FROM THE ARCHIVES

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The Shallow Land Burial of Low-Level Radioactively Contaminated Solid Waste

Panel on Land Burial
Committee on Radioactive Waste Management
Commission on Natural Resources
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1976

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

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

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PREFACE

This report is one in a series by the Committee on Radioactive Waste Management of the National Academy of Sciences. It is the result of a long study by an ad hoc panel of the problems associated with shallow land burial of solid low-level radioactive waste generated or to be generated by the establishments operated in behalf of the U.S. Atomic Energy Commission (AEC) and its recent successor, the U.S. Energy Research and Development Administration (ERDA).

The Panel on Land Burial undertook this study because the AEC was concerned with the present and long-term aspects of the burial of solid low-level radioactive wastes. These wastes make up a large fraction of the total mass and volume of solid radioactive waste, as distinguished from the smaller volume of the much more radioactive high-level wastes.

The waste with which the Panel has primarily been concerned has been the kind of trash produced by the ERDA nuclear laboratories and plants that is similar to most industrial trash, but that has either been contaminated with low levels of radioactive material or that is only suspected of having been so contaminated at levels too low to be easily measured. The total amount of such material produced annually by ERDA in the United States is relatively small; as noted in this report, it is approximately equivalent in volume and mass to the amount of ordinary trash produced by a typical American community of only 55,000 inhabitants. However, because it is radioactive and potentially hazardous, it presents special problems in its management.

The Panel was not asked to review the closely related problems of the commercial burial sites for low-level radioactive waste in the United States. However, we believe that the observations and recommendations resulting from our studies of the ERDA sites should often be directly applicable to policies about or conditions at the commercial sites in the United States.

The members of the Panel on Land Burial were selected and approved by the National Academy of Sciences with advice from the parent Committee members. The members of the Committee and Panel are named, with their affiliations, immediately following this preface. The members of both the Panel and its parent committee represent a broad range of disciplines, active in the fields of geology, nuclear engineering, radiation sanitary engineering, radiation biology, health physics, nuclear physics, hydrology, materials science, and public health.

The Panel had, in addition, members who were not uniquely familiar with radioactive waste problems but who were actively working on the very large problem of urban communities, that of management of solid waste. This was a very fruitful union, for these other specialists brought to the discussions much that was of value in the deliberations. Unquestionably their evaluations and proposals have improved the quality of the recommendations that have been made herein. Some members of the Panel have long been associated or concerned with management of radioactive waste and the health or hazard aspects of that endeavor. We believe that the amalgamation to involve people with practical experience in the management of radioactive wastes was helpful.

Those who are primarily interested in the ideas and recommendations from our discussions may limit their attention to the early portions of the report. Those who are interested in the various natures of the individual sites can go into that problem in greater detail in the appendixes. The Panel believes that the diversity of the geological nature of the sites is not well known to the general reader and that an understanding of the problems and proposed solutions presented here would be enhanced by such information. It will be noted that there is some repetition. Partly this was to make it possible for a reader to pursue a subject without a break by being referred to another and perhaps distant section of the report. Even more importantly, it permitted the members of the Panel to develop their own positions, arguments, and recommendations in a manner of their own choice. This has added a frequent change of style that we have tried to blend editorially; but this was done with a gentle hand, so that there would be no loss of the essential input from the individual panelists.

This report was reviewed extensively before it reached its present final form. Several of the reviewers wondered why we did not discuss certain subjects or make certain recommendations, such as on the exact way in which the federal government should assign responsibilities and authority for waste management (see Section 6.3). The Panel decided that its primary responsibilities were to offer the best scientific and technological recommendations that it could provide from its own ranks and obtain from trustworthy advisors. Its primary subject area was the review and evaluation of the scientific and technical aspects of the shallow land burial of waste contaminated with low levels of radioactive materials. The Panel believed that the examination of the much more complex social, sociological, political, and economic aspects of this subject was outside its original charter and areas of expertise. Other groups, such as the NAS/NRC Committee on Nuclear and Alternative Energy Systems, are addressing some aspects of these problems.

Accordingly, the Panel has in such instances attempted to point out the existence of such large-scale social problems related to waste management in the hope that this will help stimulate further study by others better qualified to work in these areas.

The Panel did not examine the low-level burial practices in foreign countries, because of our desire to keep our study within reasonable bounds of time and effort. However, discussions of the question have suggested that the United States may be able to learn some useful ideas and techniques from other countries, especially those limited in the amount of available land for shallow burial.

It is our understanding that our site visits and discussions have served as catalysts for action in several instances; accordingly, a number of our recommendations and suggestions may have already been put into effect, or, in some cases, they may have been completed or discarded.

We are especially grateful to the many individuals who contributed their knowledge and time to our discussions. Many of the matters discussed here and the possible solutions for problems came about through the frank discussions that were held.

If anyone believes that there were no vigorously presented differences in opinions aired, he does not understand the quality of the participants. This should be obvious to the reader of this report. In the end, because of the vigorous study of the subject, it is believed that the Panel was able to analyze and synthesize a reasonable series of guides for the near and midterm future for the safe management of solid low-level radioactive waste by near-surface land burial.

John H. Rust, *Chairman*
Panel on Land Burial
Committee on Radioactive Waste Management
August 6, 1976

ACKNOWLEDGMENTS

The Panel on Land Burial wishes to acknowledge with thanks the ever-helpful cooperation of Mr. Gerald H. Daly (Chief, Operations Branch, Nuclear Fuel Cycle and Production Division, U.S. Energy Research and Development Administration Headquarters). We also hereby acknowledge with special thanks the numerous individuals at the various ERDA sites and commercial burial sites who gave so generously and effectively of their time and accumulated knowledge. They were always willing to share their ideas for the improvement of the radioactive waste management programs. Without the wholehearted cooperation of all of these people, this report could not have been written.

The Panel also wishes to thank the many individuals, those both known and unknown to us, who have reviewed the manuscript of this report in its various stages of evolution. Their criticisms and evaluations have prompted us to clarify many points and have identified areas that needed additional discussion. Any remaining errors or omissions must remain the responsibility of the Panel and its limitations of time, energy, and human frailty.

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PANEL ON LAND BURIAL

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ABSTRACT OF PRINCIPAL FINDINGS

1. The Panel on Land Burial believes no measurable harm to human health has resulted from the past and present practices in the land burial of solid low-level radioactive waste at the sites managed by the U.S. Atomic Energy Commission (AEC) (now the U.S. Energy Research and Development Administration, or ERDA) (see Section 3.3).

2. The Panel is not satisfied that the plan to exhume and rebury the presently buried solid low-level transuranium radioactive waste can be accomplished without a measurable degree of hazard to the employees so engaged. We see no merit in the concept. As a consequence of our concern, we urge a reexamination and a reevaluation of the possible risks and possible benefits to be obtained before such a project is undertaken (see Sections 5.4.3 and 5.4.4).

3. While the Panel believes that there has been, and will be, no measurable harm to man from past and present practices of land burial of solid low-level radioactive waste, we are not convinced that current practices should be continued indefinitely into the future. As a consequence of the large volume of such waste anticipated in the near future from the commercial nuclear industry, we believe that a strong effort should be directed toward improving old, or developing new, volume reduction techniques prior to final disposal. These efforts are essential, because the amount of available land suitable for use for waste burial is limited in many parts of the United States. Otherwise, it may be impossible to meet future demands for space. Additional study and improvement of the

transportation system for waste is also basic to this concept (see Section 5.2).

4. This Panel also urges that there be an economic and technical reassessment of and research into the methods for recovery of useful fissile and non-fissile materials that can be recycled into the energy chain or used otherwise (see Section 5.2.7).

5. The comments of this Panel, in accord with our charter, are primarily directed at the past and present practices of the U.S. Energy Research and Development Administration. However, they must also be construed as pertaining to other governmental agencies at all levels. These include not only federal agencies, but also those of state and local governments (see Section 6.3).

6. This Panel is seriously concerned with the land burial problem that will present itself with the dismantling of present commercial nuclear power reactors as they become obsolete and are replaced. We believe much more thought must be given to the design of the fabric or basic structure of the buildings housing future commercial power-generating reactors, in order that their useful life can be extended even though their internal operational parts are replaced.

In other words, the Panel believes that reactors and other nuclear facilities should be specifically designed so that the radioactive parts of the power plant or other functional parts of the system could be removed and replaced at the end of their useful life without having to destroy or abandon the shielding, building walls, and other portions of the total facility. In this way, the future need for the disposal of solid low-level radioactive waste may be substantially reduced. Safe dismantling of the present monolithic, nearly indestructible structures of contemporary commercial nuclear power-generating stations presents a most difficult task. The methods for separation of the radioactive fraction of the debris from these structures for disposal cannot be considered lightly. This problem includes the dismantling and decommissioning of commercial nuclear power reactors, as well as of other commercial and ERDA nuclear facilities. The problem has not been discussed or presented in the body of this report, but is a general concern of the Panel.

7. The Panel is aware of ERDA's policy of not establishing any unnecessary additional land burial sites for solid low-level radioactive waste. Because of the anticipated volume of such waste to be produced in the foreseeable future, the Panel believes that this policy should be reconsidered in connection with current and long-term needs of the nuclear industry and in view of all other recommendations of this report and other current developments (see Sections 3.3.2 and 7).

1 INTRODUCTION

1.1 OBJECTIVES OF THE PANEL

This report is the result of a study of the conditions, practices, and problems involved in the near-surface ground burial by the U.S. Atomic Energy Commission (AEC) of solid waste contaminated with low levels of radioactive materials. Such contaminated waste may come from a wide variety of sources, including manufacturing, processing, and research installations. Depending on its origin, it may contain almost any radioactive isotope; however, the level of radioactivity is usually relatively low. The kinds of materials being handled are equally varied--ranging from paper towels and laboratory gloves to materials of construction from an obsolete nuclear reactor. For these reasons, the problems of handling these materials adequately and safely are not simple; neither are the solutions. No single method of disposal can be expected to be satisfactory in all cases. The disposal of high-level, or highly radioactive, waste, possibly by deep burial, was considered to be a separate problem by the Panel and so was not included in this study. It may be noted that the Committee on Radioactive Waste Management (CRWM) has already published several reports on this subject (see Appendix D).

The actual study was carried out by the Panel on Land Burial of the CRWM. This Panel was established on October 16, 1973, by the National Academy of Sciences-National Research Council in reply to a formal request from AEC (see Appendix F). (In early 1975, AEC was reorganized, and its responsibilities for the practice of land burial of radioactive wastes are now being continued by the U.S. Energy Research and Development Administration [ERDA], which has continued the sponsorship of the Panel's operations.)

AEC specifically requested that: (1) undesirable existing conditions and practices at AEC installations should be identified; and (2) appropriate corrective actions should be identified, such as changes in current burial practices, changes in the preparation of material for burial, and special treatment of the ground prior to burial.

The original request provided no specific guidance on the kinds or limits of radioactivity involved; neither did it request comments on practices used by operators of commercial land burial sites. These operators are already required to follow guidelines established by the U.S. Nuclear Regulatory Commission (USNRC), which was also formerly part of AEC. After careful consideration of their professional responsibilities, the Panel and the Committee have therefore made a decision with regard to these and other related problems to make those comments and recommendations they believed to be necessary and relevant, even though they had not been specifically requested by the AEC or ERDA.

It was agreed that one of the most important parts of the overall problem was that of the handling of the transuranium elements, many of which present special difficulties because of their potential toxicities and long half-lives. Aspects of this problem are discussed in greater depth in the following section and elsewhere in the report (see Sections 5.3, 5.4, 5.6, and 6.2).

1.2 THE SPECIAL PROBLEM OF THE STORAGE OF WASTE CONTAINING TRANSURANIUM NUCLIDES

The Panel has been particularly concerned with the temporary storage of solid materials contaminated with uranium-255 and transuranium nuclides.

A commitment was made in 1970 by the Commissioners of the AEC that all future transuranium waste would be stored temporarily in a readily accessible manner so that they would remain retrievable for 20 years (see AEC Manual 0511-01, approved September 19, 1973). This policy has recently been taken by operators to mean surface storage on specially constructed concrete or asphalt pads or in underground vaults of waste containing more than 10 nanocuries of transuranium nuclides per gram of waste. Waste contaminated with transuranium nuclides, buried below the surface in previous years, may be exhumed in the future. This will be discussed in some detail later (see Section 5.4, particularly 5.4.3).

Because of their particular significance to the problems of long-term land burial, we have included the following background discussion and rationale for considering the special problems of managing transuranium waste:

The letter of commitment, written by Chairman Glenn T. Seaborg to Senator Frank T. Church of Idaho on June 9, 1970 (see Appendix E), was aimed solely at the National Reactor Testing Station (NRTS) near Idaho Falls, Idaho (since renamed the Idaho National Engineering Laboratory [INEL]). It stated, "...AEC plans to store not only currently generated alpha wastes but also to excavate, process and ship such wastes which are being temporarily stored at NRTS. A number of years will be required to complete the transfer of such wastes from NRTS which we hope to start within the decade." Since more than half of the decade has passed and no method for final processing and no site for final disposal has been identified, it does not seem likely that the decade will see the initiation of that very large and potentially costly project. That general decision has, however, now been accepted by some as a commitment and has contributed to the dilemma of the operators of commercial land burial sites when they are presented with waste containing transuranium elements.

More recently, that part of the AEC that became the U.S. Nuclear Regulatory Commission (NRC) published an intention to modify its regulations so as to require all commercial sources of transuranium waste to ship it to selected ERDA sites for "retrievable storage" (U.S. Atomic Energy Commission 1974d:32923; U.S. Atomic Energy Commission 1974a: WASH-1539). Should this regulation be issued, the contribution from the nuclear power field will add to the size of the waste storage task at ERDA sites, and most certainly it will extend the period of subsequent handling and treatment of low-level transuranium-contaminated waste well into the foreseeable future. (The total volume of radioactive waste produced each year at ERDA sites is equivalent to the volume of ordinary solid waste produced by a town in the United States with a population of 55,000 [see Section 3.3.1 for details].) Unless there are suitable sites for the final disposal of such waste, a substantial increase in the amount of radioactive material would necessarily be placed in surface or near-surface storage at some as yet undesignated ERDA sites (see Tables 1 and 2 and Section 3.3.1).

The Panel on Land Burial of Radioactive Waste

TABLE 1 Commercial Solid Radioactive Waste Generated Annually in the United States

Calendar Year	Volume (X 1,000 cubic meters)
1962	1.9
1963	6.3
1964	13.1
1965	13.1
1966	16.2
1967	19.4
1968	19.7
1969	21.4
1970	25.1
1971	29.6
1972	44.1
1973	50[a]
1974	54[a]
1975	57[a]

[a]Estimated by ERDA.
SOURCE: U.S. Environmental Protection Agency (1974a).

TABLE 2 Projected Annual Total Volume of Transuranium-Contaminated Solid Wastes and Amount of Plutonium for Disposal

	Volume (X 1,000 cubic meters)		Plutonium (kilograms)	
Calendar Year	ERDA[a]	Commercial[b]	ERDA[a]	Commercial[b]
1980	2	5	25	90
1990	1	10	25	600
2000	1	40	25	2,700

[a]Assuming a constant rate of generation of waste, and with a reduction in volume of up to 10:1 by suitable methods (incineration, compaction, etc.).
[b]SOURCE: Data from U.S. Atomic Energy Commission (1974b: ORNL-TM-4631), adapted for commercial waste. A reduction of volume by at least 10:1 is assumed.

recognizes the magnitude and has considered many of the ramifications of the problem of transuranium waste. Notably with the management of transuranium waste, the overlap between present practice and older practices makes it impractical for us to clearly identify the problems. After a consideration of these facts, we chose to present our evaluations and recommendations concerning transuranium waste. In other somewhat less important cases, we also chose to look at problems that were closely related to but not specified in the AEC request (see Appendix E). Almost inevitably in those situations, we chose to broaden our task rather than to contract it.

There was some concern about the radiological health similarities of seepage pits and land burial sites, particularly with respect to the migration of radioelements in the soil. The Panel had originally been asked to study only the question of the disposal of solid radioactive waste; accordingly, it did not investigate the separate problem of seepage pits, where liquid radioactive waste is disposed of directly into the ground. However, data obtained from studies of seepage pits should be relevant to studies of leakages from land burials of solid waste. In addition, we recognize that radioactive contamination from seepage pits or deep-well injection of low-level radioactive waste has confused the diagnosis of the land burial problem.

1.3 PROCEDURES

1.3.1 Nature of Proceedings

Working meetings of the Panel were assisted by the presence of Mr. Gerald H. Daly (Chief, Operations Branch, Nuclear Fuel Cycle and Production Division, ERDA), who gave invaluable technical advice and assisted in arranging meetings with personnel at the sites. These sessions were followed by executive sessions of the Panel. Individual Panel members having specific qualifications wrote separate sectional reports, which were later amalgamated into the body of the final report or were included as appendixes.

1.3.2 Summary of Sites Visited Where Radioactive Waste Is Managed

The Panel inspected the major ERDA sites where land burial is practiced--i.e., the Hanford Reservation, Richland, Washington; the Los Alamos Scientific Laboratory (LASL), Los Alamos, New Mexico; the Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee; the Savannah River Plant (SRP), Aiken, South Carolina; the Idaho National Engineering Laboratory (INEL), Idaho Falls, Idaho (Figure 1).

We did not visit several older sites (e.g., the Mound Laboratory, Miamisburg, Ohio, or the Argonne National Laboratory [ANL], Argonne, Illinois, where building debris has been buried, nor did we go to any

FIGURE 1 Major generating, storage, and disposal sites for solid low-level radioactive waste. See Tables 3, 4, and 5 for further details on types and amounts of contaminated waste. SOURCE: Gerald H. Daly, ERDA (private communication, 1976); data revised to June 1976.

ERDA-operated laboratories or licensees where waste suitable for burial is generated but not buried. Individually, or as a group, we have inspected all of the commercial land burial sites except at West Valley, New York. The visits at these sites were not a part of our charter; they were only intended to be educational. We have reported on our trips to the ERDA-operated burial sites in some detail (Appendix A). The Panel was given a great deal of useful information at each of the sites that it visited. Much of this was presented orally to the Panel and has been incorporated directly into its report without specific citation to the speaker or to the published literature in the field. The Panel believes, however, that the principal recent literature sources are included in the list of References, and refers the interested reader there for more details.

1.4 SPECIALIZED TERMINOLOGY

A number of terms have been used in this report that have specific or specialized meanings or applications in this area of science and technology. For purposes of consistency and clarity, the Panel has used the following terms within the following limiting definitions.

1.4.1 Radioactive Waste

Equipment and materials from nuclear operations that are radioactive and for which there is no further economic use. Waste is generally classified as high-level (having concentrations of radioactivity of hundreds to thousands of curies per gallon or cubic foot or cubic meter), low-level (averaging in the range of 1 microcurie per cubic foot or so), or intermediate-level (between these extremes). Waste is classified by its level of radioactivity at the time of burial. As radioactive decay proceeds, the level diminishes according to known and predictable mathematical expressions, depending on the radioactive nuclides present. Unfortunately, there is no complete and generally accepted system of classification and nomenclature of radioactive waste at this time; such a system is needed (see Section 6.1).

1.4.2 Radioactive Waste Management

The policies and practices used in nuclear science and technology for the control, measurement, handling, and processing of nuclear waste materials or of other waste materials contaminated with radioactive material. It also includes the analytical and statistical methods required to account for the amounts of radioactive nuclides being handled or stored. The effective management of radioactive waste requires the skillful use of the methods and understanding of nuclear, chemical, and sanitary engineering and of geology, hydrology, ecology, and health physics.

1.4.3 Storage of Radioactive Waste

The placement of radioactive waste in a location, either above or below the surface of the ground, where it is possible to retrieve it for subsequent reprocessing or final disposal.

1.4.4 Burial of Radioactive Waste

The placement of low-level radioactive waste in trenches, pits, etc., near the surface of the ground.

It is differentiated from deep geological disposal, such as in salt beds, etc., which is being proposed for long-lived high-level radioactive waste.

1.4.5 Containment of Radioactive Waste

The confinement of radioactive waste at a burial site by the use of an engineered structure, such as a concrete-lined trench.

1.4.6 Disposal of Radioactive Waste

The placement of radioactive waste in a place called a depository, e.g., deep in a salt mine or other stable geological formation, such that it is expected to present no future hazard to the biosphere, and where no further handling is required or intended.

1.4.7 Repository for Transuranium Waste

A facility for disposal of long-lived radioactive transuranium waste, the location for which is chosen to obviate the need for continued surveillance by man. In the United States, such facilities are owned and operated by the federal government.

1.4.8 Background Radiation

Background radiation is that ever-present radiation due to natural radioactivity and to cosmic rays. The bulk of the natural radioactivity comes from members of the uranium and thorium series and from potassium-40. From the standpoint of biological effects, background radiation can be divided into that external to the organism and that arising from radioactivity incorporated in the body. Uranium, thorium, and their daughter products; potassium-40; and cosmic radiation are the principal sources of external exposure.

Potassium-40 is the primary source of internal exposure, with radium playing a role as far as exposure to bone is concerned. Background radiation varies as a function of the local composition of the soil, rock, and building materials as well as with altitude (cosmic ray intensity increases with increasing altitude). A reasonable average value for the United States is 100 millirads per year due to external and 25 millirads per year due to internal radiation (1,000 millirads equals 1 rad). All inhabited areas in the United States experience radiation well within a factor of three of this average value of 125 millirads per year total background exposure.

Other terms are defined in the text where appropriate or are listed in the Glossary.

2 RECOMMENDED PRINCIPLES FOR THE BURIAL OF SOLID WASTES CONTAMINATED WITH RADIOACTIVITY

Radioactive wastes are very diverse, both in their levels of radioactivity and in the mix of radionuclides present in the waste at any specific time. Different radionuclides differ in toxicity over many orders of magnitude, depending on their specific activity, the kind of particle or radiation emitted, the biological mobility in a particular organism, and its radiosensitivity. The rates of movement of radioactive elements with the groundwater system may vary from almost zero to a rate equal to that of the groundwater itself. The characteristics of waste management sites are also highly variable in terms of climate, soil type, hydrogeology, and demography. In many ways, therefore, waste management policies must be defined on a case-by-case basis. However, there are certain general principles that apply to all sites and all types of waste that are intended for land burial; these are discussed in detail in this section.

The Panel on Land Burial recommends that these principles be followed by ERDA and other organizations responsible for the management of radioactive waste. Some of these recommended principles have already been proposed in the technical literature (e.g., U.S. Atomic Energy Commission 1973a: WASH-1202), but are also included here for completeness and independent emphasis.

2.1 GOOD HOUSEKEEPING AND CAREFUL SEGREGATION

Segregation and good housekeeping at the source of production must be used to keep the contamination of non-radioactive waste to the lowest practicable level, and to simplify placing waste into suitable categories for particular burial facilities. This, we believe, will tend to reduce the volume of solid low-level radioactive wastes that are candidates for land burial (see Section 5.2.1). The phrase "lowest practicable level" needs a precise definition (see Section 6.3).

2.2 VOLUME REDUCTION

Solid radioactive waste should be processed for volume reduction by compaction and incineration, whenever possible, and placed in suitable containers, particularly if retrieval is foreseen. Combustible waste should be incinerated. This process reduces its volume and gives a product that is fireproof and easier to handle. Specific attention should be given to the problems of incineration of organic matter, including the carcasses of experimental animals that have been treated with radioactively labeled substances (see Sections 5.2.5 and 5.2.6).

