result is a calculation that relates a contaminant's known chemical characteristics, toxicological behavior, and conditions of exposure to the probable incidence of the adverse effect under consideration in a given population.

RCRA **Facility Investigation (RFI)-Process of de**termining the extent of hazardous waste contamination.

Radioactive Waste-Solid, liquid, or gaseous material resulting from weapons production that contains radionuclides in excess of threshold quantities.

RadionuclideCertain natural and manmade atomic species with unstable nuclei that can undergo spontaneous breakup or decay, and in the process, emit Alpha (helium nuclei), Beta (fast electron streams) particles, and Gamma rays (short X-rays), collectively known as radiation.

Record of Decision (ROD)—Document under CERCLA used to select the remedial action to be implemented at a site after the Feasibility Study is completed.

Remedial Action—Phase of the remedial process designed to implement the Remedial Action Plan as required by CERCLA and EPA-developed Superfund guidance.

Remedial Investigation (RI)-Pmcess under CERCLA for deterrnining the extent of hazardous substance contamination and conducting treatability investigations. This provides site-specific information for the Feasibility Study.

Remediation—Process of applying a chosen technique or process to correct an environmental problem.

Site Characterization-Twhnical process used to evaluate the nature and extent of environmental contamination, which is necessary for designing of remediation measures and monitoring their effectiveness.

Site Inspection—Inspection conducted after the Preliminary Assessment to evaluate the extent of contaminants release at a site and the level of risk to human health or the environment posed by that release to determine whether it meets the criteria for CERCLA remedial action.

Soil Stabilization-Tmhniques to prevent soil from moving or eroding. Measures primarily include using surface water controls such as changing the contour of the land to alter runoff or run on characteristics of the site; providing a cover barrier to infiltration by reducing the permeability of the land surface through surface sealing or capping; and vegetating the site to hold soil in place, increase evaporation, and decrease infiltration.

Stakeholders' Forum—DOE meeting to review and discuss its "Predecisional Draft" of the 1990 Five-Year Plan for cleanup at the Weapons Complex. Invited participants in the 2-day forum were mainly from affected States, Indian Nations, Government agencies, and environmental, labor, and industry groups.

Superfund—Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

Tiger Team—Teams created by Secretarial initiative consisting of DOE and contractor specialists and Occupational Safety and Health Administration compliance officers to evaluate Environmental Safety and Health programs at the Weapons Complex for compliance with DOE Orders, and existing laws and regulations.

Transuranic Waste—Waste that is contaminated with alpha-emitting transuranium nuclides with half-lives greater than 20 years and concentrations greater than 100 nanocuries per gram of waste.

Tri-Cities Region—Area including Richland, Pasco, and Kennewick, WA, situated close to the Hanford Reservation.

Tri-Party Agreement—An Interagency Agreement among EPA, DOE and the State.

Vitrification—Process of immobilizing waste by producing a glasslike solid in which radioactive materials are permanently embedded.

Volatile Organic Compounds—A group of commercially produced carbon compounds that have the ability to evaporate rapidly at ambient temperatures. They are commonly used as industrial solvents in enormous quantities throughout the Weapons Complex in chemical separation processes and degreasing operations. Eight have been listed for regulation by the EPA, including trichloroethylene, tetrachloroethylene (known animal carcinogens), vinyl chloride, and benzene (know human carcinogens).

Waste Management—All activities associated with the disposition of waste products after they have been generated, as well as actions to minimize the production of wastes. DOE has defined waste management to include waste storage, treatment, and disposal (but not transportation), and the term is used interchangeably with "waste operations" in DOE's planning documents.

Waste Minimization—Reduction, to the extent possible, of the volume and/or toxicity of hazardous or radioactive waste prior to its treatment, storage, or disposal.

Weapons Complex—*See* Nuclear Weapons Complex.