2.3 LONG-TERM MANAGEMENT AND CONTAINMENT

The Panel believes that the major goals of a permanent low-level solid waste burial operation are to contain the waste until it decays to an innocuous level, to guarantee that the radioactive waste is under control at all times, and to guarantee that if contaminants migrate from the site, their movements can be predicted so that necessary corrective actions can be taken (see Section 5.8.2).

2.4 INACCESSIBILITY OF WASTES

In the selection of permanent burial sites and the quantity and type of waste disposed at the sites, it must be realized that we cannot expect to be able to control access to the site for an indefinite time, and that any hazardous waste remaining at the site after a specified time limit must be as difficult to gain access to as possible (see Sections 5.4.4 and 5.7.1).

2.5 MONITORING SYSTEMS

A monitoring system must operate at both permanent burial sites and at storage ites so that surface or air contamination will be detected quickly. Ground and surface water beneath or very near to the burial facilities should be monitored sufficiently often to give the earliest practical warning of failure of any facilities. (For our purposes, "failure" is defined as significant contamination of the ground or surface water in excess of standards that have been set for a disposal site) (see Section 5.8). Monitoring should also include adequate biological and ecological monitoring of the biosphere to detect entrance of radionuclides into the local biosphere (see Sections 4.2 and 5.7.1).

2.6 CONTINGENCY PLANS

Contingency plans must be made to cover all foreseeable accidents or failures. They must include plans for corrective action in the event that monitoring shows a hazardous spread of contamination. If plans for such corrective action cannot be made and put into effect, then the site is not acceptable (see Sections 5.7 and 6.3).

2.7 GOVERNMENT CONTROL OR OWNERSHIP OF SITES

All radioactive waste management sites must be controlled by or both owned and controlled by a government agency. The present practice of controlling public access to such areas must be continued. The sites should be located in a place remote from human habitation (see Sections 5.7 and 6.3).

2.8 ENGINEERED CONTAINMENT STRUCTURES

Engineered structures for the containment of waste must be designed with the intent to keep water, which can mobilize the contaminants, out of the facility. They should be located in a place where rupture would not lead to rapid transfer of contaminants into the public domain before they could be recovered (see Section 5.7).

2.9 EARLY WARNINGS OF HUMAN ACTIVITIES

Note must be taken of the operations and activities of instigators or proposers for nearby real estate development, road building, airport construction, and other activities that might change the anticipated probable hazards or accessibility of the low-level waste burial facilities. The appropriate government agencies should be required to report any such considerations to those individuals or commercial venturers and to gather demographic knowledge of the area in which a land burial site is located. Forecasts of credible usage of the surrounding area by man in the future must be obtained or developed. These problems have not been discussed or presented in the body of this report but are a general concern of the Panel.

2.10 RECORDS MANAGEMENT

Duplicate records of the types, quantities, and concentrations of radioactive waste nuclides delivered to a burial site must be made and filed with more than one record bank. Reports on monitoring results and significant incidents, such as spills or unanticipated release of waste, must be filed with more than one record bank. These records should show the real (i.e., observed, not calculated) level of contamination of the environment (including the ground area). These records must be in such a form that they will be useful and available for the effective length of time that the waste burial facility will require human attention. In addition, such records must be kept not only of the ERDA burial sites but of all sites used for radioactive waste. Historical records of the use of older burial sites, although often incomplete, should be included in the record (see Section 6.3).

2.11 COST ANALYSIS

The operation of a waste management system must be governed by a realistic cost-benefit analysis, taking into account the "cost" in radiation exposure to operators or to the public of any act or failure to act. It must be recognized that the "cost" in man-rems to the community is the same whether it is absorbed by an operator or by a member of the general public outside the management area (see Section 5.4.4).

2.12 TRANSPORTATION COSTS AND RISKS

Although the location of disposal areas in inhospitable regions seems desirable, transportation of waste involves hazards normal to the transportation industry as well as hazards due to radiation. The analysis of any plan that involves transportation must include all hazards and economic data (see Section 5.7).

2.13 NON-EXHUMATION OF RADIOACTIVE WASTES

Exhumation of waste originally buried without any intent of later retrieval is a potentially very hazardous operation. Such exhumation should not be made unless there is a credible reason to believe that a significant radiation hazard could arise from leaving the waste where it is and that the wastes can be exhumed safely. As a corollary to this recommendation, radioactive waste should not be exhumed and put into temporary engineered storage where the material must await a final decision on permanent disposal (see Section 5.4.3).

2.14 FEDERAL DEFINITIONS AND GUIDELINES

The U.S. government must define the responsibilities and assign the authority for setting guidelines and policies and ensuring the proper coordination between federal, state, local, and international agencies for the effective management of radioactive waste. Division of responsibilities between the federal agencies must be done in such a way as to ensure that all significant areas of responsibility are properly covered and none is overlooked. We recognize that guidelines and standard procedures may vary from site to site because of local variations in geological conditions and other circumstances. However, the Panel believes that a standardized system of definitions, nomenclature, and classification of radioactive wastes is necessary for an effective national and international program of radioactive waste management (see Section 6.3).

3 HISTORICAL PERSPECTIVE

3.1 OPERATIONAL PROCEDURES USED DURING THE PERIOD OF THE MANHATTAN PROJECT

In the early days of the Manhattan Project, little thought was devoted to land burial of contaminated material, for it was secondary to the main task at hand. Later, as it became apparent that the laboratories would become permanent government-supported activities, increasing attention was given to land burial problems. As the research, development, and production programs expanded or were modified, the waste materials and used equipment to be buried became much more varied and more difficult to manage. Attention was forcefully drawn to the problem.

Solid radioactive waste had often been buried in the most accessible and convenient vacant place, without a great deal of thought for the long-term consequences. Fortunately, the amount of radioactive material was not large at that time. The transuranium elements were very strictly conserved and, at first, solid waste containing separated fission products was not a serious land burial problem.

Wartime pressures for production and lack of knowledge or understanding led to siting and operational practices that, in many situations, are unsatisfactory by 1976 standards. However, the amounts, varieties, and actual behavior of radionuclides in and on solid waste, in the environments of the sites used, was such that these circumstances did not lead in fact to an unacceptable exposure of man to radiation.

3.2 LATER SAFETY CONSIDERATIONS

As time passed and waste accumulated, it became apparent that the escape of radioactive material from waste management facilities might in some manner become hazardous to the operators and to the public. Concern was directed mainly toward high-level liquid waste, leading to research on fixation of fission products in ceramics and glasses and the establishment of monitoring systems around storage areas. However, it was soon realized that the practice of burying low-level waste directly in the soil might also lead to hazards of concern. Attention was then directed towards monitoring the movement of radionuclides through the soil and more careful selection of sites for waste management from among those areas where such movement could be expected to be minimal.

3.3 THE PRESENT CONDITIONS

Radioactive material has passed beyond burial site boundaries at some places (e.g., at Oak Ridge), but the amount has been so minute that the effect on human health is too small to measure. However, following the principle of the National Council on Radiation Protection and Measurements (NCRP) and the International Commission on Radiation Protection (ICRP) that the dose to man must be limited to the lowest practicable amount, these situations are not now acceptable. The dose, though very low, can be reduced by practicable measures. Steps are being taken to reduce further human exposures.

3.3.1 Sites Operated by the U.S. Energy Research and Development Administration

The various ERDA sites visited reported that waste handling, storage, and burial operations were conducted within guidelines established by the AEC (U.S. Atomic Energy Commission Manual, Chapter 0524) and various locally derived guidelines. We saw no reason to doubt these claims. Materials that have customarily been buried near the surface were classified as "solid radioactive waste other than solidified high-level waste." They include paper, rags, rubber, synthetic-rubber-like materials, wood, glassware, carcasses and excreta of experimental animals, protective clothing, small pieces of contaminated equipment, solids resulting from treatment of radioactively contaminated liquid streams, rubble from dismantled buildings, and sometimes large pieces of highly contaminated equipment.

Until fairly recently, nearly all solid low-level radioactive waste, including waste only suspected of being radioactive, was buried directly in the soil near the surface (see Tables 3, 4, and 5).

The waste was usually packaged minimally and dumped randomly at designated sites into large pits or trenches and covered with earth. Some effort was made to separate waste according to the type and energy of the particles or photons emitted. The "beta-gamma" waste was sometimes separated from the "alpha" waste. When waste had to be transported to off-site disposal sites, it was packaged to meet federal or state transportation regulations. Some solid low-level radioactive waste continues to be randomly dumped today (see Figures 2, 3, and 4).

There are several points to be considered in the interpretation of the figures in these tables. The amount of radioactivity in the waste, expressed in kilocuries, is the activity at the time of burial. As radioactive decay proceeds, this value continues to decrease.

For purposes of comparison, the amount of solid waste produced annually by a representative medium-sized town in the United States should be noted. Bloomington, Indiana, has a population of about 50,000 residents plus about 32,000 students at Indiana University. In 1975 the total production of solid waste from households only was about 6.2 million kilograms (6,800 tons), which when partially compacted, occupied 21,385 cubic meters. During 1976 a maximum total production for 1 week that included residential, business, industrial, and university sources was about 824,000 kilograms (913 tons) or 2,900 cubic meters when partially compacted. On a total annual basis, these values are 43 million kilograms (47,580 tons) and 150,000 cubic meters. The annual production of all kinds of solid radioactive waste at all ERDA sites in FY 1974 totalled 61,604 cubic meters, or about 40 percent of the total volume from Bloomington, Indiana. Therefore the volume of radioactive waste produced annually at ERDA sites is equivalent to the volume of waste produced by a typical American town of 55,000 inhabitants.

3.3.2 Commercial or Privately Owned Waste Disposal Sites

In the past, solid waste containing uranium, transuranium elements, and fission products generated

TABLE 3 Solid Radioactive Waste Stored and Buried at ERDA Sites Cumulative through June 1974

Site	Hectares	(Acres)	Total Volume (cubic meters)	Kilocuries Buried	Kilocuries Remaining	Total TRU[a] (kilograms)	Total Uranium (kilograms)	Retrievable Storage	
								Cubic Meters	TRU[a] (kilograms)
Feed Materials Production Center (Fernald, Ohio)	2.9	(7.3)	73,000	1	1	–	2,483,000	–	–
Hanford Site (Richland, Washington)	98.4	(243.1)	200,000	1,870	900	365	592,100	4,300	40
Idaho National Engineering Laboratory (Idaho Falls, Idaho)	21.0	(52)	159,000	5,970	3,600	492	276,700	22,000	119
Lawrence Livermore Laboratory (Livermore, California)	2.3	(5.7)	700	*b*	*b*	–	32,900	–	–
Los Alamos Scientific Laboratory (Los Alamos, New Mexico)	23.1	(57.2)	220,000	210	160	15	245,100	700	8
National Lead Co. of Ohio (Niagara Falls, New York)	0.4	(1)	7,000	*c*	*c*	–	9,000	–	–
Nevada Test Site (Las Vegas, Nevada)	64.8	(160)	7,400	5	*b*	*c*	–	–	*b*
Oak Ridge Gaseous Diffusion Plant (Oak Ridge, Tennessee)	<0.4	(<1)	1,100	*c*	*b*	–	45,400	–	–

Oak Ridge National Laboratory (Oak Ridge, Tennessee)	23.8	(58.8)	176,000	<60	*b*	13	100	800	3
Oak Ridge Y-12 Plant (Oak Ridge, Tennessee)	2.1	(6.2)	26,000	*b*	*b*	–	NA	–	–
Paducah Gaseous Diffusion Plant (Paducah, Kentucky)	0.7	(1.7)	6,000	1	1	–	2,133,500	–	–
Pantex Plant (Amarillo, Texas)	<0.4	(<1)	100	*c*	*c*	2	20,200	*c*	2
Portsmouth Gaseous Diffusion Plant (Portsmouth, Ohio)	<0.4	(<1)	300	*c*	*b*	–	2,300	–	–
Sandia Laboratory (Albuquerque, New Mexico)	0.57	(1.4)	1,200	6	3	*c*	17,600	*c*	*b*
Savannah River Plant (Aiken, South Carolina)	37.6	(93)	273,000	8,440	4,280	50	72,000	2,000	44
Weldon Springs (St. Charles County, Missouri)	3.0	(2)	43,000	*c*	*c*	–	*b*	–	–
TOTAL	279	(690)	1,193,800	–	–	937	–	30,500	–

[a]TRU: Transuranium nuclides.
[b]Data not available.
[c]Negligible.
SOURCE: Gerald H. Daly, ERDA (private communication, 1976); data revised to December 1975.

TABLE 4 Solid Radioactive Waste Stored and Buried at ERDA Sites during Fiscal Year 1974 (July 1, 1973, through June 30, 1974)

	Total Quantities		Retrievable Storage	
Site	Cubic Meters	Kilocuries	Cubic Meters	TRU[a] (kilograms)
Feed Materials Production Center (Fernald, Ohio)	400	c	–	–
Hanford Site (Richland, Washington)	6,500	375	700	10
Idaho National Engineering Laboratory (Idaho Falls, Idaho)	7,100	57	3,800	36
Lawrence Livermore Laboratory (Livermore, California)	–	–	–	–
Los Alamos Scientific Laboratory (Los Alamos, New Mexico)	3,900	35	370	7
National Lead Co. of Ohio (Niagara Falls, New York)	–	–	–	–
Nevada Test Site (Las Vegas, Nevada)	580	c	c	c
Oak Ridge Gaseous Diffusion Plant (Oak Ridge, Tennessee)	10	c	–	–
Oak Ridge National Laboratory (Oak Ridge, Tennessee)	3,600	1	200	2
Oak Ridge Y-12 Plant (Oak Ridge, Tennessee)	90	b	–	–
Paducah Gaseous Diffusion Plant (Paducah, Kentucky)	90	c	–	–
Pantex Plant (Amarillo, Texas)	2	c	–	–
Portsmouth Gaseous Diffusion Plant (Portsmouth, Ohio)	7	c	–	–
Sandia Laboratory (Albuquerque, New Mexico)	80	<1	–	–
Savannah River Plant (Aiken, South Carolina)	14,100	175	80	2
Weldon Springs (St. Charles County, Missouri)	–	–	–	–
TOTAL	36,459	–	5,150	57

[a]TRU: Transuranium nuclides.
[b]Data not available.
[c]Negligible.
SOURCE: Gerald H. Daly, ERDA (private communication, 1976); data revised to December 1975.

in various commercial nuclear fuel preparation and reprocessing enterprises has been placed in commercial burial sites. Land burial at commercial sites is under the jurisdiction of the U.S. Nuclear Regulatory Commission (NRC) or of an "Agreement State" (referring to an agreement between a qualified state and the U.S.

Atomic Energy Commission under Federal Statute 42 U.S.C. 2021). The general guidelines for the application for a burial license and the necessary environmental statement are given in the NRC Regulations 10CFR 20, 30, 40, 51, and 70. Inspections are made and sites periodically "audited" by the NRC and/or by the Agreement State inspectors.

The locations of commercial burial sites are shown in Figure 1. They are at or near West Valley, New York; Barnwell, South Carolina; Morehead, Kentucky; Sheffield, Illinois; Beatty, Nevada; and Richland, Washington. The commercial burial site at West Valley is operated by Nuclear Fuel Services, Inc. The site at Barnwell is operated by Chem-Nuclear Services, Inc. The remaining sites are operated by the Nuclear Engineering Company.

The total volume of solid radioactive waste buried at commercial sites through 1975 was about 370,000 cubic meters (13 million cubic feet) (see Table 1). This waste was estimated to contain about 3.3 million curies of radioactivity, uncorrected for decay.

About 1,000 kilograms (2,200 pounds) of special nuclear material containing about 113 kilograms (250 pounds) of plutonium is buried at commercial sites.

It has been estimated that by the year 2000, the annual volume of transuranium waste generated commercially will be contained in about 40,000 cubic meters (1.4 million cubic feet) of material and will include 2,700 kilograms (2.97 tons) of plutonium (see Table 2).

An additional projection for the accumulation of cladding waste was presented in the Draft Environmental Statement (U.S. Atomic Energy Commission 1974a: WASH-1539). It is summarized in tabular form (see Table 6).

We have mentioned earlier the reconsideration of the former practices of land burial and the establishment of a policy of 20-year retrievable storage for transuranium waste generated by ERDA operations (see Section 1.2). At the time that this policy was being developed, it was also recognized that a similar problem existed at the commercial burial sites. Further, the magnitude of the waste management problems at commercial burial sites in the future would be expected to dwarf the programs now operating at the ERDA sites. Therefore, at the time of the announcement of the changed policy for ERDA burial sites, it was also stated that the NRC anticipated that it might need to identify and consider some radioactive waste (i.e., transuranium waste) as being unsuitable for commercial burial. This policy would relieve the increasing burden of such waste upon commercial operators.

There were two prospective changes in regulation: (1) to prohibit the disposal by burial in soil of

TABLE 5 Solid Radioactive Waste Generated at ERDA Facilities without Burial Grounds

	Cumulative Quantities through 1974				FY 1974[d] Quantities			
Site	Total (cubic meters)	Total (kilocuries)	TRU[a] Waste (cubic meters)	TRU[a] (kilograms)	Total (cubic meters)	Total (kilocuries)	TRU[a] Waste (cubic meters)	TRU[a] (kilograms)
Ames Laboratory (Ames, Iowa)	100	<1	–	–	10	c	–	1
Argonne/West (Idaho Falls, Idaho)	23,000	7	70	5	900	1	c	c
Atomics International (Santa Susana, California)	900	1	5	c	300	c	c	–
Bendix Plant (Kansas City, Missouri)	800	c	–	–	5	c	–	–
Bettis Atomic Power Laboratory (West Mifflin, Pennsylvania)	7,500	2	c	c	1,600	1	c	c
Brookhaven National Laboratory (Upton, L.I., New York)	300	45	–	–	200	45	–	–
Burlington ERDA Plant (Burlington, Iowa)	5	c	–	–	c	c	–	–
Fermi National Accelerator Laboratory (Weston, Illinois)	100	c	–	–	50	c	–	–

Lawrence Berkeley Laboratory (Berkeley, California)	200	1	40	[c]	60	1	[c]	–
Lovelace Foundation Laboratory (Albuquerque, New Mexico)	400	<1	1	[c]	110	[c]	–	[c]
Mound Laboratory (Miamisburg, Ohio)	24,000	85	17,000	5	1,500	12	1,000	<1
Naval Reactors Facility (Idaho Falls, Idaho)	17,000	3,200	1	–	900	10	–	–
Pinellas Plant (Clearwater, Florida)	700	110	–	–	60	12	–	–
Rocky Flats Plant (Golden, Colorado)	88,000	310	70,000	440	7,000	16	6,000	22
Shippingsport Atomic Power Station (Shippingsport, Pennsylvania)	700	[c]	–	–	300	[c]	–	–
TOTAL	163,705	3,760	–	450	12,995	–	7,000	–

[a]TRU: Transuranium nuclides.
[b]Data not available.
[c]Negligible.
[d]FY 1974: Fiscal Year 1974 (July 1, 1973, through June 30, 1974).
SOURCE: Gerald H. Daly, ERDA (private communication, 1976); data revised to December 1975.

FIGURE 2 Solid waste with very low levels of radioactivity (near background level) is disposed of in cardboard boxes into trenches 6 meters (20 feet) wide and 6 meters (20 feet) deep at the Savannah River Plant. Trenches are backfilled periodically, then finally covered with 1.2 meters (4 feet) of soil when full. The soil is a mixture of sand and clay; the distance to the water table is 13 meters (43 feet).

transuranium-contaminated solid waste at commercial burial grounds; (2) to require that transuranium-contaminated waste be in a solid form (solidified if originally a liquid), be packaged, and be transferred to ERDA custody as soon as practical. In any event, it must be transferred within 5 years of its generation. When this anticipated regulation is established, there will be a statement of consideration, which accompanies the proposed rule-making (the formalizing of the proposed change) by the NRC, that will note that transuranium waste will include, in addition to the solid waste previously buried in commercial burial grounds, fuel hulls and certain fuel-processing waste other than high-level waste (also called "intermediate-level waste").

Proposed rules are to be published in the Federal Register, and comments will be invited before the rules

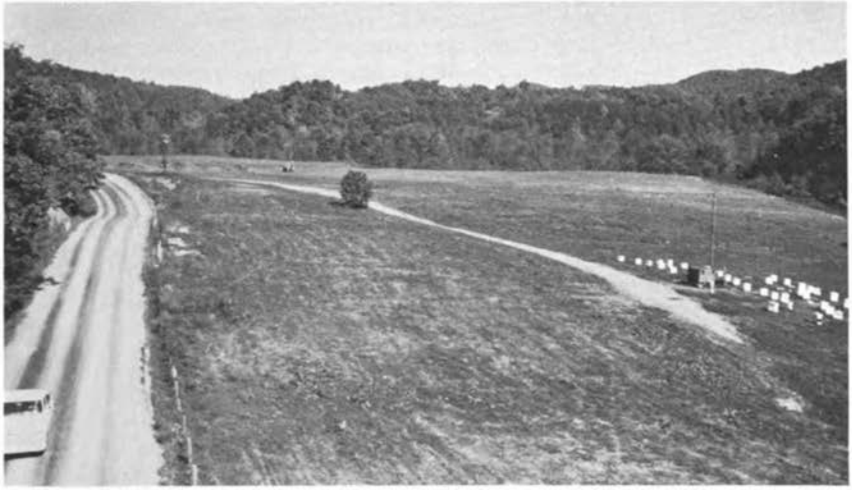

FIGURE 3 The Solid Waste Storage Area 4 at the Oak Ridge National Laboratory after it was no longer in use for burials. The burial area has been contoured and planted with grass. It occupies about 9.3 hectares (23 acres).

became effective. To date (June 1976) these rules have not been published. On September 12, 1974, a news release from the Atomic Energy Commission stated, "AEC Proposes Soil Burial Ban for Transuranic Waste and Requirement for AEC Storage." This release referred to a proposed "...new rule prohibiting commercial burial in soil of transuranium elements in waste. The proposed amendment to the AEC regulation would provide for such waste materials to be transferred to the AEC for storage and ultimate disposal." Also eliminated was the current regulation that permitted "...disposal of specified small quantities of transuranium elements by burial without specific approval of the AEC."

The statement of consideration mentioned above addresses itself to the matter of specific activity of the waste (radioactivity per unit weight) as the criterion of choice by operators of waste management sites. Measurement methods are to be established and measurements made to determine the presence or absence of transuranium elements. The methods must be sensitive enough to detect radiocontamination levels as low as 10 nanocuries of transuranium nuclides per gram of waste. The suggested upper limit of 10 nanocuries per gram has been generally used since it was first proposed by Soule (1970). He stated: "In terms of long half-life and high specific radiotoxicity, plutonium-239 is compared to radium-226. Radium is

TABLE 6 Accumulation of Cladding Waste

	Annual Addition			Total Accumulation		
Fiscal Year	Volume (cubic meters X 1,000)	Actinide Mass (kilograms)	Radioactivity (megacuries)	Volume (cubic meters X 1,000)	Actinide Mass (kilograms)	Radioactivity (megacuries)
1980	0.116	940	13.1	0.433	3,520	37
1990	0.436	3,420	52.0	3.203	25,880	210
2000	1.730	7,440	321.4	13.247	81,680	1,004
2006	3.293	10,240	689.6	28.947	136,490	2,120

SOURCE: U.S. Atomic Energy Commission (1974a: WASH-1539).

widely dispersed through the earth's crust, frequently near the surface...It seems reasonable, therefore, to bury plutonium--not at random, but at carefully selected sites--in concentrations no more than the upper range of natural radium concentrations in the earth. The actual value proposed is 10 nanocuries per gram (for pure plutonium-239, this is equal to 0.16 micrograms plutonium per gram of waste)."

The Panel is not satisfied that this criterion is necessarily the proper or only one. We believe that before this limiting value is accepted, it should be

FIGURE 4 Shafts, 0.75 × 0.75 meters (2.5 × 2.5 feet), are drilled into the tuff in Area G at the Los Alamos Scientific Laboratory to dispose of solid waste that requires shielding. Some of the shafts are concrete lined. A sealing plug of concrete 1 meter (3.3 feet) thick is poured when the shaft is full.

studied carefully by experts in the fields of transuranium toxicity and waste management and that final standards be based on their recommendations. The Panel understands that ERDA initiated a study in September 1975 on this question. The results of this study are expected in early 1977 and should be of particular interest and significance.

Waste that is suspect, but which has been measured and does not contain more than 10 nanocuries per gram, can be consigned to a licensed commercial burial ground.

It can be assumed that "intermediate-level waste" from nuclear fuel processing that does not qualify for ERDA waste management will be sent to commercial sites and will add substantially to the present load of the operations of commercial burial grounds.

The Panel has been informed that ERDA has decided on a policy that no unnecessary additional land burial sites should be established (U.S. Atomic Energy Commission 1973a: WASH-1202). Whether or not commercial burial sites or ERDA sites can be held at their present number is problematic. We believe that this commitment will need to be reevaluated periodically, and far enough in advance of need to be prepared for foreseeable eventualities.

4 PROBLEMS OF POTENTIAL HAZARDS FROM WASTE MANAGEMENT FACILITIES TODAY

4.1 AIRBORNE HAZARDS

Radioactive gases are not discharged in appreciable amounts from land burial sites, but radioactive dust might be carried by the wind beyond the site boundary. This can be avoided by good handling practices and prompt clean-up of spills. Adequate supervision by qualified people is necessary.

Concern has been expressed that natural processes of erosion may expose buried radioactive waste, leading to its dispersion. This possibility must be borne in mind, not only in the design of waste management facilities, but also in the selection of the site, and in the location of its boundaries in relation to populated areas.

4.2 WATERBORNE HAZARDS

These hazards begin when water comes in contact with the waste and dissolves radionuclides. The release of these radionuclides cannot be recognized immediately because it takes time--perhaps many years--for a detectable amount of radioactive material to pass through the unsaturated soil and then through the groundwater system to a monitoring well. If monitoring points were located immediately under the facilities, movement of radionuclides could be detected earlier than if monitoring wells were placed beside the facilities. This precaution must be considered during design of waste facilities.

Surface waters associated with waste management sites can become contaminated by: (1) airborne radionuclides, (2) surface runoff, (3) spills that have not been cleaned up, and (4) seeping groundwater. Routine techniques are available for the detection and measurement of surface-water contamination and with the exception of seeping groundwater, contamination of surface waters can be avoided or controlled by good housekeeping procedures and careful supervision. Seepage can be controlled by proper selection of the burial site and techniques of burial, including packaging.

As noted in Section 5.7.1, radionuclides exposed to groundwater may become mobilized by plants, animals, or microorganisms and may also become concentrated as parts of various complex food chains. For these reasons, operators of waste facilities and other people responsible for monitoring their air, water, and groundwater should make sure that adequate biological and ecological monitoring is also carried out.

4.3 HAZARDS TO OPERATORS

The potential hazards to operators are usually considered to be contamination by radioactive materials and direct external radiation received during handling of waste. However, in actual practice, the real hazards are mainly those experienced in many other industrial jobs, such as cuts, bruises, broken bones, damage to eyes, and head injuries, which have nothing to do with radiation. Normal health physics surveillance, with the use of protective clothing, good housekeeping, and adequate shielding, is designed to keep radiation exposure below maximum permissible limits.

4.4 HAZARDS TO THE PUBLIC

The escape of radioactive material beyond the boundary of a controlled area would be a hazard with a potential effect on the general public. Means must be provided for estimating the total transfer of any radionuclides from the waste management system into the public domain, and this value must be reported regularly and frequently. At present, no radioactive material is lost from most burial sites. However, the amount of escaped radioactive material is an important number that needs to be known, even if it is zero. It is not now readily available at most burial sites.

4.5 MISCELLANEOUS HAZARDS: THE NEED FOR EXPERT MANAGERS

One reviewer of a preliminary version of this report pointed out that many of the problems of management of radioactive waste are primarily administrative or disciplinary ones, because nearly all of the critical decisions are being made by individual people subject to the same weaknesses and temptations as the rest of the human race.

Strict discipline and alert management and supervision appear to be essential to the operation of any adequate program of waste management. When waste is being sorted into the radioactive and inactive fractions, this requires discipline and conscientiousness. Since the radioactive trash may be very similar to ordinary inert trash, it may be difficult to take seriously the dangers associated with it. Other potential dangers are in improper handling and packaging, careless transport, fire, inattention to scattering of the waste during burial, and theft and pilfering of attractive objects from the waste.

Control of these factors requires that the managers of such operations must be skilled in motivating the members of their staff to live up to their individual responsibilities.

5 THE CONDITIONS TODAY, SOME POSSIBLE FUTURE PROBLEMS, AND POSSIBLE SOLUTIONS

5.1 PLANS FOR EXHUMATION AND LONG-TERM STORAGE OF TRANSURANIUM-CONTAMINATED WASTES

The present plans for management of solid radioactive waste at the various ERDA sites include dealing separately with waste contaminated with more than 10 nanocuries of transuranium nuclides (alpha-particle-emitting waste) per gram of waste. This material is commonly called "transuranium waste" and requires special treatment because of the extreme toxicity of these nuclides under certain circumstances and because they have long half-lives compared with most fission products.

In the recent past, considerable effort has been expended in studying and testing methods of exhumation of buried waste and assessing related hazards. An early beginning has been made in the task of rehabilitating land burial areas from which transuranium-contaminated waste is being removed. Research and development efforts with respect to land burial of radioactive waste of all types are numerous. Examples are: (1) improvement in monitoring methods so that they will be sensitive at the level needed for long-term surveillance; (2) land use plans that will reduce the acreage required for land burial; (3) techniques for surface and subsurface stabilization of land burial tracts; and (4) solution of drainage problems generated by the soil disturbance resulting from emplacement of radioactive waste.

In the long-range plan at the Savannah River Plant, transuranium waste would be retrieved from the burial ground and converted to a form suitable for long-term engineered near-surface or surface storage beginning about 1990. These wastes could also be sent to a federal repository. The development plan is concerned with assessments and determinations of the improvements necessary for the eventual minimal custody and surveillance of the burial site. It calls for volume reduction and fixation of transuranium waste in acceptable forms for on-site storage. Primary consideration in the development of the plan will be the safety of plant personnel and the public, especially during the exhumation, retrieval, and processing of the waste. Another aspect will be the review and alteration of present plant operations and procedures to reduce the amount of transuranium waste generated. Volume reduction will use commercially available compactors with modifications to safeguard against the release of contaminated dust and liquids during compaction and to minimize risk of fire. Incineration will be evaluated, but current views are that compaction may reduce volume sufficiently.

At the Savannah River Plant, since already contaminated soil from the burial ground would represent the largest volume of transuranium waste to be stored, procedures will be developed for the extraction of plutonium from the contaminated soil. Plutonium extracted from the soil would be incorporated into concrete using technology developed for solidification of high-level radioactive waste. If extraction of the plutonium is impractical, other alternatives will be evaluated including: (1) incorporation of the soil into a concrete product acceptable for engineered storage, (2) storage of soil in engineered storage without incorporation into a concrete product but in containers suitable for eventual transfer to a repository, and (3) storage of soil at the burial ground in containers or in lined earthen trenches so that future retrieval would be possible if warranted.

It was reported that the Hanford Works and the Rocky Flats Plant (Golden, Colorado) have had considerable experience in operating small special-purpose incinerators as a step in the recovery of plutonium. The concentration of fissile material handled in these plants is considerably greater than that ever likely to be encountered in an incinerator for plutonium-containing combustible waste from other sites.

Inspection procedures and inventories of the plutonium in the incinerators successfully helped to control build-up and selective plating on the walls or other surfaces. Because of the reduction in volume and concentration of plutonium, a limit of 0.1 curie of plutonium-239 per cubic foot (3.6 curies per cubic meter) of incinerator feed was established for safety. If a different mixture of plutonium isotopes were in the waste, such as that of the U.S. Bureau of Standards Reference Material No. 948, a different limit would need to be set. It would also be necessary to know the fission product content of the incinerator feed at all times. The treatment of off-gases will call for decontamination factors of a thousand to a million times greater than those required for removing non-radioactive particulates.

Direct burial was the method first chosen for disposing of transuranium and other solid radioactive waste because it was the least expensive method when land was readily available and soil conditions were reasonably acceptable. Burial at the generating site required a minimum of transportation, little handling, no sorting, and no off-gas treatment. But now there is increasing concern over transuranium waste because of the possiblity of the leaching of radioactive materials from buried waste by ground and surface waters. Because the materials have such long half-lives, the land devoted to such burial practices must be restricted to keep the problem of long-term control and management at a reasonable level. The past practices of filling trenches with cardboard boxes of transuranium waste, although no longer used, makes any subsequent retrieval costly and hazardous.

The requirement for packaging in water-tight retrievable metal, plastic, or concrete containers and the increased costs resulting from the future processing of the large bulk of unprocessed waste is also of concern.

Volume reduction of transuranium waste, as a general principle, will be practiced in the future to minimize the amount of space required for its final disposal.

The Oak Ridge National Laboratory has definitions specific to its own waste. The category of "fissile transuranium waste" includes the transuranium nuclides (primarily americium, curium, and plutonium); ORNL also includes the isotope uranium-255. The alpha-particle activity in this waste has to be isolated. It is now stored retrievably. Due regard has to be given to the criticality problem arising from the fissile character of the waste.

In some cases, notably those involving "even-even" nuclides of transuranium nuclides, spontaneous fission occurs, creating a source of neutrons. Beryllium and deuterium become neutron sources when exposed to photons of sufficiently high energy, and so combinations of these nuclides with sources of high-energy gamma photons require special handling.

Beta-gamma activity is associated with these nuclides, which originate primarily from the transuranium processing facility and as a result of fuel reprocessing operations.

Since facilities for repackaging the waste are not available at the Solid Waste Storage Area (SWSA) at ORNL, the waste must be placed in suitable containers at its points of origin. Three types of containers are used routinely: stainless steel canisters, which are inserted into a stainless-steel-lined auger hole; concrete casks; and stainless steel drums. The operator at the point of origin is responsible for selecting the right kind of container and for compliance with health physics regulations regarding radiation and surface contamination.

In the handling of waste containing uranium-235, which is a non-alpha fissile nuclide, one control problem is that of preventing inadvertent criticality; thus, the amount of fissile material in each package must be determined prior to its delivery for transport to the burial ground. This material must be packaged in containers suitable for burial in lined auger holes, and no container may hold more than 200 grams of fissile material unless approved beforehand by the ORNL Criticality Safety Review Committee.

5.2 VOLUME REDUCTION

Several techniques for volume reduction are now under consideration and in some cases are either in advanced states of investigation or early engineering and small pilot plant trials. Included are efforts to recover uranium and transuranium elements by waste-partitioning methods, that is, by separation of waste streams according to their probable radioisotope content.

It is quite apparent that the most burdensome aspect of the future problem of land burial of solid low-level radioactive waste at ERDA (and at commercial sites) is the large volume of the waste. It is not the radioactivity *per se*. The Panel believes that this problem can be diminished substantially by advanced techniques of volume reduction. Unless the volume is reduced, the problem will eventually present major technical difficulties in finding suitable land space. Some ERDA sites are already running low of available space for burial of waste in the future. Much of the waste is produced in the Eastern United States, but most of the suitable desert land for burial is in the Far West, presenting more problems to those responsible for the transportation of radioactive waste over long distances.

5.2.1 Sorting of Waste at the Management Site

Immediate sorting of solid radioactive waste from non-radioactive waste is an essential initial step in any scheme for the reduction of the volume of that waste and for the recovery of radionuclides from uranium and transuranium waste.

It is probably optimistic to expect much reduction of that volume of waste by sorting out of uncontaminated waste unless it is done at the point of origin. Training of plant personnel to do this work at the point of origin has been reasonably successful. To ask radioactive waste management personnel to do the sorting of an unknown mixture of wastes at a subsequent time and place creates an unacceptable hazard of exposure to radiation by inhalation, injury, or ambient external exposure.

A burdensome component of much of the present day waste is that material only suspected of being radioactively contaminated, without necessarily actually being radioactive. Much of the so-called "radioactive" waste fits into such a category merely because of the place where it was generated. The cost of assaying such suspected low-level solid wastes to determine their true radioactive content is such that it is often cheaper to combine suspected waste with known radioactive waste than to separate it. This possibly non-radioactive waste unnecessarily takes up burial space; and time, effort, and money are needlessly expended.

It is now a general practice at all ERDA sites, and probably with all licensed users of radioactive materials, to assume that all waste is radioactive if it has been generated in a laboratory using radioactive materials or by a radiochemical or similar processing activity. It is termed "Radiation Zone" or "Contaminated Area" waste. The burden of proof that the waste is not radioactive is on the person certifying or releasing the waste. The test is that no detectable response can be obtained by the most sensitive, appropriate measuring instrument held as close as practicable to the surface of the item or items being measured. Wipe tests can be substituted when the person certifying the absence of radioactivity (usually a health physicist) considers this to be necessary. The use of this time-consuming and burdensome system is too often omitted, and non-radioactive waste gets mixed in with radioactive waste only for the sake of convenience.

It may also be pointed out that separate burial of waste containing low levels of short-lived radioactive materials may be economically advantageous, because burial grounds of this kind would not need monitoring or special maintenance after the levels of radioactivity had decayed to innocuous levels. This would be a suitable subject for further cost-benefit analysis.

5.2.2 Reduction of Non-radioactive Waste Included in Radioactive Waste: Redefining Radiation Zones

Probably the method most likely to succeed is that of reducing the amount of non-radioactive waste that is considered, administratively, to be radioactive by a careful delineation and reduction of the so-called "Radiation Zones" and "Contamination Areas." It is now common to define such areas rather broadly and to include certain zones and areas from which it should be obvious that the waste would not be radioactive. An example would be the office and administrative areas within a Radiation Zone. Such areas produce much non-radioactive waste that is often included for convenience in the low-level solid radioactive waste from the technical areas.

Additional control of the amount of low-level waste produced in a zone or area can be achieved by controlling the amount of potential waste going into the zone or area.

5.2.3 Sorting for Incineration, Compaction, or Local Requirements

Separation of combustible or compactable waste is being done at a few ERDA sites at the point of origin of the solid low-level radioactive waste. However, it is being done mainly at the treatment point, in most cases by the incinerator and compactor operators. It is neither wise nor practical for all sorting to be done at the incinerator or compactor. The cost for such sorting for incineration could be high, and it would be hazardous to the often unskilled operators who would do the unattractive work.

There may also be sorting at times to meet other local needs or requirements, such as those related to higher level gamma-radiating waste. Local restrictions are intended to reduce the possible radiation exposure of personnel during handling and burial-ground operations. Such waste is usually buried separately in deep trenches or in special sunken tubular devices. Old railroad running stock is used at the Hanford Site to store large, obsolete, and heavily contaminated process equipment. The loaded flat cars, etc., are run into a specially constructed, heavily shielded, ground-level railroad tunnel.

5.2.4 Sorting of Transuranium Wastes

Sorting and labeling of containers has been done to meet the requirements of the U.S. Department of Transportation (DOT). This is done almost entirely at laboratories or production facilities that do not have a site for land burial of solid low-level waste, which must be shipped elsewhere. The Rocky Flats Plant is an example. In this case, classification is done at the point of origin by the operators generating the waste. Sometimes special crews for pickup of radioactive waste, especially trained for the work, have been used to identify and label the shipping containers.

There is a special problem in sorting the transuranium waste. The difficulty is in measuring the limiting 10 nanocuries of plutonium per gram of waste. This is equivalent to only 0.16 micrograms of plutonium-239 per gram. Other isotopes of plutonium have different specific activities.

A sensitive survey instrument is commercially available, with an unattenuated sensitivity for plutonium of 1.3 nanocuries (0.02 micrograms) for a point source placed essentially in contact with the detector face. It depends on detection of soft X rays. For an area source, its sensitivity is 120 nanocuries per square meter (1.9 micrograms plutonium-239 per square meter). If a scaler is substituted for a count-rate meter and a counting time of 20 minutes is used, the sensitivity is increased tenfold. However, the counting time is then so long that the method is unsuitable for measuring large numbers of containers.

A second radioactivity detector for waste stream monitoring for the presence of fissionable transuranium nuclides depends on "interrogation" with a thermalized neutron source. The energy released by fission is measured. With californium-252 now available for such a neutron source, it is a promising prospect for the future separation and segregation of waste contaminated with fissionable uranium and transuranium nuclides. A sensitivity of much less than 1 milligram of plutonium-239 per cubic foot (35.3 milligrms per cubic meter) is anticipated. If we assume 5 gallons (0.019 cubic meters) of plutonium-contaminated waste in a 210-liter (55-gallon) drum, we can expect a detection limit of at most 0.67 milligrams per drum. Since there would be a little over 3 milligrams in 5 gallons of transuranium waste at the level of 10 nanocuries per gram, such a detector would be fully adequate for segregating transuranium waste containing largely plutonium-239 as the transuranium contaminant.

It is not a trivial matter that monitoring devices being used at present are not adequate for measuring a relatively rapidly moving stream of drums of low-level alpha radioactive waste. Without a really sensitive device, waste management that requires sorting or identification at the 10-nanocuries-per-gram level is not reasonably possible on a satisfactory scale.

The Panel believes that research and development on improved techniques of monitoring low levels of alpha radioactivity is needed, because of its potential importance in the field of radioactive waste management as well as in other areas.

The Panel is also aware of some of the problems caused by the use of hybrid units in this area of health physics, e.g., milligrams per cubic foot or milligrams per gallon, and suggests that, at the time of standardization of nomenclature and classification of radioactive waste (see Section 6.3), this specific problem should also be solved.

5.2.5 Volume Reduction by Compression

Compression of solid low-level radioactive waste is suitable for about half the waste generated at ERDA installations. There are three kinds of compression devices:

(1) Compactors, which force material into the final storage, shipping, or disposal container. A favorite container is the 210-liter (55-gallon) drum. Some space saving is possible. A variant of the compactor is called the packer. In this device, the material is compressed into a reusable container. At the burial grounds, the compacted material is dumped directly without any effort to retain its compacted form. Space saving is minimal with packer systems (see Figure 5).

(2) Balers, which compress the waste into bales that are wrapped, tied, or banded and then stored, shipped, or disposed of in burial grounds. Considerable space saving is possible.

(3) Baggers, which compress waste into a predetermined shape that is injected into round or rectangular bags, boxes, or drums before storage, shipment, or disposal. Some space saving is possible.

These three techniques may be suited to general and sometimes even to unique situations. Unfortunately, such treatment does not reduce the possibility of burning while in storage, and only certain materials are suitable for compaction. These include paper, cloth, rubber, plastics, wood, glass, and small light metal objects. Large rigid metal objects must be excluded because they are usually relatively incompressible and cause damage to the container and the compressing machinery. Moisture, free or absorbed

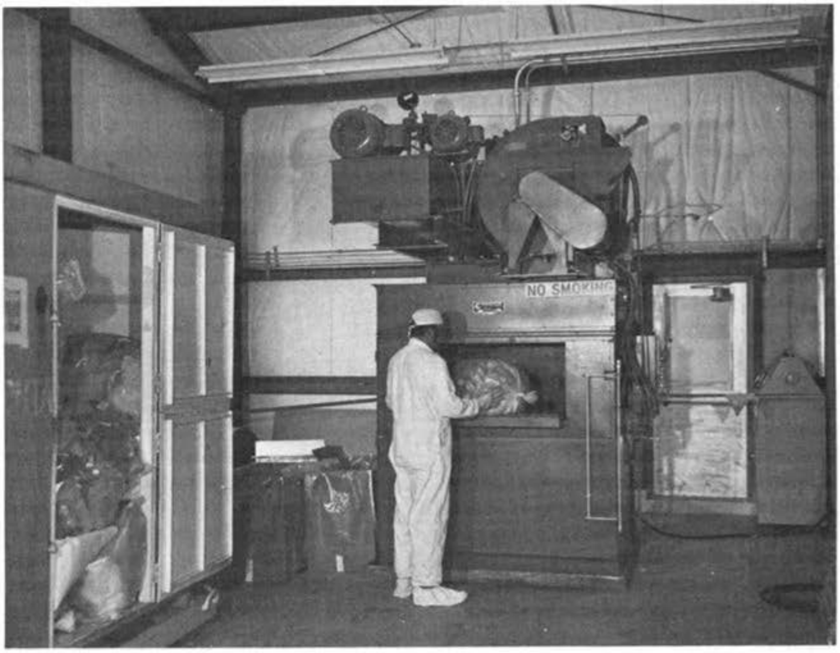

FIGURE 5 Operation of a 50-ton hydraulic solid waste compactor at the Idaho National Engineering Laboratory reduces the waste volume by a factor of 10 to 1 and produces 0.4-cubic-meter (14-cubic-foot) bales averaging 270 kilograms (600 pounds) contained in plastic-lined cardboard boxes. Only waste with low levels of beta-gamma contamination is processed in this way.

in large quantities by blotting paper or rags, has to be avoided because of its potential forcible release when under high pressure, creating a great hazard to operators. Obviously, corrosive, pyrophoric, and explosive waste must be excluded from such processing, whether it is organic or inorganic.

The compression machinery must be economical, reliable, and easy to operate. Many commercial devices are available, but all must be modified by providing air containment, off-gas ventilation, often filtration, and, if necessary, shielding.

5.2.6 Volume Reduction By Incineration

Reduction of volumes of solid radioactive waste by incineration has interested managers of low-level radioactive waste, particularly in those parts of the world where land area is at a premium and costs are high. Under these conditions, the advantages of volume reduction are so great that the drawbacks seem only obstacles to be surmounted; however, this has not been a general feeling in the United States. In Europe, where land is scarce and more revered, the incineration of solid combustible radioactive waste is a common and apparently satisfactory method of pretreatment before final disposal. The methods of incineration used in the United States have been comparatively primitive. The incinerator design, with rare exceptions, has been by trial and error and without reference to the more satisfactory designs used in Europe. The Panel believes that new methods of volume reduction by incineration should be given greater use. ERDA has a program under way at LASL to build and operate a development facility to prove out various incineration techniques.

There is sufficient volume of burnable solid radioactive waste at several ERDA sites to support one or more incinerators. There are certain advantages, such as volume reductions of 80 to 90 percent reported for selected burnable waste. This may be a high estimate if such factors as residues from off-gas treatment and refractory changes are considered. This would represent a considerable saving in land used for burial, in transportation, and in long-term monitoring. In addition, it would free us from the nagging worry about the possible problem of long-burning subterranean fires. Special attention should be given to the problems of burning organic matter (solvents, ion-exchange resins, etc.) and putrescible biological material (animal cadavers, excreta, etc.). Incineration of radioactive waste must be carried out under controlled conditions to prevent the formation of radioactive aerosols.

5.2.7 Possible Recovery of Transuranium Elements during Volume Reduction

It may be feasible to recover transuranium elements following the combustion of some solid waste. Both laboratory and plant experience is available for guidance. There are a wide variety of combustion techniques with cleanup of off-gases after combustion that make this system attractive.

Acid digestion, or wet oxidation, has been proposed as a substitute for incineration. It is claimed that it has a better record of operational performance, i.e., it is more trouble-free for a wide range of feed materials, and the off-gas problems are greatly reduced. The volume reduction ratio of about 99 to 1 is much better than for incineration. The isolation of plutonium as an insoluble compound by simple chemical methods is quite efficient. Some other advantages are that it can be used on a small scale at a reasonable cost of operation; the process operates at atmospheric pressure; and reaction rates can easily be controlled by changing the reaction temperature, the rate of addition of the digesting acids, or the rate of addition of the waste feed material. The system is still in the experimental stage, but may offer an attractive option for the treatment of some combustible solid radioactive waste. Wet oxidation should not be used indiscriminately, however, since it is a messy, resource-wasteful process. It would be preferable to use incineration for paper and plastic waste, for example.

The Panel believes that, in addition to the recovery of fissile transuranium nuclides that may be recycled into the nuclear fuel cycle, the opportunity of obtaining other useful materials must always be carefully considered. These may include specific fission products or materials of construction used in nuclear technology.

5.3 STORAGE OF TRANSURANIUM WASTE AT ERDA SITES

5.3.1 Idaho National Engineering Laboratory (INEL)

Transuranium waste shipped to the Idaho National Engineering Laboratory (INEL) from the Rocky Flats Plant is received in government ATMX railroad cars or commercial trailers and is stored on the INEL's Transuranic Storage Area (TSA) in retrievable storage or disposed of on Pad A if the transuranium level is below 10 nanocuries of transuranium nuclides per gram of waste. This subject is discussed in detail in Appendix A.5.2 (see Figures 6, 7, 8, and 9).

In 1970, when the decision was made by ERDA's predecessor, the U.S. Atomic Energy Commission, to store all transuranium waste aboveground for later retrieval, most of the alpha-particle-emitting waste generated at the Rocky Flats operation was being buried in the trenches at the Idaho National Engineering Laboratory. This laboratory has designated a special storage area, now called the Transuranic Storage Area (TSA). The local present practice, discussed in additional detail later, is to place transuranium waste contained in drums, coated boxes, and metal bins on an engineered asphalt pad where the drums, boxes, and metal bins are carefully stacked with interlayered plywood and covered with a waterproof membrane. Earth is then mounded over the pile as the stacking progresses forward to cover the pad. This method of

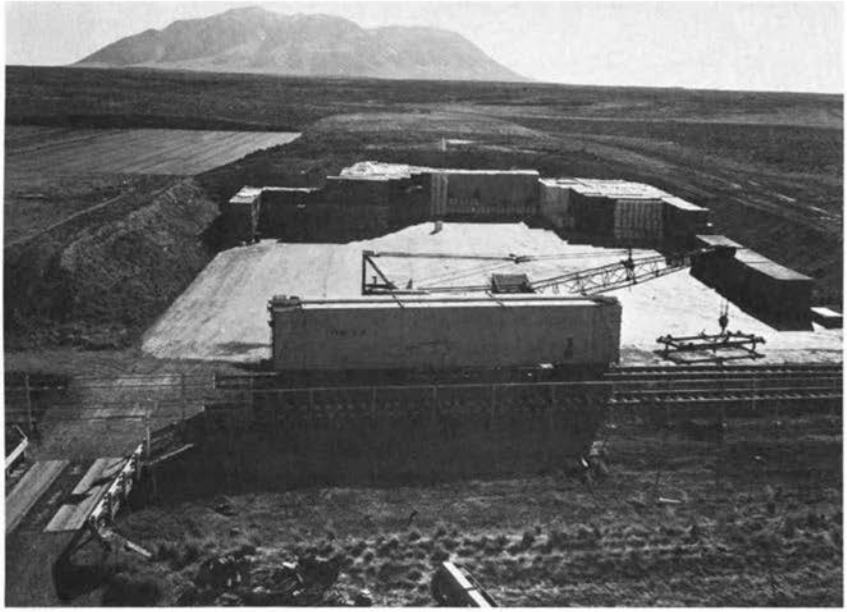

FIGURE 6 Shown is the working face of the Transuranic Storage Area (TSA) at the Idaho National Engineering Laboratory. Waste arrives by truck or in special railcars and is stacked on an asphalt pad 45 × 730 meters (150 × 2,400 feet) in cells 24 meters (80 feet) deep. When a cell is complete, the cell is covered with plywood, a waterproof membrane, and soil, and is then seeded to prevent wind erosion. Initial construction of a second pad is shown on the left.

storage differs substantially from that used in the past.

The transuranium waste generated at Rocky Flats and shipped to the INEL has always been packaged by techniques that satisfied the U.S. Department of Transportation regulations. The low specific activity waste (LSA) consists of non-line-generated waste and evaporator salts (last stage). "Non-low" specific activity waste (non-LSA) consists of line-generated waste, first-stage sludge, second-stage sludge, cemented liquids (complexing agents, ion exchange resins, etc.), and organic liquids mixed with calcium silicate to form a putty-like mass called "grease."

Now employed, however, is a more useful operational classification developed in 1970 at the INEL when it became necessary to establish the retrievable storage operation. Category one includes paper, rags, miscellaneous filters, glass, gloves, and general garbage. Category two includes all metallic waste.

FIGURE 7 Drums (210 liters or 55 gallons) of transuranium-contaminated waste are stacked on an asphalt pad at the Idaho National Engineering Laboratory in the Transuranic Storage Area (TSA) for retrievable storage. The drums and coated boxes are covered with flame-resistant plywood and reinforced plastic sheets before being covered by 1 meter (3 feet) of soil for protection from the weather.

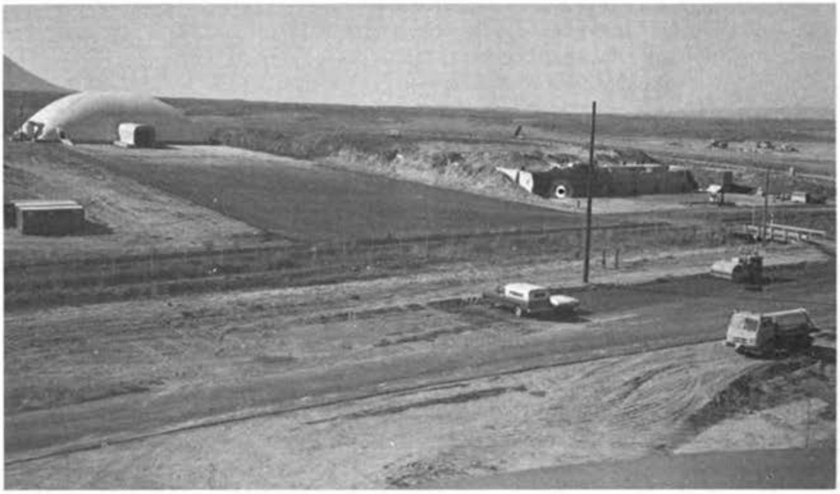

FIGURE 8 On the left is shown an air support structure erected over the first cell of the second pad in the Transuranic Storage Area (TSA) at the Idaho National Engineering Laboratory. To the right is shown the final cell of the first pad being completed. Note that an airlock permits truck access to the air support structure without disturbing operations.

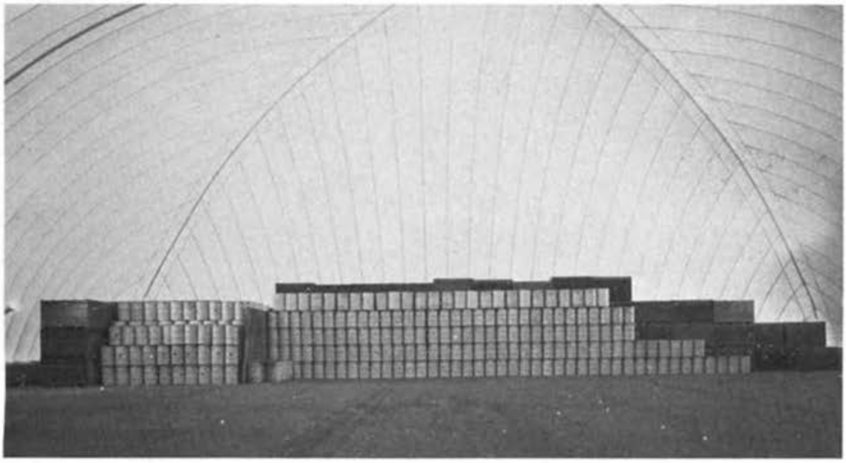

FIGURE 9 An air support structure over the first cell on the second pad of the Transuranic Storage Area at the Idaho National Engineering Laboratory protects the waste from the weather and allows year-round operation. When the cell is complete, the air support structure will be moved to cover the second cell, and the first cell will be covered with plywood, a waterproof membrane, and 1 meter (3 feet) of soil.

Category three contains the sludges, the cemented liquids, and "grease." Category four consists of "undefined waste." Fortunately, the volume of the last category is small and creates no problems in waste management.

5.3.2 Oak Ridge National Laboratory (ORNL)

Transuranium and fissile waste that is placed in 20-year retrievable storage at the Oak Ridge National Laboratory (ORNL) is all locally generated. The details of the ORNL program are discussed in Appendix A.7 (see Figures 10, 11, 12, and 13).

5.3.3 Savannah River Plant (SRP)

At the Savannah River Plant (SRP), 19,000 curies of plutonium-238 waste, 1,000 curies of plutonium-239 waste from finishing operations, and 40,000 curies of curium-244 waste from SRP production operations are stored along with 290,000 Ci of plutonium-238 waste from the Mound Laboratory and the Los Alamos Scientific Laboratory (LASL) in an array of concrete containers

FIGURE 10 Transuranium waste with low external gamma radiation is packaged in stainless steel drums and stored in a corrugated metal building at the Oak Ridge National Laboratory. A reinforced concrete and concrete block pit-type structure is under construction; this waste will be transferred to the new structure when it is completed.

designed for ease of monitoring and retrieval. These are discussed in Appendix A.8 (see Figures 14 and 15).

5.3.4 Los Alamos Scientific Laboratory (LASL)

Radioactive waste is routinely stored retrievably at Los Alamos in a covered pit in a manner similar to that used at other ERDA sites (see also Appendix A.1). A special retrievable mode is shown in Figures 16, 17, and 18.

5.3.5 Hanford Works

Transuranium wastes generated by operations at the Hanford Works are placed in retrievable storage in a system similar to that used at the INEL (see Figure 19).

FIGURE 11 Transuranium-contaminated waste at the Oak Ridge National Laboratory that has high gamma radiation levels is sealed in reinforced concrete casks 1.4 meters (4.6 feet) in diameter and 2.4 meters (7.9 feet) long having wall thicknesses from 12 to 30 centimeters (4.7 to 12 inches), depending on the shielding required. Casks are retrievably stored below grade in trenches 3 meters (10 feet) deep.

FIGURE 12 Small packages of transuranium-contaminated waste at Oak Ridge National Laboratory that require shielding are packaged in stainless steel capsules of various sizes and stored retrievably in auger holes 2.75 meters (9 feet) deep. The holes have concrete walls and bottom, which are 24 centimeters (9.5 inches) thick and are provided with a stainless steel waterproof liner. Sizes vary from 20 to 75 centimeters (7.8 to 30 inches) in inner diameter. Closure is by means of a concrete plug 46 centimeters (18 inches) thick.

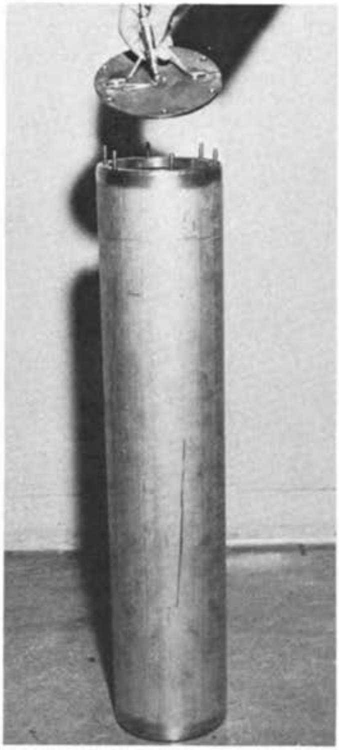

FIGURE 13 Stainless steel capsules with metal gaskets and bolted closures are used at the Oak Ridge National Laboratory for storage of small packages of transuranium-contaminated waste containing high-radiation-level gamma emitters. The capsules are stored in stainless-steel-lined wells with concrete shielding plug closures.

FIGURE 14 Transuranium-contaminated waste in steel drums was originally sealed in concrete casks 2 × 2 meters (6.6 × 6.6 feet) and retrievably stored in trenches up to 6 meters (20 feet) deep at the Savannah River Plant.

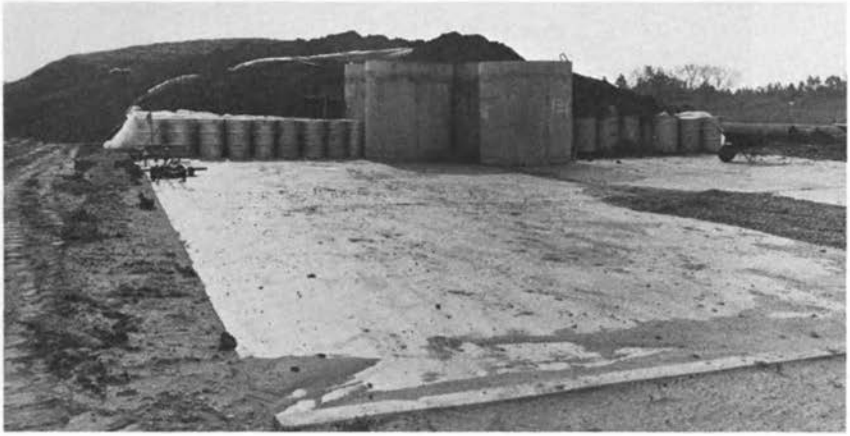

FIGURE 15 Solid transuranium-contaminated waste at the Savannah River Plant is now sealed in plastic-lined 210-liter (55-gallon) galvanized steel drums and retrievably stored on a concrete pad. Drums that contain waste packages with more than 0.1 curies of transuranium nuclides are additionally sealed in reinforced concrete casks 2 × 2 meters (6.6 × 6.6 feet) and 15 centimeters (6 inches) thick. Sheets of reinforced plastic are placed over the waste before the soil cover to prevent the infiltration of rainwater.

FIGURE 16 Waterproofed concrete cylinders are placed into trenches (122 X 9.2 X 6.1 meters, or 400 X 30 X 20 feet) in Area G at the Los Alamos Scientific Laboratory to retrievably store waste contaminated with plutonium-238. Topsoil is about 0.6 meters (2 feet) thick over tuff. The water table is 275 meters (900 feet) below the surface.

FIGURE 17 Drums (115 liters or 30 gallons) of waste containing more than 100 nanocuries of plutonium-238 per gram of waste are placed into waterproof concrete casks for retrievable storage in Area G, at the Los Alamos Scientific Laboratory. Each cask contains two drums.

FIGURE 18 Concrete casks for storing drums of waste contaminated with plutonium-238 are sealed before being covered with 2 meters (6.6 feet) of crushed tuff and soil in Area G at the Los Alamos Scientific Laboratory.

FIGURE 19 Transuranium-contaminated waste requiring shielding because of the external level of gamma radiation is sealed in concrete boxes and buried in trenches 5 to 8 meters (16 to 26 feet) deep at Hanford. Soil is placed on the waste to limit radiation to 100 milliroentgens per hour. The completed trench is later covered with 2.5 meters (8 feet) of soil or enough to reduce surface radiation to 1 milliroentgen per hour. The soil is a mixture of gravel and fine sands and silts. The water table is at least 100 meters (330 feet) below the trenches.

5.4 EXHUMATION OF RADIOACTIVE WASTE

5.4.1 Exhumation of Transuranium Waste at the Idaho National Engineering Laboratory

Trial retrieval, or exhumation of buried waste, has been attempted with some degree of success because of the possibility that the nearly 57,000 cubic meters (2 million cubic feet) of transuranium waste received from Rocky Flats during 1954 through 1970, and which still remain buried in pits at INEL, might eventually be retrieved, processed, and shipped to a federal repository. Neither the site nor the design for this special federal repository has yet been established.

In the test exhumation programs, a backhoe, road grader, and bulldozer with earth scraper were used in removing the gross quantities of overburden and for backfilling. However, because of the likelihood of damage to the containers, considerable time was spent in digging around the buried containers using hand tools. It was necessary to uncover the barrels very carefully during the final steps of exhumation to prevent them from rupturing in the pits where the barrels had been stacked (see Figure 20). In pits where the barrels had been dumped, even more extensive digging by hand tools was required, because of the random orientation of the barrels.

Because of the possibility of ruptured or leaking containers, barrels that were exhumed were bagged in plastic and put into larger 314-liter (83-gallon) barrels. Improved containers for this repackaging are being developed to reduce the cost of the operation. Barrels that had been buried up to 18 months in a stacked pit were in good condition, and 95 percent of them could usually be identified by their Rocky Flats tags. Some of these barrels contained sludge or salt material that had leaked, but the low levels of plutonium in that type of barrel made it possible to continue their exhumation with a minimum of difficulty. Plutonium levels in the soil varied from less than 3×10^{-4} to 1×10^{-3} nanocuries of plutonium per gram of soil.

Barrels that had been buried from 3 to 7 years in pits where they had been randomly dumped were considerably more difficult to exhume than those in the pits where they had been stacked. The main contributing factors were the random orientation of the barrels and the damage that the barrels had incurred during dumping. Identification by paper labels from the Rocky Flats Plant was possible for only 40 percent of the barrels. Open barrels and leaking sludge-salt barrels caused plutonium contamination levels

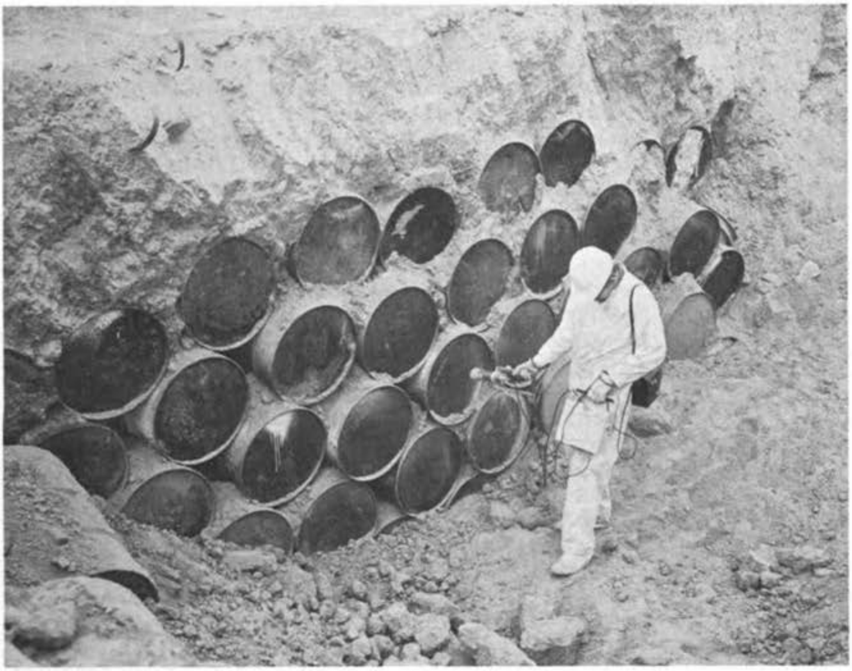

FIGURE 20 A health physicist monitors 210-liter (55-gallon) drums of transuranium-contaminated waste for external contamination before they are removed as part of a study program after being buried for 5 years at the Idaho National Engineering Laboratory. Almost all of the drums are intact.

approximately one order of magnitude higher than from the stacked 18-month-old barrels. Contamination levels here ranged from 1 x 10^{-3} to 1 x 10^{-2} nanocuries of plutonium per gram of soil.

Waste containers that had been stored in stacked pits for 12 years were in poor condition, mainly due to corrosion. Contamination levels were as high as 5 nanocuries of plutonium per gram soil in this area. This did not stop exhuming efforts, but workers in the area needed to use half-face respirators.

A limited number of exhumed drums of transuranium waste were examined in a hot cell. It was found that waste was loose within some barrels, i.e., there was no liner. Other waste was within the liner, but was saturated with moisture, and in other cases the barrel liner was broken or the barrel was unsealed. On occasion, waste had been mixed, including both combustible and non-combustible materials. It was said that newer waste containers received there are now packaged more carefully, in contrast with the practices that existed earlier and caused the conditions just described. Waste now received for retrievable storage is contained in a heavy-walled plastic liner inside a steel drum.

Efforts to exhume a plywood box, which was about 5 years old, were thwarted because of the poor condition of the box. Soil samples showed contamination levels in the area from 5×10^{-4} to 5×10^{-3} nanocuries of plutonium per gram of soil, and slight amounts of airborne contamination were encountered.

Cardboard cartons containing Rocky Flats Plant filters were found with the barrels that had been buried about 7 years. The cardboard had disintegrated, and soil contamination was at a relatively high level of 0.1 to 1 nanocuries of plutonium per gram of soil. This type of container requires additional precautions and techniques for handling.

Migration of the plutonium was limited. Most of the contamination outside the barrels was found within 15 centimeters (6 inches) of the waste containers. At the oldest site excavated, contamination of about 0.1 nanocuries of plutonium per gram of soil was found 1 meter (3 feet) below the barrels. That level of contamination was 1 percent of the value recommended by the General Manager's Task Force on Sorting Solid Radioactive Wastes, beyond which special treatment and/or handling is required. It is postulated that it moved by way of fissures in the basalt.

Criteria for removing and special handling of contaminated soil from the INEL burial site have not been established. However, the Task Force on Sorting of Solid Radioactive Wastes has recommended continued burial of waste (at carefully selected sites) whose concentration is less than 10 nanocuries per gram. No soil sample collected during the Special Test Exhumation Program contained more than about 5 nanocuries of plutonium per gram of soil. With the Task Force recommendation as a guideline, it now appears to have been unnecessary to have removed soil from the burial site at the areas sampled. This conclusion seems appropriate, based on the facts that: (1) the burial area is a carefully selected site, (2) migration of plutonium in the soil is limited, and (3) small total quantities of plutonium are involved. This conclusion does not preclude the possibility that there might have been higher soil concentrations of plutonium in "hot spots" from which the soil should be removed.

The conclusion at the termination of part of the test program was that gross quantities of soil should not have been removed, pending a better definition of the criteria. These studies also indicated that the facilities at the INEL were not adequate for a large-scale operation of exhuming waste. The lack of electrical power, water, support facilities, and communication hampered retrieval work. The hot cell where sorting operations were conducted was adequate for only limited operations and was not specifically designed for transuranium waste. It was also shown that waste in damaged and leaky containers was more difficult and costly to retrieve than waste in intact containers.

The objectives of an additional study at the INEL are: (1) to demonstrate the technique for the safe retrieval of drums and to gain experience in handling and repackaging (to be used in developing the process for retrieving the older Rocky Flats Plant waste in containers that may have failed or completely disintegrated); (2) to develop and use a storage container that would meet the 20-year interim storage criterion and provide a more economical storage method than the 314-liter (83-gallon) containers currently being used; and (3) to retrieve, repackage, and store on the TSA pad as many of the recently buried Rocky Flats Plant waste drums as possible before they deteriorate further.

Once a drum is removed from the pit, an attempt will be made to identify it from its original markings. Drums in good condition and identified as containing less than 10 nanocuries of transuranium nuclides per gram of waste, but which have lost their integrity (holes or evidence of leakage), will be repackaged either in 314-liter (83-gallon) drums, wooden boxes, or metal containers before being sent to Pad A for disposal.

All other retrieved drums will be repackaged in either 314-liter (83-gallon) steel drums, fiberglass-coated wooden boxes, concrete containers, or metal containers and sent to the TSA for retrievable storage. If a drum is rusted through and badly damaged, its fate will be determined in accordance with local "abnormal operations" procedures and safety rules.

In order to provide a more acceptable and less expensive container, it is anticipated that fiberglass-coated wooden boxes with inside dimensions of 1.22 x 1.22 x 2.44 meters (4 x 4 x 8 feet) or large concrete or metal containers will be used for packaging degraded drums in the future. The wooden boxes will hold ten 210-liter (55-gallon) drums.

Soil containing less than 10 nanocuries of plutonium per gram of soil will be left in place and covered when the retrieval is completed. Soil contaminated with greater than 10 nanocuries of transuranium nuclides per gram of soil will be packaged and stored at the TSA.

In the event that a waste drum is found open or is ruptured during excavation or retrieval, work will stop and a health physicist will make a radiological survey. An evaluation will be made by the project engineer and the health and safety personnel of the situation, and continuation of the retrieval effort will be dictated by the levels of contamination present. The project engineer and the health physicist on duty will direct a qualified worker, who will wear full protective anticontamination clothing and respirator in repackaging the container, or will take such other action as is required to prevent or minimize the spread of the contamination.

In the event of fire at the work area, evacuation will be made immediately in an upwind direction from the fire or as directed by the health physicist. The fire department will be notified immediately. The project engineer, or his designated alternate, will take further appropriate action, in accordance with the existing Radioactive Waste Disposal and Storage Area Fire Protection Plan.

Developments now in progress will identify the presence of significant quantities of fissile materials that might constitute a criticality hazard if rearranged or moved near other fissile material.

In current practice, there is a cutoff contamination level established for any transuranium waste stored at INEL. It is actually the same as that used at all other ERDA operations. Waste having greater than 10 nanocuries of transuranium nuclides per gram of waste is stored on the engineered pads in containers (55-gallon or 83-gallon drums, coated boxes, or metal bins) designed to keep their integrity for 20 years or more. If the contamination level is lower than 10 nanocuries per gram, then the containers need not have a 20-year integrity.

5.4.2 Retrieval at the Savannah River Plant (SRP)

At the Savannah River Plant (SRP), approximately 11,300 cubic meters (400,000 cubic feet) of transuranium waste produced locally before 1965 has been buried without special treatment. The exact locations of these burials are known. This material contains about 200 curies of plutonium-239. A test, simulating conditions that would be encountered in exhuming transuranium waste, was carried out at the SRP in 1972. In the test, low-level fission-product-contaminated waste was retrieved. This waste was selected because of its physical similarity to buried transuranium waste and because of the lesser radiological hazard associated with its recovery. The test indicated that it was feasible to exhume the transuranium waste; however, the excavation revealed that some waste material containers and packaging had substantially deteriorated. Recovery of the associated contaminated soil would increase the volume of transuranium waste by as much as a factor of seven.

In a separate test, the retrievability of transuranium waste buried in a concrete container was demonstrated. Further work will be aimed at developing methods for full-scale exhumation and retrieval of transuranium waste stored in concrete containers since 1965.

The total quantity of transuranium waste buried and stored at the SRP burial ground approximates 24,000 cubic meters (850,000 cubic feet). In addition, there may be 70,000 cubic meters (2.5 million cubic feet) of soil contaminated by deterioration or leaching of transuranium waste not encapsulated in concrete. The wide variety of types of transuranium waste will require the development and testing of several methods for volume reduction.

There is a need to develop and evaluate alternative procedures for simplifying and improving the retrievability of waste now being stored in the burial ground at SRP. At present, waste destined for retrieval is placed in galvanized drums or concrete containers and covered with a waterproof membrane and earth on a concrete pad at ground level. All other ERDA sites use retrievable storage methods similar to those at the INEL or SRP.

In summary, the Panel believes that the most radical and most important recent change in the technology of land burial of radioactive waste has been in the handling of transuranium waste. The dimensions of the prospects for the future are not known because of the recent proposal that commercially generated transuranium waste should be shipped to and stored at ERDA sites, and the administrative intent to send to a federal repository all transuranium waste now stored on ground-level pads, as discussed earlier.

5.4.3 Special Admonition on Exhumation of Radioactive Waste

The Panel on Land Burial regards exhumation of waste originally buried without any intent of later retrieval as a potentially very hazardous operation. It can cause dispersion of radioactive material by rupture of corroded containers or by scattering of uncontained material during excavation and recovery. We advise against exhumation except where there is a credible reason to believe that a real radiation hazard could arise from leaving the waste where it is.

No major exhumation program should be undertaken until adequate proof has been obtained by experimental trial that buried waste in containers in all stages of deterioration can be exhumed safely.

Exhumation is a difficult and costly operation. It should only be done when the alternative mode of disposal, after exhumation, is manifestly safer than leaving the material in the present burial site. Obviously this determination cannot be made until it is known what the ultimate disposal method will be. For these reasons, the Panel strongly recommends against exhumation and transfer of waste to temporary engineered storage where the exhumed material must await a decision on permanent disposal.

5.4.4 ERDA Long-Range Policies on Retrieval of Transuranium Wastes

The rationale stated by ERDA for the potential exhumation requirement is that the transuranium waste, particularly that bearing plutonium-239 with a long half-life of 24,390 years, is so highly radiotoxic to man that near-surface land burial should not be an acceptable disposal method because of the costly long-term surveillance burden. It has also been suggested by ERDA that it is no longer certain that all land now held at ERDA sites will remain permanently as isolated and protected enclaves. This is a very important consideration. With program changes and public pressure to release land, it may no longer be practicable to attempt to control large tracts of isolated land not directly or obviously needed for long-term programs.

There does not seem as yet to have been much effort to do a cost-benefit analysis of the potential exhumation operations. The costs, as we see them, are not merely the dollar costs--which will often be very large. They also include the "cost" of the exposure to radiation incurred by the operators, and perhaps by the general public, during exhumation and the manipulations involved in achieving final disposal. The positive benefits can only be represented by the elimination of radiation exposure to man by the operation, plus such public relations benefit as might accrue to ERDA for having made the effort.

A cost-benefit analysis should also consider that, to date, no adverse environmental effects have been detected at any of the ERDA low-level waste management sites that the Panel visited. Despite this, the Panel believes that the data are lacking that would enable us to predict the ultimate effect of current and future burial at these sites. The collection of these data, together with the cost of monitoring, should also be a part of the cost-benefit calculations.

ERDA has made a public commitment to minimize the number of its active burial sites and assumes that the same consideration will be applied to establishment of new commercial sites. By various means, it is hoped that better use can be made of land now set aside for burial of radioactive waste, and that control can be improved. The Panel believes that it remains to be seen whether these somewhat difficult objectives can be achieved.

A determined effort is being made at all ERDA sites that we visited to fulfill the spirit and the letter of the ERDA desire to hold all significant amounts of waste containing transuranium nuclides in retrievable storage at appropriate sites. The interpretation of "significant" has been taken to mean an amount of radioactive material that could believably be expected to have any effect on man, assuming the worst credible conditions existing over an indeterminate period.

Some very low-level, off-site, beta-gamma radioactive effluents have been reported, but were considered to be acceptable because they had undergone great dilution or wide dispersion. No off-site migration of transuranium waste was reported from any of the burial sites.

One of the results of the studies of the transuranium waste was that the Panel learned that very little seemed to be known about the rate of movement of transuranium elements through the soil under field conditions or in laboratory experiments simulating field conditions. For example, how does plutonium move in soil--as an ion, as a coordination complex, or as a radiocolloid? How does its movement vary with the pH of the system? What are the components of the soil that adsorb or bind plutonium? What are the comparable factors affecting the behavior of the other transuranium elements in different types of soil? Nothing was reported to the Panel about the rates of movement of the transuranium elements through the groundwater system. Perhaps this is because there is little, if any, movement. We tend to believe that the movement is very slow, but knowledge would be preferable to speculation. Without such knowledge gained both in the laboratory and in the field, it will be impossible to evaluate the cost-benefit relationships properly (see also Section 6.1).

There are at least two kinds of events on earth that have produced fission products and transuranium nuclides in geological systems; the Panel believes that studies of these events may produce experimental data directly related to the questions of the short-term and long-term behavior of these by-products of nuclear fission. The first is the Oklo phenomenon in Gabon, Africa. The evidence points to the occurrence more than a billion years ago of a natural nuclear chain-reacting system in a swamp. The second kind of event would include the numerous nuclear explosions that have been set off underground in recent years in a variety of geological environments. Significant and relevant data may possibly be obtained from these test sites, or may already be in existence.

In its effort to improve the management of transuranium waste, ERDA commenced the construction of a Transuranium Solid Waste Development Facility during the fiscal year 1974 at the LASL. The staff of this new research and engineering development facility will study the treatment of solid transuranium waste in an attempt to reduce its volume and to devise a product that is suitable for very long-term storage or disposal. Primary volume reduction techniques will be sorting, compaction, and incineration. Some of the other candidate concepts for study at ERDA sites are unconventional methods such as continuous pyrolysis, acid digestion, and burning in molten salt. These studies should advance the technology of the management of transuranium waste.

5.5 SOME SAFETY CONSIDERATIONS

Any waste disposal facility handling fissile materials must be properly designed and operated with due consideration of all problems of critical mass analysis.

Off-gases from compaction equipment require collection and venting through High Efficiency Particulate Air (HEPA) filters. An incinerator for radioactive waste is no different in this respect from any other plant processing radioactive material. Storage of solid low-level transuranium waste above ground until shipment to a federal repository, if sanctioned, should prove to be both less costly and also safer than burial with later retrieval. Surveillance of containers for leakage and deterioration would be relatively easy. Containers for transuranium waste could be less expensive if they were not expected to withstand burial conditions for extended periods of time. Waste stored above ground could be unprocessed, that is, neither compacted nor incinerated.

Storage of non-incinerated waste could offer potential problems, because decomposition might create explosion or fire hazards and the production of radioactive aerosols. However, adequate fire protection measures could be taken such as by storing all combustible waste in sealed, fire-resistant containers and installing fire suppression systems in the waste storage areas. In the future, when radioactive waste must be shipped to federal repositories, combustibles contaminated with radioactive materials must be carefully controlled to prevent fires.

5.6 INSTRUMENTATION AND DETECTION OF TRANSURANIUM NUCLIDES IN RADIOACTIVE WASTE

Monitoring is a necessary part of the program for the immediate protection of all employees having contact with transuranium waste from their initial source through the exhumation, sorting, and repackaging operations, as well as for the protection of populations who may become exposed as a result of the failure of any of these operations.

Any practical application of a definition of "plutonium-contaminated waste" involves the capabilities of existing radiation instruments for measuring the amounts of these materials in the various containers packaged and shipped for storage and retrieval. The following discussion outlines the present state of the art and the possibilities of improvements in the reasonably near future.

The sensitivity for detection, i.e., measuring the nature and amount of the radioactivity present, depends primarily on these factors: (1) the specific activity (either induced or natural), i.e., radioactivity per unit measured of the radiation to be detected; (2) the nature of the extraneous or matrix material; (3) the package size or form in which the material is available for measurement; (4) the external background from the plant environment; and (5) the time allotted and accuracy required for the individual measurement. Because of these factors, the sensitivity for detection can vary widely.

Sensitivity values reported for the equipment in use today varied from 10 milligrams of plutonium per container for the "barrel counter" at the Lawrence Radiation Laboratory at Livermore to a few grams of plutonium per container.

The factors that have the greatest prospect for improvement in sensitivity are the specific activity and the package size and form. If the material presented to the measuring apparatus is in a form that minimizes attenuation effects (for example, if it is chopped or cut and mechanically sorted according to density and then passed by the counting apparatus on a belt or conveyor), then it is possible to take advantage of some recent developments in instrumentation.

The first of these is a survey-type device (U.S. Atomic Energy Commission 1970), now commercially available, which measures the X ray activity of the nuclide of interest. The unattenuated sensitivity of this device for plutonium-239 is 1.3 nanocuries (200 nanograms) for a point source placed essentially in contact with the detector, and 120 nanocuries per square meter (1.9 micrograms per square meter) for an area source. The sensitivity can be increased by an order of magnitude if a nuclear instrumentation scaler is substituted for the count-rate meter as a readout device and a counting time of 20 minutes is used. Further instrumental refinements are expected to increase the sensitivity by another order of magnitude.

A second possibility is to use a thermalized neutron source to induce fission; the fission events are then detected, in particular the delayed neutrons (Idaho Nuclear Corporation 1968; U.S. Atomic Energy Commission 1968). The sensitivity depends on the strength of the available neutron source, as well as the efficiency of the neutron detection provided. Calculations show that either commercially available neutron generators or californium-252 would yield sensitivities for plutonium-239 of much less than 35.3 milligrams per cubic meter (1 milligram per cubic foot). This method is specific only for the isotopes fissionable by thermal neutrons.

In short, the fundamental physical and engineering principles exist today that could provide, if required, an increase in sensitivity for detection of plutonium-239 of at least two to four orders of magnitude. It remains, of course, to translate these principles into a practical system that could function in the environment of the day-to-day operation of the plant.

5.7 SELECTION OF SITES FOR MANAGEMENT OF RADIOACTIVE WASTE

Implicit in all discussions of the selection of burial sites for radioactive waste of all kinds is the relationship between the rates of radioactive decay of the buried material and the long-term stability of the selected burial site. This stability may be controlled by several factors; one is the political stability of the government or other organization controlling the site. The Panel did not feel qualified to address this complex political and sociological problem, but was aware of the fact that many isotopes of concern in radioactive waste management have half-lives much longer than the whole lives of most governments in world history.

The Panel felt that it is more important to rely as much as possible on an adequate geological selection of a burial site, since much is known about the time scales and rates of action for most geological phenomena, which are discussed in this section in more detail.

The Panel did not discuss the question of the long-term variations in geological factors, such as climate, that have produced the extensive glaciation of the Ice Age that ended only about 12,000 years ago; but it believes this is an important factor to be considered in all discussions of burial or disposal of long-lived radionuclides. The Panel understands that this subject is expected to be covered as part of a more broadly geological study by another Panel of the Committee on Radioactive Waste Management, to be established in the near future.

5.7.1 General Considerations

The obvious place for shallow land burial of low-level radioactive waste seems to be in desert areas where the environmental conditions make it almost inconceivable that there could be any significant contamination of groundwater that would be used by man.

The Panel is not aware of any likelihood that there would be such a pressure of population in these areas in the foreseeable future, that land would be in such demand for industrial occupation, or that the presence of inaccessible sites would be embarrassing. The area of desert country needed for waste management would be small compared with the total area of available land.

It seems, therefore, that desert areas are the preferable locations for burial sites. It is recognized, however, that road transportation--especially if the loads are heavy and the distances great--exposes people to ordinary traffic hazards even if the loads are so well packaged that no danger from radioactive contamination could exist. If rail transportation can be arranged, these hazards can be reduced materially. We believe that the risk inherent in transportation is more than compensated by the greater radiological safety of desert burial of solid radioactive waste.

In desert areas, erosion could be a problem. If the possibilities of soil erosion are taken into account by the designers, it seems to the Panel that there is little reason to suppose that the anticipated difficulties could not be overcome. Seismic considerations are in the same category. Known techniques for building underground structures to resist earthquakes are commonly and successfully employed in the construction industry. Earthquakes perhaps will not have an adverse effect; nevertheless, when possible, such burial trenches should be located in regions not likely to be subject to earthquakes.

In general, desirable features for land burial sites of low-level radioactive waste include (not necessarily in order of importance):

(1) a desert climate;
(2) a deep groundwater table;
(3) a low population;
(4) a slow erosion rate;
(5) land not suitable for agriculture and an absence of useful or potentially valuable mineral deposits;
(6) good access by road, rail, or both;
(7) an availability of inexpensive and abundant building materials, such as sand and gravel;
(8) topography suitable for easy movement of heavy machinery; and
(9) an absence of any special environmental attractiveness, such as spectacular scenery, unique flora or fauna, or high recreational potential.

A number of excellent papers have been published during the last few years on the general hydrogeologic aspects of radioactive waste disposal. These include papers by Winograd (1974), Papodopulos and Cherry (U.S. Environmental Protection Agency 1974b), and Cherry et al. (1974). Much of the following is based on these papers, and the reader is referred to them for a more detailed treatment of this subject.

One of the concerns involved in the burial of radioactive waste is that groundwater or infiltrating surface water will leach the waste and mobilize the radioactive materials, which will then be carried by this water back to the surface as a part of natural groundwater discharge or through a water well. Data that should be considered for an understanding of these processes at a given disposal site are listed in the following section. These data include factors affecting the mobilization of contaminants (infiltration of water through the waste and the position of the water table with respect to the waste), the movement of groundwater in the subsurface (the permeability of the earth materials, the groundwater gradient, and flow path), and the movement of the contaminants with the groundwater (dispersion, diffusion, and distribution coefficients).

It is not possible to immobilize a radioactive contaminant in a burial site for long periods of geologic time (i.e., for millions of years) with complete certainty; however, there appear to be hydrogeologic environments in which these contaminants can be kept below the surface and away from man until they have decayed to acceptable levels.

The problem is not merely a matter of ensuring optimum confinement, but is also one of ensuring confinement for a minimum but specified time period and of describing and predicting the performance of these radioactive contaminants in the subsurface until this time period has elapsed. For this reason, burial sites having complex hydrogeology in which such predictions are difficult or impossible are probably not suitable for the burial of radioactive waste.

From a geological standpoint, there appear to be two basic approaches to the long-term control of buried radioactive waste. The simplest approach is to prevent water from reaching the waste and thereby to eliminate the possibility of contaminants in the waste being mobilized. In arid climates, where there is little or no infiltration, this appears to be feasible. Winograd (1974), although concerned primarily with the storage of high-level radioactive waste, discusses most of the aspects of the arid-zone environment that would be of concern in the burial of solid low-level radioactive waste.

In humid climates, where there is infiltration, some sort of engineered container or facilities that would isolate the waste from the water for hundreds of years would be necessary, and such facilities may not be practical at the present time.

The second approach to long-term control involves burying the waste in a hydrogeologic environment that can be demonstrated to be safe despite the fact that radioactive contaminants can and will be mobilized. Demonstrating that such sites are, in fact, safe requires a quantitative evaluation of the factors influencing contaminant movement. Such an evaluation may be quite difficult but appears to be our only option if we wish to bury radioactive waste in humid climates or in climates where infiltration is capable of mobilizing or leaching the buried waste.

It is also important to give attention to the possible biological and microbiological environment of a burial site. Soil microorganisms, earthworms, larger burrowing animals, and the deep taproots of plants seeking water and nourishment (particularly in desert areas) can all be factors in moving components of waste out of a burial place into the biosphere. Some organisms can release organic compounds into the soil that can serve as complexing agents to mobilize otherwise insoluble contaminants. Some organisms can concentrate radionuclides by surprisingly high factors from their environment and so can change both the biochemical availability and the distribution of a radionuclide.

5.7.2 Hydrogeologic and Hydrochemical Considerations in Site Selection

The types of hydrogeologic and hydrochemical data that may be needed to determine whether proposed or existing sites are adequate have been listed by Papadopulos and Winograd (U.S. Environmental Protection Agency 1974b:17):

(1) depth to water table, including perched water tables, if present;
(2) distance to nearest points of groundwater, spring water, or surface water usage (including well and spring inventory, and particularly water wells available to the public);
(3) ratio of pan evaporation to precipitation minus runoff (by month for a period of at least 2 years);
(4) water table contour map;
(5) magnitude of annual water table fluctuation;
(6) stratigraphy and structure to base of shallowest confined aquifer;
(7) baseflow data on perennial streams traversing or adjacent to storage site;
(8) chemistry of water in aquifers and aquitards and of leachate from the waste trenches;
(9) laboratory measurements of hydraulic conductivity, effective porosity, and mineralogy of core and grab samples (from trenches) of each lithology in unsaturated and saturated (to base of shallowest confined aquifer) zone--hydraulic conductivity to be measured at different water contents and tensions;
(10) neutron moisture meter measurements of moisture content of unsaturated zone--measurements to be made in specially constructed holes (at least 2 years' record needed);
(11) in situ measurements of soil moisture tension in upper 4.5 to 9 meters (15 to 30 feet) of unsaturated zone (at least 2 years' record needed);
(12) three-dimensional distribution of head in all saturated hydrostratigraphic units to base of shallowest confined aquifer;
(13) pumping, bailing, or slug tests to determine transmissivity and storage coefficients;
(14) definition of recharge and discharge areas for unconfined and shallowest confined aquifers;
(15) field measurements of dispersivity coefficients;

(16) laboratory and field determination of the distribution coefficient for movement of critical nuclides through all hydrostratigraphic units; and

(17) rates of denudation and/or slope retreat.

These data are necessary for a complete definition of flow and nuclide transport through both the unsaturated and saturated zones. To obtain such information, exploration costs could total several tens to several hundreds of thousands of dollars, depending on many factors. However, not all the outlined information listed above is likely to be needed at all sites.

The Panel realizes that no single prospective site is likely to fulfill every criterion of desirability. Compromises will have to be made because of availability of space, transportation, cost, or convenience; even political factors might play a part.

5.8 MONITORING OF GROUNDWATER

5.8.1 Objectives

The objective of a groundwater monitoring system at a burial site for solid low-level radioactive waste should be to detect any movement of dissolved solids from the disposal trench and, if such movement is detected, to predict how this material will move in the future. Studies at LASL and Hanford indicate that little or no water is infiltrating from the surface to the zone of saturation, and, therefore, the movement of contaminants in solution should not be a problem. The monitoring program at these sites should continue to be directed towards detection of any movements of contaminants, whether in solution or airborne. On new sites, this monitoring is a logical extension of the site selection procedure discussed in Section 5.7. At SRP, ORNL, and INEL, it has been demonstrated that contaminants have left disposal trenches; the objective of a monitoring program at those sites should be to predict how the dissolved solids will move in the future.

5.8.2 Predictions

If the approach given above is taken, the subsurface can be regarded as part of the waste-handling facility. An estimate of the concentrations of contaminants that would be expected in the groundwater, as observed in monitoring wells along the groundwater flow path at various distances from the trenches at various times in the future, would be necessary. If monitoring showed that concentrations of contaminants were not within the expected limits, the waste management operations (or the estimates) should be modified. The prediction of contaminant levels should also include predicted levels of non-radioactive substances, because these substances may be used as tracers and also because chemical contaminants can sometimes damage the environment, either directly or by mobilizing radionuclides.

There are some serious difficulties in applying this approach to solid waste disposal operations. These include the problem of predicting the rate at which buried waste containers will disintegrate and how long it would take for water to enter a failed container, dissolve the contents, and reenter the soil. Variations in leaching rate would also follow climatic changes. Fortunately, the policy of segregation of transuranium waste in retrievable storage has alleviated the problem for this kind of waste generated in the future, although location of retrieved waste above the ground surface introduces new possibilities for dispersion.

Attempts have been made to construct predictive models of the movement of contaminants with the groundwater. The construction of such models depends on the amount and accuracy of the input of basic hydrogeologic and geochemical data and the availability and accuracy of records of the past hydraulic and geochemical behavior of the disposal site (see also Section 6.1). In the Panel's opinion, insufficient data are available for the construction of such models to describe the low-level solid waste management sites. Data collection and computer time are expensive, and model-making demands strenuous intellectual effort. There is sometimes a tendency to regard the model as the end product, rather than the predictions produced by the model. It is therefore essential to bear in mind the role of the humble monitoring system, which will show whether or not the theoretical model works in the real world.

5.8.3 Early Warnings

Early detection of contamination is most important. Unlike surface water, groundwater usually moves slowly, and if contaminants move unexpectedly, we must know about it before significant amounts have left the disposal site. Interception of the contaminants is not likely to be simple or prompt if this has not been considered in the selection of the site or the design of facilities. It might then, for practical reasons, be impossible at some locations.

Should it be necessary to take remedial measures to eliminate further discharges, the smaller the amount of waste involved, the simpler these measures are likely to be. Early detection of contaminants generally requires that monitoring points be placed as close as possible to the waste. If the waste is above the water table, the monitoring devices might be placed between the waste and the water table, or if the waste is beneath the water table, they should be immediately down-gradient from the waste.

The Panel believes that the amount of all radioactive material that escapes from burial sites to the public domain must be monitored continually and reported frequently and on a regular basis to the public.

In addition, such notification must be accompanied by accurate and meaningful information on and interpretation of the nature of the hazards involved. The public has a great deal of misinformation and misunderstanding about the nature of radioactive wastes and often has no real understanding of the difference between the hazards of high-level transuranium waste and of trash contaminated by radioactive materials at levels essentially that of the natural background. Such information should also include comparisons with other present-day environmental hazards. The public should be informed of such facts as that plutonium is principally dangerous to human beings when inhaled as particles or taken into cuts but is less harmful when ingested.

Such adequate education of the public should also be considered as a part of the responsibilities to be assigned by the federal government among the different federal agencies (see Section 6.3).

5.9 CURRENT RESEARCH AND DEVELOPMENT PROGRAMS

Considerable research has been conducted in the past on radioactive waste management at the principal ERDA land burial sites for solid radioactive waste (see also Appendix C). At the request of the Chairman of the AEC in 1973, bibliographies were prepared with abstracts of publicly available literature on radioactive waste management published by the several AEC laboratories as technical reports and journal articles from January 1951 to July 1973. During this period, the contractors at the Hanford operation published 1,098 reports, those at the Savannah River operation published 197, the agencies at the Idaho National Engineering Laboratory published 272, the Oak Ridge National Laboratory and associated agencies published 448, and many reports were also issued by the Los Alamos Scientific Laboratory.

Although much of the effort towards improved research and management has been concerned with the problems of high-level waste, a considerable amount of the work is applicable or useful to waste suitable for land burial. There should be more effort in these areas. In general, we believe that the research and development activities are well chosen and are now directed to the solution of the problems at hand.

The titles and abstracts in the above-mentioned bibliographies show that the early studies largely tended to be related to ecological and environmental surveys and monitoring. This is most apparent in the waste management literature prior to 1963. Since 1963, there has been an increasing emphasis on studies of soil characteristics, ground disposal, hydrology, geology, and waste fixation and solidification at all of the ERDA establishments where land burial is practiced.

6 CONCLUSIONS

6.1 SPECIAL LOCAL PROBLEMS

ERDA operates sites for radioactive waste management in both arid and humid regions with varying soils and hydrogeological regimes. Information is therefore available that should have wide application. Opportunities should be provided for coordinated and comparative research using data obtained at all the sites.

The Panel believes that, although present practices have not created a hazardous situation, there is no doubt that the solid waste at the Oak Ridge National Laboratory and the Savannah River Plant is being leached and that contaminants are slowly moving from the waste in the subsurface. Present data indicate that the contaminants are well adsorbed in the soils or are adequately diluted by natural processes. However, further studies, now and in the future, will be necessary to establish and to test the details of these assumptions more securely.

At the Savannah River Plant (SRP), information about the migration of buried radionuclides has been obtained by extensive exploratory drilling, routine surveillance of a network of monitoring wells, and laboratory tests with SRP soils. Under the soil conditions at SRP, plutonium is believed to move at a considerably slower rate than cesium, which may move at 0.5 percent of the rate of groundwater.

It is particularly necessary to continue attempts to obtain quantitative information in the field on the rates of movement of water and of specific radionuclides in the subsurface soils and structures under various climatic conditions. Very little information seems to have been developed on this factor.

Although we are aware that research has been carried out at several ERDA sites on the geochemistry of soils in relation to movements of waste through the ground, we were struck by the fact that this subject was rarely mentioned in presentations made to the Panel. The NAS-NRC Committee on Geologic Aspects of Radioactive Waste Disposal (National Research Council 1966) recommended that changes in the distribution of radionuclides sorbed in the ground should be carefully monitored, particularly where pits have leaked or overflowed (as at ORNL).

The Committee also concluded that there was insufficient knowledge of the three-dimensional movement of water, particularly in the vertical dimension. The Panel concurs with these opinions and believes, as the Committee did, that the study of past discharges is a worthwhile method of gathering information, which can be used to predict the results of future disposal operations. These steps should be a part of the establishment of a monitoring program as described elsewhere in this report, and as this program proceeds, other necessary research will become apparent. Very few data were presented to the Panel on the three-dimensional configuration of the groundwater flow system, and, to our knowledge, discharge points for flow lines originating in or below the disposal trenches have not always been demonstrated by field measurements. Unless the groundwater-flow lines are defined, it is difficult to interpret the results of water quality analyses.

6.2 PERMANENT DISPOSAL OF TRANSURANIUM WASTE

The Panel believes that the location and installation, as rapidly as possible, of a permanent repository for properly segregated and treated transuranium solid waste is necessary. Such action would require:

(1) proper site selection, taking into account all known and foreseeable hazards and the results of detailed investigations of climate, topography, geology, hydrogeology, geochemistry, seismology, tectonics, and demography;

(2) modern design of advanced waste management facilities;

(3) assurance that the operation will conform to accepted standards related to the results shown by the monitoring system;

(4) assurance of direct control in perpetuity by the federal government through its designated agent or agents;

(5) the use of the best available techniques for reducing the volume of the waste by compaction, incineration, recovery, etc., and avoidance of dilution with nonradioactive materials;

(6) setting aside of the area for disposal of transuranium radioactive waste and for no other purposes, and restriction of the area from any other use or unauthorized access; and

(7) assurance that proper and durable records will be maintained in at least two different locations of all materials put in the repository; the records should include location of the materials in the site and a qualitative and quantitative characterization of the waste as received for disposal.

If the above actions were taken, the Panel believes that there would be no further need for what appears to us a hazardous policy of "20-year retrievability" of transuranium radioactive waste.

6.3 ROLE OF THE FEDERAL GOVERNMENT

The Panel believes that the federal government must exert a strong leadership in defining the responsibilities, assigning the authority for setting and implementing definite standards, and for ensuring coordination between federal, state, and local agencies and private industry for the effective management of radioactive waste. It is to be hoped that the national government will effectively be able to continue to maintain these high standards and policies in spite of the relatively transient nature of changes in political administrations and the often short operational lifetimes of national policymakers. It is also essential that our designated standards in radioactive waste management be based upon the best available scientific knowledge and the most credible conclusions derived therefrom.

The Panel is also aware of the difficulties inherent in a system in which concern about various aspects of the problems of radioactive waste is distributed among at least the following elements of the U.S. government:

Energy Research and Development Administration,
Nuclear Regulatory Commission,
Council on Environmental Quality,
Environmental Protection Agency,
Federal Energy Agency,
National Science Foundation,

Department of State,
Department of Defense,
Department of Transportation,
Geological Survey, and
Office of Management and Budget.

It will be difficult to sort out the respective responsibilities, and particularly to divide the authority and power for action among these disparate groups. The Panel does not wish to make recommendations concerning the respective roles of these agencies. However, the Panel firmly believes that the responsibilities and authorities assigned these agencies need to be carefully evaluated and coordinated in the interests of the public. These responsibilities should include guidance on the general characteristics of places suitable for location of waste management operations and definition of the objectives and scope of monitoring procedures to be used and standards to be attained in the avoidance of hazards to the public. Detailed contingency plans must be made for suitable actions to be taken (both on a short-range and long-range scale) if potentially hazardous situations develop at any burial site, such as accidental leakage, sabotage, civil strife, or war. Each agency must actively and vigilantly pursue its specific responsibilities in all these areas because of the great importance of these programs and the possible high social cost of negligence.

For one specific detail, the federal government should assume direct control in perpetuity of a permanent repository for the long-lived and transuranium waste, as discussed in Section 6.2.

It is implicit that the federal government must have responsibility for the regulation not only of federally owned but also privately owned facilities for radioactive waste management, not only now, but for an indefinite future time as a national obligation and commitment. The federal government must also negotiate agreements with foreign nations and international organizations when needed, because of the possible extraterritorial aspects of management of radioactive waste.

The Panel observed that the different sites use a number of different systems of classification and nomenclature for radioactive wastes. These different systems apparently developed historically because of differing local conditions, types of material being handled, and so forth. The Panel believes that these local differences present difficulties in an overall national system of radioactive waste management. The appropriate federal agencies should agree on a consistent national system of nomenclature and classification of radioactive wastes as part of a national system of guidelines for their management.

At the same time that the nomenclature and classification of radioactive wastes are being clarified, the federal government should assign a specific responsibility to some agency for transmission to the public of accurate and meaningful information on and interpretation of the hazards of radioactive waste. This point is also discussed in Section 5.8.3.

One problem that needs specific reevaluation is the present upper limit of 10 nanocuries of transuranium nuclides per gram of waste; above this level, such waste cannot be buried, but must be placed in a separate transuranium repository as discussed elsewhere. This limit was empirically established by reference to the range of natural radioactivity caused by radium in the earth's crust. This criterion should be critically reviewed in the light of more recent work on the biological and ecological effects of low levels of radiation for occasional or long-term exposure. The Panel understands that ERDA has initiated such a study, with results expected in early 1977. The Panel recommends that the results of this study should be reviewed critically at that time. At the same time, the Panel recommends a critical review of the criteria that are required to keep the contamination of radioactive waste to "the lowest practicable level." Such regulatory terms as "lowest practicable" are sufficiently ambiguous as to leave loopholes and room for endless dispute between opposing factions about nuclear waste management.

The Panel is concerned about the possibility that, because of the number of federal and other agencies involved in the problem, important decisions or actions may not be taken as a result of responsibility or authority having fallen between the cracks. This must be prevented.

But in addition to all these problems of allocations of responsibility and authority, there remains the over-arching problem of a need for the federal government to take firm and credible action in the near future. Many students of the political and economic aspects of nuclear energy believe that its future development may depend on a rapid solution to the problem of the management of nuclear waste, one that is satisfactory not only technologically, but politically as well.

7 POSTSCRIPT, AUGUST 6, 1976

At the time of writing this report, the Panel strongly believed that better coordination of the efforts concerning radioactive waste management by the various federal agencies was essential, but did not feel qualified to make specific recommendations on how this should best be done; the Panel felt that this was not a scientific problem, but a sensitive political and economic one. While this report was in its final stages of review, the Panel learned that the President's Office of Management and Budget (OMB) initiated on March 25, 1976, an Interagency Task Force on Commercial Nuclear Waste to identify the time tables and objectives of each federal agency and to clarify the various agency roles in managing high-level, low-level, and transuranium wastes and uranium mill tailings. Results from this study are expected later. Because of the position and functions of the OMB in the federal government, the Panel assumes that the results from the study of the OMB Task Force may serve to clarify some of the questions that we have raised about the role of the U.S. government in this area.

The Panel notes that the OMB study does not appear to cover the questions of radioactive residues from other non-nuclear operations, such as phosphate mining, the wastes generated by the AEC and ERDA for military purposes, or possible international discussions and agreements on the management of radioactive waste. However, the Panel understands that these questions may be considered by the OMB after the present study is completed.

An International Symposium on the Management of Wastes from the LWR Fuel Cycle, sponsored by ERDA, was held in Denver, Colorado, on July 11-16, 1976. Nearly 60 papers, totalling over 1,100 pages of text, were delivered by scientists from this country and abroad before about 700 participants. Publication of the proceedings of the meeting was scheduled for October 1976. Many of the topics included in this report were discussed extensively at the symposium, and much new information was presented; nevertheless, we believe that our basic conclusions and recommendations are still valid.

A follow-up Symposium on Public Policy Issues in Nuclear Waste Management is scheduled to be held in Chicago, Illinois, on October 27-29, 1976. This meeting is expected to go into depth on many of the political, economic, sociological, and environmental questions that have been asked about nuclear wastes and may provide useful information to help answer some of the kinds of political and administrative problems that this Panel did not feel qualified to answer in this report.

The Panel also understands that President Ford met with the heads of a number of government agencies in late July 1976 to review the domestic policies and practices on nuclear energy, particularly as they relate to questions of the foreign and international development of nuclear energy. Part of the subsequent discussions are expected to concern problems of the organization and structure of the national nuclear energy enterprise, including the management of radioactive wastes. These discussions may also be expected to lead to new national policy statements and legislation on the overall management of nuclear energy in the United States sometime in the near future.

In conclusion, the Panel on Land Burial hopes that this report may be a useful source of information and viewpoints during this period of intense reexamination of the problems (and possible solutions) of radioactive waste management in the view of urgent national needs.

APPENDIX

A SUMMARIES OF THE SITES VISITED AND OF OTHER SITES THAT PLAY AN IMPORTANT ROLE IN SOLID WASTE PRODUCTION

This Appendix consists of a summary of the best available hydrogeologic, climatic, and physiographic data. It includes, in places, excerpts from the original literature. Citations are given as appropriate; one citation may cover several preceding sections or paragraphs.

A.1 LOS ALAMOS SCIENTIFIC LABORATORY, LOS ALAMOS, NEW MEXICO

(Operated for ERDA by the University of California)

A.1.1 Nature of the Site

A.1.1.1 Location and Topography The Los Alamos Scientific Laboratory (LASL) is located at Los Alamos, New Mexico, about 56 kilometers (35 miles) by highway to the northwest of Santa Fe. It is at an elevation of between 2,100 and 2,400 meters (7,000 and 8,000 feet) on the eastern slopes of the Jemez Mountains, west of the Rio Grande Depression on the Pajarito Plateau. Only the Mesita del Buey, which is a mesa on the Pajarito Plateau, is used at present for the disposal of solid radioactive waste. This mesa is a long narrow interfluve sloping gently from the west to the east, which is bounded on the north and south by steep walled canyons cut 15 to 30 meters (50 to 100 feet) below the surface of the mesa by intermittent streams.

A.1.1.2 Geology The mesa is covered by a clay-like soil and underlain by 75 to 180 meters (240 to 590 feet) of volcanic tuff and pumice (Bandelier Tuff). These materials are in turn underlain by basalt with interbedded sediments (Chino Mesa Formation) and volcanic debris (Puye Formation). The tuff and pumice are broken by nearly vertical joints, which formed as the ash flows cooled. These joints may be closed or open as much as 5 centimeters (2 inches), although they are usually less than 5 millimeters (0.25 inch) wide. The upper meter (3 to 4 feet) of these joints is commonly filled with a light brown clay.

A.1.1.3 Tectonics The Los Alamos Scientific Laboratory has been classified as being in a Tectonic Zone 2 (International Conference of Building Officials, Uniform Building Code), but there is no geological evidence to indicate that strong earthquakes have occurred in the Los Alamos region within recent geologic history. According to a consultant's report, "...risks from possible surface faulting and volcanism are minimal...but there is a risk of moderate seismic ground motions at the site." (U.S. Atomic Energy Commission 1973b: WASH-1527; 37, 39)

A.1.1.4 Climate The Los Alamos Scientific Laboratory has a semiarid continental mountain climate. The average precipitation is 480 millimeters (18 inches) per year, 75 percent of which falls from May through October. There are 1,270 millimeters (50 inches) of snow in the average winter. Tornadoes occur in New Mexico, but are rare above an elevation of 2,100 meters (7,000 feet) and are not considered a hazard at the disposal site. Vegetation is sparse, with ponderosa pine and Douglas fir predominating at elevations about 2,100 meters (7,000 feet); pinon pine and one-seeded juniper are more abundant at the lower elevations.

A.1.1.5 Regional Hydrology The regional water table is at a depth of approximately 260 to 320 meters (850 to 1,050 feet) and slopes to the east into the valley of the Rio Grande. The horizontal velocity of the groundwater is estimated to be 30 centimeters (1 foot) per day (University of California 1971: 9). There is some perched water in stream-connected aquifers in the alluvium in the canyons to the south of the mesa. These aquifers are recharged by intermittent streams.

According to Abrahams et al. (1961: D-145), where the normal soil cover is undisturbed there would be little or no recharge to the zone of saturation from precipitation on the surface of the plateau. The main aquifer at depth is recharged by precipitation on the mountains and in the deep canyons cut into the western part of the plateau.

A.1.1.6 Hydrogeology of Burial Sites for Solid Waste Both trenches and shafts are excavated in the tuff for disposal purposes. The trenches are 9 to 10 meters (30 to 35 feet) deep, unlined, backfilled with waste and tuff, and topped off with 2 to 3 meters (6 to 9 feet) of tuff. The shafts are up to 19 meters (64 feet) deep, lined with concrete or asphalt, backfilled with waste, and topped off with concrete.

According to Purtymun and Kennedy (University of California 1971: 8), where the soil cover has been disturbed, as in the disposal area, precipitation may infiltrate to depths of 3 meters (10 feet), but below this depth it is redistributed by diffusion and there is not enough water to leach the contaminants from the waste and move them into the tuff.

Studies have also been made of the movement of tritium from a solid waste storage shaft. Purtymun (University of California 1973) discovered that some tritium was moving from these shafts in the vapor phase through open joints in the tuff and through the tuff matrix.

A.1.1.7 Hydrogeologic Monitoring Monitoring sites at Los Alamos consist of shallow wells, deep wells, surface wells, and springs. They are laid out to survey the entire reservation. Emphasis has been placed on monitoring the quality of the water in the regional aquifer, in the perched aquifer, and in spring discharge into the canyon. There are only a few monitoring stations specifically intended to monitor the waste disposal areas on the Mesita del Buey.

Routine monitoring has not revealed any significant migration of radioactive material from the solid waste burial grounds. Studies of a liquid waste disposal site (Christenson and Thomas 1962: 281) have shown that some nuclides migrated at least 8.5 meters (28 feet) through fissures in the tuff.

A.1.1.8 Special Problems Some concern has been expressed that buried waste at Los Alamos could be exposed by erosion. Purtymun and Kennedy (University of California 1971: 10) estimated that it will require 27,000 years for downward erosion to expose the refuse ard 110,000 years for lateral erosion from the canyon walls to reach the burial site.

There is some concern at Los Alamos that there will not be enough space available to bury waste in the future. At the present rate of waste production, space for land burial on the mesa should last for 20 to 30 years. However, it did not appear to us that suitable space was necessarily limited to this one mesa.

Four waste disposal sites are no longer used. They will represent a problem should there be a future need to recover the plutonium and other heavy elements. One of these sites is covered and used as a parking lot for automobiles and recreational vehicles.

Concern has also been expressed that climatic changes may occur in this area before the transuranium waste that is buried at this disposal site has decayed to acceptable levels. If this were to occur, it is conceivable that increased precipitation and subsequent infiltration through the burial trench could mobilize the radioactive contaminants and carry them downward to the underlying aquifer. The consequences of such an event could be calculated.

A.1.2 Current Experience

The Los Alamos Scientific Laboratory produces a large variety of contaminated solid waste. The principal contaminant of concern is plutonium-239. Non-transuranium waste is usually packaged in plastic bags and fiber containers only strong enough to provide contamination control en route to and at the land burial site prior to emplacement in large pits and covering with soil. Fission product waste with high gamma readings (greater than 5 roentgens per hour at the surface of the container or 200 milliroentgens per hour at 1 meter) is handled separately, being shielded during transport and at the burial ground, and is then placed in specially drilled shafts in the burial area.

Solids from the treatment of liquid streams are produced in two separate facilities, Buildings TA-21 and TA-50. The principal radiocontaminant of concern is plutonium. TA-50 produces a dewatered sludge--30 to 40 percent solids--which is sometimes mixed with cement and is sent to the burial ground either as a cement or as a sludge in 210-liter (55-gallon) drums. The waste has been placed in recent years in "retrievable storage" trenches. TA-21 produces a fluid cement paste that is piped into large diameter, asphalt-lined, drilled shafts and allowed to harden in place.

Tritium-contaminated material is treated prior to disposal by encasement in asphalt (bitumen) and is then placed in large-diameter drilled shafts. Metal containers for contaminated oil are stacked in a large-diameter deep-drilled shaft. The shaft is plugged with a cement cap, which is rounded on top to cause the movement of water away from the buried containers.

About 80 percent of all the radioactive waste that has been buried is contaminated with transuranium elements and includes a large amount of americium-241. In 1974, the annual burial was 32,020 curies in 4,071 cubic meters (144,000 cubic feet) of solids, including the binding or encasing materials. Plutonium (mainly plutonium-239) in the solid waste amounts to about 150 grams (0.55 pound) per year, and about 5 kilograms (11 pounds) accumulated prior to the time retrievable storage of transuranium contaminated waste was instituted. Most of the plutonium currently comes from TA-21 mixed with a cement paste. The treated liquid streams contribute annually 460 cubic meters (16,000 cubic feet) of solid from TA-21 as cement and 190 cubic meters (6,700 cubic feet) of solid from TA-50 as a sludge.

A.1.3 Research

Plans for research and development include studies on: (1) a more efficient method for dewatering sludges and additional ion-exchange treatment of effluent from TA-50, for removal of chemicals as well as included radioactive ions; (2) the incineration of organic substances (burnables); (3) the systematic evaporation of some waste streams rather than the current flocculation treatment; (4) more conversion to cement paste rather than to a floc; and (5) the construction and operation of the Transuranic Solid Waste Development Facility, which is an engineering demonstration of processes for treatment of burnable solid radioactive waste.

A.2 ROCKY FLATS, GOLDEN LAKE, COLORADO

(Operated for ERDA by Rockwell International [Atomics International Division]; formerly operated by Dow Chemical Company; not visited by the Panel)

A.2.1 Facilities Available

At present no radioactive waste is being buried at Rocky Flats. In the past some burials occurred locally, but most of the plutonium-containing waste has been retrieved and shipped to the Idaho National Engineering Laboratory (INEL). The small remainder is in a known location and is under surveillance. The waste currently shipped to INEL is stored in a retrievable Transuranic Storage Area (TSA) if the contamination level exceeds 10 nanocuries of transuranium nuclides per gram of waste. Some lower-level transuranium waste continues to be buried at the INEL, as was all Rocky Flats waste received prior to 1970.

A.2.2 Current Experience

About 50 percent of the radioactive solid waste from the Rocky Flats Plant results from the treatment of liquid streams. The rest is produced by a variety of chemical plants and laboratory operations. A recent categorization was by the LSA (Low Specific Activity) or non-LSA (non-Low Specific Activity) waste definitions set by the U.S. Department of Transportation.

Shipments of alpha-particle-emitting waste are made in 210-liter (55-gallon) drums, or plywood boxes coated with a glass-fiber-impregnated polyester. Rigid polyethylene liners in the drums and the box coating provide the integrity needed for "20-year retrievable" storage. Waste not requiring retrievable storage is packaged only to meet transportation requirements but not to provide control after burial.

Alpha-particle-emitting waste comprises about 90 percent of the total generated. About 7,000 cubic meters (247,000 cubic feet) of alpha-particle-emitting waste is currently generated each year, containing about 20 kilograms (44 pounds) of plutonium of various isotopic compositions. The 15,500 cubic meters (4.1 million gallons) of liquid waste, when treated, produces 3,700 cubic meters (130,000 cubic feet) of solids, a reduction to 24 percent of the original volume.

A.2.3 Research

Development efforts have been directed toward the improvement of the packages designed for retrievable storage of alpha-particle-emitting waste. Process improvements are planned to decrease the amount of radioactive effluents in waste streams (both solid and liquid) and, ultimately, to recycle all liquid streams so that there are no liquid discharges on site.

A.3 MOUND LABORATORY, MIAMISBURG, OHIO

(Operated for ERDA by the Monsanto Corporation; not visited by the Panel)

A.3.1 Facilities Available

No waste is at present buried on the site. Some building rubble contaminated with plutonium was buried in the past, and the burial site is well identified and frequently monitored. All current waste is shipped off-site for burial by a commercial organization or for burial or storage at an ERDA site.

A.3.2 Current Experience

The laboratory generates a miscellany of many kinds of solid waste and solids resulting from the treatment of liquid waste streams. The principal contaminant is plutonium-238, with some plutonium-239. Tritium-contaminated waste is also produced. "Low-risk" alpha-particle-emitting waste is treated by precipitation, flocculation, and scavenging. The floc is solidified with cement in polyethylene bags in 114-liter (30-gallon) drums. "High-risk" alpha-particle-emitting waste is packaged directly by mixing with an absorbent material in 110-liter (29-gallon) polyethylene containers with bung openings. These are placed in 114-liter (30-gallon) drums.

Low-level tritium liquid waste has been shipped (but not currently) in a tank truck for burial to the Nuclear Engineering Company at Morehead, Kentucky. The Panel visited this site. On arrival, the waste was solidified with cement and buried in a plastic-lined trench. Some small quantities are mixed with absorbent and cement and shipped to Morehead in 114-liter (30-gallon) drums. High-level tritium liquid waste is solidified as a cement in small metal containers placed in larger metal containers that provide at least two encasements in asphalt. These are presently stored at Mound Laboratory. The usual amount shipped each year is about 2,250 cubic meters (80,000 cubic feet), and, of this, about 75 percent is plutonium-contaminated. About 10 percent of the solid waste is a result of the treatment of 23,000 cubic meters (810,000 cubic feet) of a liquid stream.

A.3.3 Research

New developments include the installation of a facility to improve the handling of "low-risk" plutonium waste. It will utilize centrifugation to reduce sludge volume and will automate the processing of filling the drums. New facilities are being planned for handling "high-risk" plutonium waste by solidification with cement.

A.4 ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

(Operated for ERDA by the University of Chicago; not visited by the Panel)

A.4.1 Facilities Available

There is no active burial ground at the Argonne National Laboratory (ANL), but at the time of the decommissioning of the original laboratory in the City of Chicago, building rubble was buried in the Cook County Forest Reserve. The site is known and is kept under surveillance. Other ANL-generated waste and building rubble was also buried at that location.

A.4.2 Current Experience

The Argonne National Laboratory (ANL) (including the University of Chicago) produces a wide variety of solid radioactive waste suitable for burial. Some solid waste arises from the treatment of liquid waste streams. This is done mainly by evaporation of the liquid waste to a high salt content and then self-solidification with vermiculite in 210-liter (55-gallon) drums. About 40 cubic meters (1,400 cubic feet) per year of solid waste result from the treatment of about 380 cubic meters (13,000 cubic feet) of liquid waste streams. The total solid waste produced is about 845 cubic meters (30,000 cubic feet). At Argonne, Illinois, all waste suitable for burial is shipped to the Nuclear Engineering Company burial site at Sheffield, Bureau County, Illinois.

The ANL also operates one facility at the INEL, where it utilizes the local land burial services.

A.5 IDAHO NATIONAL ENGINEERING LABORATORY, IDAHO FALLS, IDAHO

(Formerly the National Reactor Testing Station [NRTS]; now operated for ERDA by Aerojet-Nuclear Corporation and the Allied Chemical Company)

A.5.1 Nature of the Site

A.5.1.1 Location The Idaho National Engineering Laboratory (INEL) is a government reservation located in southeastern Idaho. The surrounding areas are sparsely populated, the nearest populated place being Atomic City with about 14 residents, located approximately 19 kilometers (12 miles) to the southeast. The major population center is Idaho Falls, approximately 32 kilometers (20 miles) east of the eastern boundary. (U.S. Atomic Energy Commission 1974a; WASH-1539; 28-39).

A.5.1.2 Topography The INEL is on the Columbia Plateau in the eastern part of the Snake River Plain.) The surface of the plain is generally flat or hummocky, except for a few buttes, with a local relief of about 60 meters (200 feet) and, in one instance, more than 600 meters (2,000 feet) above the plain. Most of the INEL lies within a closed topographic depression. The surface rock over large areas is black basalt of recent origin. Some flows are still fresh, unaltered by weathering and bare of vegetation. Elsewhere there is a thin veneer of soil. Vegetation is sparse, consisting of coarse grasses and desert plants with a few low bushes (National Research Council 1966: 15).

A.5.1.3 Geology The INEL is located entirely on the Eastern Snake River Plain, with the mountains to the northwest providing the northern boundary of the plain. Formation of the plain and filling to an unknown depth with tuffs, lavas, and sediments began in the middle Pliocene and apparently continues at present. The last volcanic eruption at the Craters of the Moon (21 kilometers, or 13 miles southwest of the INEL) occurred about A.D. 400 (U.S. Geological Survey 1974b: 20).

The particular area occupied by the INEL has been intensively studied since 1949. Except for small areas along the mountain fronts and two volcanic cone-like buttes, the entire INEL area is underlain by a succession of Pliocene, Pleistocene, and geologically recent basaltic lava flows. These form layers of hard rocks of thickness varying from 3 to 30 meters (10 to 100 feet). Unconsolidated material, cinders, and breccia are interbedded with the basalt. The beds are nearly horizontal with no structural deformation evident. These layers have been penetrated by drilling to a depth of 456 meters (1,497 feet). On the basis of geophysical and geologic evidence gathered from surrounding areas, the depth of these layered deposits is inferred to range from less than 300 meters (1,000 feet) to more than 1,500 meters (5,000 feet).

Surface soils and regolith along the streams are made up of alluvial sands and gravel of varying thickness. These grade into the finer textured sediments towards the terminal ends of the streams. The surface soils over the remainder of the INEL are formed by eolian and loessial deposits of varying thickness. Sandy soils derived from wind-worked beach and bar deposits formed in old playa lakes or ponds are especially common in the northern part of the site. In many places basalt rock is not covered. Local playa areas contain deposits 3 to 4.6 meters (10 to 15 feet) in thickness. Alluvial fans occur along the mountain fronts.

The cation exchange capacity of the soils in the area has been determined and formulas developed for estimating the amount of radioactive cesium and strontium that will be sorbed under given circumstances. (U.S. Atomic Energy Commission 1974a: WASH-1539; 2.8-42 to 2.8-44).

A.5.1.4 Tectonics Relatively recent volcanic activity has occurred at several places on the Snake River Plain, including at least one site adjoining the southwestern portion of the INEL. That volcanic activity will not take place again on or near the site cannot be assured. However, the present inactivity has lasted for some hundreds of years, suggesting the possibility of cessation of volcanism, rather than simply quiescence between active periods. There is a low probability, therefore, of a major eruption on or near the INEL site. Seismographic monitoring, conducted by the U.S. Geological Survey's National Center for Earthquake Research in 1968 and 1969, detected no earthquakes within 70 kilometers (43 miles) of the reservation (U.S. Geological Survey 1975b). However, this does not disprove the possibility that strain in the earth's crust could produce slippage along a nearby fault and thus generate an earthquake.

A.5.1.5 Climate The climate at the INEL has semidesert characteristics with a yearly precipitation of 200 to 250 millimeters (8 to 10 inches).) The normal annual snowfall is about 660 millimeters (26 inches) and accounts for about 30 percent of the annual precipitation (U.S. Geological Survey 1974b: 7-8). The climate is cool with an average maximum ranging from -2.2°C (28°F) in January to 32°C (89°F) in mid-July. Three confirmed funnel clouds have been recorded during the 23-year history of the INEL (U.S. Atomic Energy Commission 1974a: WASH-1539; 2.8-41).

A.5.1.6 Regional Hydrogeology The INEL is underlain by the Snake Plain aquifer. The aquifer is about 320 kilometers long by 50 to 100 kilometers wide (200 miles by 30 to 60 miles) and comprises an area of about 25,000 square kilometers (9,600 square miles). Lithologically, the aquifer is composed of a series of thin basalt flows, generally 3 to 23 meters (10 to 75 feet) thick, with interbedded layers of fluvial, lacustrine, wind-blown, and pyroclastic sediments. Most of the aquifer permeability occurs along the upper and lower contacts of successive basaltic flows that have large and irregular fractures, fissures, and other voids. This leads to a large degree of heterogeneity and anisotropy in the hydraulic properties of the aquifer. Most evidence indicates that the aquifer is between 300 and 3,000 meters (1,000 and 10,000 feet) thick. Seismic and deep resistivity data indicate that the aquifer may be about 1,500 meters (5,000 feet) thick in the INEL region.

Groundwater flows generally southwestward through the aquifer from the north and northeastern recharge areas to the south and southwestern discharge areas. Depth to the regional water table at the INEL varies from about 60 meters (200 feet) in the northeast corner to 275 meters (900 feet) in the southeast corner. The average hydraulic gradient is about 1 meter per kilometer (5 feet per mile) to the southwest.

The only significant natural recharge to the aquifer in the INEL vicinity is from the Big Lost River. A small amount of recharge occurs from infiltration of precipitation directly on the site, and, during some years of high runoff, Birch Creek water flows onto the station and seeps underground. The Big Lost River drains into a closed basin terminating at the northern end of the station. When the Big Lost River flows onto the site, it infiltrates the channel bottom and percolates downward toward the aquifer. Layers of fine-grained sediments with low permeability tend to retard the downward percolation forming perched groundwater beneath the river. Perched water undoubtedly occurs beneath other parts of the Big Lost River system where there are high seepage losses, such as at the INEL diversion area. However, there are very few wells available for monitoring such perched water. The most significant body of perched water resulting from waste disposal occurs at the Test Reactor Area (TRA) beneath the seepage ponds for liquid waste. Minor perched zones resulting from waste disposal in other areas are also present (U.S. Geological Survey 1974a: 12-15).

A.5.1.7 Hydrogeology of Burial Sites for Solid Waste
The INEL burial ground consists of 36 hectares (88 acres) of land approximately 11 kilometers (7 miles) east of the western boundary of the station and 6 kilometers (4 miles) north of the southern boundary. The terrain is rolling and the burial ground is located in a depression or small valley with no marked drainage channel.

Waste is buried in trenches that bottom some distance above the bedrock. The soil depth varies from 6 meters (20 feet) to less than 1.5 meters (5 feet), with exposed rock being common at the higher elevations surrounding the area. The surface soils are silt loams derived from loessial depositions. The texture of the soil changes with depth through silty clay loams to a silty clay that covers the basalt rock. Caliche deposits occur at various depths, which indicates that the development of soil has been interrupted by sequential deposition of parent material (U.S. Atomic Energy Commission 1972: 31, 33).

Based on preliminary data supllied to this Panel during its visit to the INEL, the top of the zone of saturation beneath the solid waste burial ground is at a depth of approximately 180 meters (600 feet). There is evidence that some of the 200 to 250 millimeters (8 to 10 inches) of annual precipitation infiltrates to depth at the burial grounds because the sediments are at field capacity, and some water is found perched in sediment layers interbedded with the lava flows beneath the burial ground. These preliminary data also indicated that the solid waste may have been leached by infiltrating water and some radioactive contaminants carried downward beneath the burial ground. This migration is not considered to present any danger to the environment, but should be a fruitful object for future study. It should be noted that the data presented in this paragraph are not based on published data, but on information provided to the Panel on preliminary work not verified to the degree that it could be submitted for publication at this time.

A.5.1.8 Hydrogeologic Monitoring Most of the subsurface monitoring at the INEL is concerned with the liquid waste disposal operation. A large number of monitoring wells have been installed, and an extensive sampling program has been carried out on a continuing basis. The results of this work have been used to construct mathematical models describing the movement of these contaminants in the subsurface (U.S. Geological Survey 1974a). In view of the other waste disposal activities carried on at the INEL, it is unlikely that the effects of the solid waste disposal operation, if any, would be noticed in this reservation-wide monitoring network.

Some groundwater monitoring installation points have been installed at the solid waste burial ground in conjunction with current research. Only preliminary results are available, and the data have not as yet been published (J. T. Barraclough, J. B. Robertson, and V. J. Janzer 1975, unpublished paper: A Study of Potential Migration of Radionuclides from the Solid Waste Burial Ground, Idaho National Engineering Laboratory, Idaho [with appendix compiled by L. G. Saindon], U.S. Geological Survey, Idaho Falls). This investigation is continuing.

Earlier work (U.S. Atomic Energy Commission 1972) has confirmed that the present land burial site as it is currently used is acceptable. So far as the Panel knows, the monitoring points installed as part of this earlier study are no longer used.

A.5.2 Current Experience

About 6,000 cubic meters (210,000 cubic feet) of transuranium-contaminated solid waste is stored annually at the INEL from the Rocky Flats operation. This material was formerly buried in pits, but waste above the 10 nanocuries per gram level is now stored on asphalt pads under sheet plastic and plywood with a compacted earthen cover. The waste is contained in plastic-lined 210-liter (55-gallon) drums or special fiberglass-plastic-covered boxes (see description of Rocky Flats, Appendix A.2). This facility provides retrievable storage for alpha-particle-emitting waste. A similar pad is used for disposal of radioactive waste with high salt content and low plutonium content, which is not required to be retrieved.

Currently, the Rocky Flats operation generates about 20 kilograms (44 pounds) of waste plutonium annually. The accumulated plutonium in the burial site now amounts to about 500 kilograms (1,100 pounds), of which about 120 kilograms (260 pounds) is in retrievable storage.

Low-level waste originating at the INEL represents less than 0.01 percent of the solid waste stored locally at the Idaho Transuranic Storage Area (TSA). About 1,100 cubic meters (39,000 cubic feet) of waste to be buried is generated locally at the chemical-processing plant and research reactors. The remainder is derived from the naval reactors and minor programs. At present, no effluent streams from the solid waste disposal area are intentionally released to the environment. The only effluents resulting from the solid waste handling operations are those occurring from natural phenomena, such as runoff of meteoric moisture and windborne particulate waste.

Water samples are collected after storms and analyzed for radioactivity. A water-sampling station is located at the low end of the TSA storage pad to collect the rain runoff water. All the cells within TSA have moisture-sampling pipes. Four of the cells have 10-centimeter (4-inch) vertical air- and temperature-sampling pipes that can be opened for inspections. Four wells for routine water sampling, approximately 210 meters (700 feet) deep, are located outside the burial grounds of which TSA is a part. One 76-meter (250-foot) hole is located within the burial grounds for monitoring. Twenty-seven additional shallow holes within the burial grounds are available to monitor the water and soil for migration of contamination in the subsoil.

There is always a possibility of airborne releases whenever waste is being handled. Air monitors are therefore located upwind and downwind from operational areas whenever weather or other conditions warrant.

Solid waste that has been dumped into trenches or pits is covered every week to minimize the chance of waste and contamination leaving those areas.

Test exhumation work has been done on previously buried waste from the Rocky Flats plant, which was contaminated with transuranium nuclides. Core samples were collected prior to excavation work to determine the general level of contamination that would be encountered. Standard hand-operated samplers were used to collect soil samples in the vicinity of the excavation work.

Concern exists on the subject of possible criticality during retrieval of buried Rocky Flats waste containing plutonium. There are several factors that help minimize the magnitude of that problem. Since only drums are to be retrieved during the initial effort, the emphasis here will be on drums. The factors are as follows:

(1) All containers of transuranium waste currently buried at the Radioactive Waste Disposal and Storage Area contain quantities of waste in subcritical array. Removal of the soil cover and other surrounding drums will tend to lower the nuclear reactivity of those drums remaining in the stack, hence no criticality problems should arise with those drums left in the ground.

(2) The same drums removed from the ground and stacked so they are surrounded only by air will also be less reactive than when they were buried with companion drums. However, there is a possibility of restacking the previously buried drums with other drums in such a way that the reactivity could be increased. The probability of stacking together two or more drums overloaded with plutonium (greater than 200 grams per drum) is remote, since the probability of several drums being overloaded is small. At the end of 1970, there were approximately 51,000 cubic meters (1.8 million cubic feet) of Rocky Flats plutonium-contaminated waste buried, which contained 368 kilograms (810 pounds) of plutonium or about 7 grams of plutonium per cubic meter (0.2 grams per cubic foot) of waste. This is equivalent to about 1.5 grams of plutonium in each 210-liter (55-gallon) drum.

(3) Drums that are retrieved are to be repackaged by placing intact drums in new and larger containers. This will lower the plutonium-to-package ratio, thus lowering the reactivity by further separating the fissile material.

(4) Survey of the retrieved drums, using the best portable instruments presently available, will not give a definitive or quantitative answer to how much plutonium is actually present in the drum. However, the use of these instruments will allow detection of anomalously high radiation readings, which will detect a drum suspected of containing significant amounts of alpha-particle-emitter waste and allow special handling and/or analysis prior to repackaging and stacking of the drums on an TSA pad.

(5) Rearrangement of fissile material in any one potentially overloaded drum into a critical configuration with other drums is considered to be only a remote possibility.

In conclusion, retrieval of presently stored plutonium-bearing waste will not increase the present levels of reactivity. The use of survey instruments to screen for drums heavily loaded with transuranium elements will further ensure that no criticality problems will arise.

The nature of plutonium dictates that maximum precautions must be used to ensure personnel safety and to prevent the spread of contamination. Continous surveillance by qualified health physics personnel is required to check for sources of alpha-particle emitters and beta-gamma contamination that may be exposed during the retrieval operations. Any source of contamination exposed by excavation that in the judgment of the health physics representative may lead to a condition of airborne activity or the uncontrolled spread of contamination will be contained before continuing any further retrieval effort.

Previous exhumation operations performed out-of-doors have been limited to times when the wind velocity was less than 32 kilometers per hour (20 miles per hour); however, retrieval operations performed inside the air support structure can continue when the outside wind velocity is as great as 120 kilometers per hour (75 miles per hour). An anemometer 6 to 7.5 meters (20 to 25 feet) high is used to measure wind velocity.

Anticontamination coveralls, hard hats, plant safety shoes, safety glasses, leather anticontamination shoe covers, and anticontamination gloves are needed for working personnel. Non-working spectators require anticontamination coveralls, shoe covers, safety glasses, and anticontamination gloves. Respirator training will be required for all participants, whether observers or workers, who enter the controlled access area. Each individual in the controlled access area keeps a respirator on his person available for use as needed.

Health physicists keep a continuous surveillance of the work area while work is in progress. The surveillance consists of the following:

(1) Frequent checks are made at the work area while removal of dirt is in progress. These checks include visual inspections for uncovered drums, contamination checks for beta-gamma and alpha emitters, and checks for direct radiation.

(2) The working face of the drum stack is monitored for beta-gamma activity and alpha-particle activity as drums are removed from the stack.

(3) Frequent checks for alpha-particle activity are made in the work area and on the soil surrounding the drums.

(4) One alpha-particle detector (air) and one beta-gamma emitter air monitor are in continuous operation in the immediate vicinity of the work area in positions chosen by the health physicist. Also, two high-volume air samplers are operated in the vicinity of the work area.

(5) All health physics data such as survey results, analyses of air samples taken, and work summaries are recorded in permanent books assigned to the project.

The health physicists in the air support building perform health physics functions as defined in Safety Division Procedures, as specified in the work procedure, or both. The operation is stopped if contamination spread exceeds the limits specified in the work procedure. Work does not continue until the contamination has been reduced to acceptable limits. All users of respiratory gear must have completed the respirator training course given by Aerojet-Nuclear Corporation Industrial Hygiene Division. All users of half-face respirators and full-face respirators are smoke-tested with each type of unit to assure that a proper seal can be attained with that type of mask. The requirements for mask usage are determined by survey instrument analysis of the soil and of air filter samples counted on the alpha smear counter, or as measured by air activity levels.

The program will initially be based on the use of portable criticality survey equipment to survey retrieved drums for high plutonium content. However, a study of state-of-the-art plutonium assay equipment is under way. The study is expected to produce equipment specifications that may later be used to procure improved criticality survey equipment (drum counters) for this program.

A.5.3 Research

Development efforts have been directed toward improved compaction techniques. Further studies are needed in techniques and evaluation of exhumation hazards in connection with the planned removal and treatment of buried alpha-particle-emitting waste. Migration studies have been conducted and continue as part of the assessment of the need for an exhumation program. Recently, an improved system of monitoring wells has been established.

A.6 HANFORD WORKS, RICHLAND, WASHINGTON

(Waste facilities now operated for ERDA by the Atlantic-Richfield Hanford Company)

A.6.1 Nature of the Site

A.6.1.1 Location The Hanford site is located in the southeastern corner of the state of Washington, about 50 kilometers (30 miles) east of Yakima and 5 kilometers (3 miles) north of Richland (U.S. Energy Research and Development Administration 1975b: ERDA-1538;II.3, 1).

A.6.1.2 Topography The Hanford site is in the rain shadow of the Cascade Range on the Columbia Plateau in the Pasco Basin, a topographical depression between the Saddle Mountains, on the north; the Rattlesnake Hills and the Horse Heaven Hills, on the west and southwest; and the Blue Mountains of Oregon, on the southeast. Topographic relief within the basin is low except for the ridge of Gable Mountain, which rises some 180 meters (600 feet) above the plain. The area is bounded on the north and east by the valley of the Columbia River.

A.6.1.3 Geology The Pasco Basin evidently was formed by slow and prolonged subsidence concomitant with filling of the basin by basaltic lavas.) Periods of volcanism and uplift were coupled with periods of erosion and deposition by the Columbia River. In the Pleistocene Epoch, a number of gigantic floods occurred with ponding, sedimentation, and subsequent erosion by the Columbia River to its present level. Some sand dunes developed late in the history of the area (U.S. Energy Research and Development Administration 1975b: ERDA-1538; II.3, 9-11).

Three major geologic units are present. A basaltic lava with interbedded sediments (Columbia River Basalt Series) is the basal unit and is probably about 1,500 meters (5,000 feet) in thickness. Overlying these basalts are semiconsolidated clays, conglomerates, sands, and silts (Ringold Formation) up to 370 meters (1,200 feet) in thickness, which are in turn overlain by unconsolidated silts, sands, and gravels up to 600 meters (200 feet) in thickness. The basalt outcrops at the surface to form Gable Mountain and Gable Butte. (U.S. Atomic Energy Commission 1974a: WASH-1539; 248-259).

A.6.1.4 Tectonics The eastern part of Washington, including the Hanford site, is classified by the International Conference of Building Officials, Uniform Building Code, as being in a Seismic Zone 2. This implies a potential for moderate damage from earthquakes, but the underlying sands and gravels are thought to provide excellent protection from damage (U.S. Atomic Energy Commission 1974a: WASH-1539; 62-64).

A.6.1.5 Climate The Hanford climate is mild and dry. Summers are generally hot and dry, while winters are not as dry and are relatively mild for this latitude. The area is subject to wide ranges in seasonal temperature. The average annual precipitation is 160 millimeters (6.25 inches) with November, December, and January contributing 42 percent of the total. About 45 percent of all precipitation during the months of December through February is in the form of snow (U.S. Energy Research and Development Administration 1975b: ERDA-1538; II-3, 32-36).

Tornadoes are relatively rare in this region and tend to be small with little damage when they do occur. Data have been analyzed to determine the probability of a tornado hitting a particular facility on this site. It was estimated that the probability during a year is six chances in one million (U.S. Energy Research and Development Administration 1975b: ERDA-1538; II-3, 13-16).

A.6.1.6 Regional Hydrogeology Surface water bodies associated with the Hanford reservation consist of the Columbia River, the Yakima River, two ephemeral streams, one natural pond that reflects the top of the zone of saturation, and a number of man-made ditches and ponds used for the disposal of liquid low-level radioactive waste and cooling water (U.S. Energy

Research and Development Administration 1975b: ERDA-1538; II-3).

In general, groundwater in the surficial sediments occurs under unconfined or water table conditions, although locally confined zones do exist. Water in the basalt bedrock occurs mainly under confined conditions. There are certain "erosional windows" where a possibility exists for hydraulic communication between the unconfined and the deeper confined aquifers (U.S. Energy Research and Development Administration 1975b: ERDA-1538; II-3, 13). The major source of natural recharge to the unconfined aquifers is precipitation on the uplands to the south and the west of the reservation. The natural recharge due to precipitation over the low land of the Hanford reservation is not measurable, as the evaporation potential during the summer months greatly exceeds the total precipitation. Data on migration of moisture from natural precipitation in deep soils (below 9 meters, or 30 feet) show a movement rate less than 1.3 centimeters (0.5 inch) per year at one measurement site (U.S. Energy Research and Development Administration 1975b: ERDA-1538; II-3, 24).

Large volumes of process water disposed to ponds on the Hanford reservation have caused the formation of significant groundwater mounds in the water table since the start of Hanford operations (U.S. Energy Research and Development Administration 1975b: ERDA-1538; II-3, 25). The depth to the water table varies greatly from place to place depending chiefly on local topography, ranging from less than 1 foot to more than 300 feet below the land surface. The current estimate of the maximum saturated thickness of the unconfined aquifer is about 70 meters (230 feet). The hydraulic conductivity of the consolidated and semiconsolidated materials overlying the basalt excluding clay zones is variable, ranging from 3 meters (10 feet) per day to 3,700 meters (12,000 feet) per day (U.S. Energy Research and Development Administration 1975b: ERDA-1538; II-3, 24).

From the limited amount of research that has been done to date it appears that a number of confined aquifers are present underneath the Hanford reservation. Relatively impermeable confining beds commonly include the individual basalt flows where they are continuous and greater than about 15 meters (50 feet) thick and the silts and clays of the lower part of the Ringold Formation.

In general, the hydraulic potential observed in the confined aquifer zones above the basalt is greater than in the overlying unconfined aquifer. Exceptions are the recharge mounds, which have raised the potential in the unconfined aquifer.

Groundwater flow in both the confined and unconfined aquifer is to the southeast. (U.S. Energy Research and Development Administration 1975b: ERDA-1538; II-3).

A.6.1.7 Hydrogeology of Burial Sites for Solid Waste Solid waste not intended for retrieval is placed in trenches 3 to 6 meters (10 to 20 feet) deep in the unconsolidated surficial deposits and covered with soil. The base of these trenches is well above the top of the zone of saturation. Studies by Isaacson et al. (Atlantic Richfield Hanford Company 1974: 18) indicate that precipitation does not percolate to the water table, and, therefore, radioactive contaminants will remain immobilized in the vadose zone. To the knowledge of the Panel, there have been no investigations of the hydrogeology of specific burial trenches for solid waste.

A.6.1.8 Hydrogeologic Monitoring Monitoring of ground and surface waters at the Hanford reservation is directed toward determining the effect of past and current operations for the disposal of liquid waste. The disposal sites for solid waste are not monitored, presumably because it is felt that contaminants are not being leached from the waste, or that if they are, the amount would be insignificant compared to other subsurface discharges.

Monitoring of the reservation as a whole is quite extensive and the results of this monitoring have been used to model the aquifer and the distribution of radioactive contaminants therein.

A.6.2 History

Past land burial practices at this site are of interest because they serve to give a historical insight into the attitudes prevailing at various periods. From 1944 to 1954, there was no serious segregation of different types of low-level radioactive waste. Combustibles and non-combustibles were buried in the same trench. Burial records were incomplete, and there was a minimal amount of information as to the quantity or type of radioactive material present.

From 1955 to 1965, there was an increased interest in developing alternative disposal methods. Some were actually put into practice. For instance, there were no further burials in the N-reactor area. Record keeping was improved and more faithfully maintained. The open-air accidental burning of some radioactive combustibles quickly ended any further efforts or desires to reduce volumes by that method.

From 1966 to 1974, a program of centralization of the burial grounds in the 200 Area was started and completed. The measurement of the kinds and amounts of radioactivity in the buried waste improved. Sites were marked with informative semipermanent markers. Record keeping was further improved and segregation of radioactive waste by categories was initiated. The N-reactor and N-fuel fabrication are now the principal sources of waste.

Since 1970, in keeping with the modified policy of the U.S. Atomic Energy Commission (now ERDA), transuranium waste is kept separately in a retrievable form.

A.6.3 Monitoring Experience

In addition to routine monitoring of the ground and surface waters (including the Columbia River), studies have been made of the vertical migration of water contaminated with radionuclides in the unsaturated zone. The monitoring program is designed to analyze the gross model of the whole reservation, so contributions by contaminants coming from land burial of solid waste are difficult to identify specifically.

A.6.4 Research

Studies on geochemistry in relation to movement of radionuclides through the soil are continuing.

A.7 OAK RIDGE NATIONAL LABORATORY, OAK RIDGE, TENNESSEE

(Now operated for ERDA by the Union Carbide Corporation)

A.7.1 Nature of the Site

A.7.1.1 Location The Oak Ridge National Laboratory (ORNL) is located in the west central portion of eastern Tennessee, bounded on the northeast, southeast, and southwest by the Clinch River and on the northwest by Black Oak Ridge. The area surrounding the laboratory is generally rural to urban in character with the largest population center (Knoxville, population 157,000) located 24 kilometers (15 miles) to the east. Other population centers, all with populations of less than 35,000 persons, are Oak Ridge, Clinton, Kingston, Harriman, and several smaller communities within Anderson and Roane counties (U.S. Atomic Energy Commission 1974c: WASH-1532; 24, 25).

A.7.1.2 Topography The ORNL is located in the ridge and valley physiographic province, which is characterized by parallel ridges of sandstone, shale, and cherty dolomite, separated by valleys of less weather resistant limestone and shale. The ridges are oriented southwest to northeast; elevations range from 230 to 240 meters (750 to 800 feet) at the valley floor to 300 to 370 meters (1,000 to 2,000 feet) at the ridge crests.

Surface drainage is controlled by the topography and is through small intermittent and permanent streams into Milton Creek and from Milton Creek into White Oak Creek and then to the Clinch River. The stream valleys are relatively closely spaced. The area is thickly wooded with grassy clearings (U.S. Atomic Energy Commission 1974c: WASH-1532).

A.7.1.3 Geology The ridges and valleys of the area are the result of the geologic structure and stratigraphy.) All the rocks of this region dip from about 30 to 40 degrees in approximately a southeast direction. The more resistant rocks make up the ridges and the less resistant ones, the valleys. The same formations are repeated over and over again in the ridge and valley province by the intervention of many thrust faults.

The lowest formation is the Rome Formation, which consists of even-bedded, very fine-grained sandstone and much shale of red, green, and other colors. It is in excess of 300 meters (1,000 feet) thick and forms ridges in the area.

Overlying the Rome is the Conasauga Group, about 460 meters (1,500 feet) thick, consisting of olive-drab shale with siltstone beds and some beds and lenses of gray limestone, most of which occur in the upper few hundred feet of the formation. The Conasauga Group underlies the valleys of the region. The Knox Group of formations is up to 800 meters (2,600 feet) thick and lies above the Conasauga. It consists largely of light-to-dark-gray cherty, dolomitic limestone and forms ridges. The Knox Group is covered nearly everywhere by a residual light-to-red clay soil. There are many sinkholes in its area of outcrop and sizable springs issue from the base of the limestone.

Above the Knox Group is the Chicamauga limestone, consisting of thin-bedded limestone and shale, about 520 meters (1,700 feet) thick (Theis 1956; 123-125).

A.7.1.4 Tectonics Within the southeastern United States, the only zones of highest risk (Zone 3) are those around centers of seismic activity in the Mississippi Valley and at Charleston, South Carolina, both of which are about 640 kilometers (400 miles) from the ORNL site. The area experienced an earthquake on November 30, 1973; the epicenter was about 50 kilometers (30 miles) southeast of the ORNL site, with an intensity of approximately IV to V (Modified Mercalli). The intensity at ORNL has been estimated at about IV and there was no observed damage. (U.S. Atomic Energy Commission 1974c: WASH-1532; 28)

A.7.1.5 Climate The climate at ORNL is typical of the humid summer Appalachian region. The mean annual rainfall is approximately 1.35 meters (53.5 inches), and the mean temperature is 14.4°C (57.9°F). Precipitation is predominantly in the form of rainfall, although snowfall can represent a significant portion of the total winter precipitation. The precipitation pattern is characterized by wet winters and comparatively dry springs, followed by relatively wet summers and dry autumns (U.S. Atomic Energy Commission 1974c: WASH-1532; 25).

A.7.1.6 Regional Hydrogeology Few data are available on the regional groundwater flow patterns in the vicinity of the Oak Ridge National Laboratory. Precipitation would be expected to infiltrate in the uplands and discharge locally to provide the base flow in small streams and creeks and into the Clinch River. The configuration of the top of the zone of saturation roughly parallels the topography.

According to De Laguna (1956), the rocks in this area have the following hydrogeologic characteristics:

The Knox Group is solid, massive where unweathered and undeformed; however, where it has been fractured by faulting, its permeability has been considerably increased. In many places these fractures have been enlarged by solution and large openings have been formed, so that sinkholes and caverns are common.

The Chicamauga limestone is composed largely of a thin bed of shaly limestone and shale and has a very low porosity. Fractures between the beds transmit water; some of them have been somewhat enlarged by solution, but large openings like those found in the Knox dolomite are not present.

The Rome sandstone is fine-grained, and its ability to hold and transmit water is due almost entirely to fractures between the beds. The permeability is believed to be low, and porosity is known to be very small. The shales in the Conasauga Group are somewhat weathered and weakened to a depth of 3 to 6 meters (10 to 20 feet) and some of the weathering extends deeper, although the alteration is minor below the water table. In this weathered zone, perhaps as a result of the volume changes in the rock associated with the weathering, there is a closely spaced network of thin partings or fractures, both along the bedding planes and at somewhat larger intervals across them. The permeability of this material, which is small by water supply standards, appears to be somewhat more uniformly distributed than that of the other three formations in the area.

Pressure testing of wells shows that, where tested for a few feet below the water table, the ability of the Conasauga shale to accept water in measurable amounts is mainly confined to a few thin zones. Below 25 or 30 meters (80 or 100 feet), there are few fractures and the formation appears to be essentially impermeable below 38 meters (125 feet). The general appearance of the Conasauga shale suggests that the permeability is greater along the strike, and field investigations confirm this. Because groundwater flow is through fractures in the Conasauga shale, the velocity of underground flow is higher than might be expected from the permeability. Long travel times cannot be anticipated over the short travel distances available. The closely spaced partings of the shale, however, suggest that adsorption will act effectively. This favorable outlook is somewhat strengthened by the high ion-exchange capacity of samples of the Conasauga shale as determined in the laboratory (Delaguna 1956: 443-447).

A.7.1.7 <u>Hydrogeology of Burial Sites for Solid Waste</u>
In the early years of operation at the ORNL, burial sites were located close to the source of waste. However, some years ago, it was decided that the shales in the lower part of the Conasauga Group were most suitable for waste disposal, and since that time all of the low-level solid radioactive waste has been buried in or about this unit. As previously noted, although permeability of the Conasauga Group is generally low, pressure testing has shown that there is jointing and fracturing near the surface (De Laguna 1956).

Burial grounds Nos. 4, 5, and 6 were located in the Conasauga shale and in somewhat similar hydrogeologic environments. At these burial grounds, the elevation of the top of the zone of saturation has been defined, is usually between 1.5 to 4.5 meters (5 to 15 feet) below the surface, and conforms roughly to the topography with horizontal gradients toward nearby stream valleys. It is assumed that all of the water that moves beneath or infiltrates into the burial ground discharges into a nearby stream valley, but the base of this local flow system has not been defined. Burial trenches were initially constructed above the top of the zone of saturation.

Leachate springs near the downslope end of burial ground No. 4 indicate that groundwater is moving through the solid waste and carrying contaminants away from the disposal site. Work to date (U.S. Energy Research and Development Administration 1975a) indicates that this discharge does not have an appreciably adverse effect on the environment away from the burial ground. Burial ground No. 4 was operated from 1951 to 1959; but although now closed, it is still the major contributor of strontium-90 to White Oak Creek in the Clinch River watershed. Offsite release of radioactive strontium-90 is 1 percent of the allowable level for unrestricted use of river water (U.S. Energy Research and Development Administration 1975a). (See additional discussion in Section B.1.1.)

The leachate springs at burial ground No. 4 are probably caused by precipitation surface runoff and groundwater entering the landfill trenches, moving downgradient through the refuse and spilling over the ends of the trenches at the downslope end surface because the permeability of the subsurface materials is not adequate to allow all of this water to move out in the subsurface.

At the time this report was drafted, it was hoped that burial grounds Nos. 5 and 6 would be constructed so that infiltration would be lower and that less surface water would enter the trenches. Therefore, the leachate leaving the trenches was expected to remain in the subsurface. Since that time, the Panel has learned that springs have developed at burial ground No. 5.

A.7.1.8 Hydrogeologic Monitoring Monitoring wells have been installed around burial grounds Nos. 4, 5 and 6 and will be sampled periodically. These wells sample the top of the zone of saturation, however, and, if there is a vertical component of groundwater flow beneath the site, may miss that part of the leachate plume that moves downward.

A.7.2 History

Historically, a variety of systems has been used for the land burial of solid low-level radioactive waste. Early in the operation of ORNL, the Solid Waste Storage Areas (SWSA) Nos. 1 and 2 were small and were located in Bethel Valley at the main ORNL site. Wastes were dumped into trenches and backfilled. These areas used about 2.02 hectares (5 acres) and were closed in 1946. No records were kept of quantity or kind of solid waste. In fact, it is quite possible that fluid combustibles were also buried. It is also likely that little fissionable material was in the waste because of the extreme effort made at that time to conserve it. In all probability there was only a small amount of radioactive waste present as solids because the operations did not then include isotope separation and concentration. These areas are now covered and no longer set aside by fences. No evidence of the movement of radioactive waste has been developed (U.S. Energy and Development Administration 1975a: 3), but we are not aware of any monitoring procedures presently being used at these locations.

Solid waste storage area No. 3 (SWSA No. 3), also in Bethel Valley, was opened in 1946 and was operated in the same manner as were SWSA Nos. 1 and 2 until it was closed in 1951. Laboratory debris and heavily contaminated equipment were buried in trenches. Lightly contaminated equipment, and that considered salvageable or too bulky to bury, were stored within the fenced area on the surface. The trenches were backfilled, but many of the surface-stored items still dotted the site in 1971. About 2.8 hectares (7 acres) were used. After this site was opened, it was found to be underlain with rock and excavations were difficult. There is little information on the volume or character of the materials buried. It remains fenced because of the on-surface storage of contaminated material and equipment.

Solid waste storage area No. 4 (SWSA No. 4) was located in the Melton Valley, because it was considered that its Conasauga shale was ideal for the burial of solid radioactive waste. Little was done in detailed geologic and hydrologic before-use studies of the site. As a result, it turned out that parts of the surface are close to the water table. The area is no longer operational, having been opened for use in 1951 and closed in 1959, but it remains a problem.

SWSA No. 4 is still the major contributor of strontium-90 to White Oak Creek in the Clinch River watershed. This landfill had an improper design. The fill is now a terrace that is low in the valley of a tributary of White Oak Creek, and by its construction is presently a poorly surface-drained landform. A valley slope rises almost 200 feet above the landfill on its north side. Low-order drainageways descend the hillslope into the landfill. Thus, the fill is not only a catchment for precipitation, but also must receive runoff from the hillslope and drainageways and groundwater from upslope. As a result, the water table is at or near the surface in low areas of SWSA No. 4, and most of the landfill is saturated.

This landfill is environmentally unsuitable or unacceptable to the Panel, and a clean-up would be desirable. The uncontaminated water from upslope might possibly be intercepted by a tile line on the north side and diverted around the fill to White Oak Creek. The surface of the fill might be shaped by adding landfill or soil to accentuate runoff (but not permit erosion); with proper cover, it could decrease the infiltration of precipitation.

Draining trenches by installation of sump wells and pumping fluid to an evaporation plant would be costly and perhaps radiologically hazardous. The exact location of trenches and an inventory of material in the trenches are not known with any certainty.

Prior to any decision on the modification of the drainage system of SWSA No. 4, the ground- and surface-water systems relating to the hillslope terrain on the north side of the landfill must be studied and quantified. Design of, or renovation of, the drainage system must be based on a careful analysis of the system.

Another problem of ORNL landfills is the "bathtub effect" at SWSA No. 5. The buried trench fills with water that spills over the lower end of the trench, causing seepage of radioactive water. Trenches were dug with their long axes downslope and paralleling the hydraulic gradient of the water table. If the long axis of the trench paralleled the hill-slope contours and crossed the hydraulic gradient, the "bathtub effect" could have been reduced.

Some attempts to segregate beta-gamma radioactive waste from alpha-particle-emitter waste were started. In some cases the latter type of waste was covered with concrete prior to backfilling. The area used was 9.3 hectares (23 acres). It is now seeded with grass and fenced, with warning signs indicating that the posted area is radioactive. Records were kept but were destroyed by a fire in 1961 along with early records for SWSA No. 5.

Solid waste storage area No. 5 (SWSA No. 5) was developed as a result of the difficulties encountered at the previous sites. The area is not stated but is probably about 30 hectares (75 acres). Much more care was taken in its selection. The site chosen has gentle relief for ease of operations and freedom from flooding. The surface is essentially free of erosion by runoff of rainwater. The soil is easily excavated by heavy equipment and the walls of deep cuts will stand. The haul to the site is reasonably short along limited-access roads. It is a great improvement over earlier burial grounds.

It is anticipated that there will be need for the burial of about 3,000 cubic meters (125,000 cubic feet) per annum for the next 10 years at ORNL. Because of this, a tract of 27.5 hectares (68 acres) has been selected and designated SWSA No. 6. The criteria for its selection were the same as for SWSA No. 5. This area is now being used for the "non-retrievable" trenches and auger hole storage of radioactive waste as at SWSA No. 5.

A.7.3 Current Experience

A.7.3.1 Operational Experience At ORNL, the solid radioactive waste is generated in a number of ways and forms. The most bulky, and least contaminated, is laboratory refuse. It consists of animal carcasses, animal waste, glassware, rubber and synthetic rubber goods, paper, rags, and a miscellany of items either known, or suspected to be, contaminated with radioactive materials. Another source of lesser volume comes from a variety of chemical and physical research and development activities. There is also the usual array of discarded equipment, machinery, tools, tanks, valves, and pipes that are no longer needed or are so radioactive as to preclude successful or economic decontamination. Finally, there is soil, concrete flooring, and building materials contaminated by spills or leaks.

During the period 1955 to 1963, the ORNL was the Southern Regional Storage Area for solid waste, so about 28,000 cubic meters (100,000 cubic feet) of solid radioactive waste was derived from numerous sources of research and operational waste sent to ORNL for land burial. The variety, character, and even the amount, of radioactive waste acquired in this way is unknown.

ORNL classifies locally generated radioactive waste intended for burial as follows:

The fissile-alpha waste (corresponding to transuranium waste as defined by AEC IAD 0511-21) is the solid waste that exceeds a concentration of "10 microcuries of alpha particle activity per kilogram of waste associated with fissionable isotopes." This category includes primarily americium, curium, and plutonium, as well as some uranium-255. This material must be handled so as to permit retrieval within 20 years. The problem of criticality is of concern and must be considered before burial. These materials originate primarily in the transuranium-processing facility and in fuel-reprocessing research and development operations. Beta-gamma-emitting nuclides are often included with these nuclides, and, in the very heavy elements, spontaneous fission often occurs with the production of neutrons. Certain beryllium isotopes or deuterium, when exposed to sufficiently high energy photons, will emit photo-neutrons. These special situations all create unique problems and demand special methods for the handling of the fissile-alpha waste.

The fissile non-alpha waste (in contrast to that just described) is solid waste that contains 1 gram or more of non-alpha-particle-emitting fissionable material (uranium-235), regardless of concentration, or more than 35.7 grams per cubic meter (1 gram per cubic foot) of the same material regardless of quantity.

Sources for this waste include various metallurgical operations and other analytical and research and development operations. The object in handling this waste is to prevent criticality during or after burial. It is not a direct radiation hazard.

General radwaste consists of all solid radioactive waste intended for burial and not included in the above categories. Generally this waste can be considered to contain beta-gamma radioactivity and possibly non-fissile alpha-particle activity, e.g., from polonium, thorium, radium, or uranium-238. It originates in many places within and without the ORNL and comes from a wide range of physical, chemical, biological and medical research, and research and development activities located at the ORNL facility. It is the predominant bulk of the material intended for land burial. If the radiation intensity at the surface of the package is less than 200 millirads per hour, it is categorized as "low-level radwaste"; above that dose rate, it is "high-level radwaste." Different handling procedures are then utilized during the waste management operations.

The volume of waste buried at this site since the fire in 1961 is about 87,500 cubic meters (3.1 million cubic feet) in an area of 7.45 hectares (18.4 acres).

Transuranium and uranium-contaminated waste buried at ORNL before 1974 amount to about 685 cubic meters (24,200 cubic feet) and fissionable-material-contaminated waste amounted to about 200 cubic meters (7,100 cubic feet). Not all of the transuranium waste can be considered reasonably retrievable.

Fissile alpha-particle-emitting waste (corresponding to transuranium waste) is solid waste having alpha-particle radioactivity in excess of 10 microcuries per kilogram (10 nanocuries per gram), originating from fissionable isotopes. This kind of waste, when accompanied by high levels of beta-gamma or neutron emission, is packaged at the point of origin in reinforced concrete casks. These casks are available in three wall thicknesses--11, 15, and 30 centimeters (4.5, 6, and 12 inches). The loaded casks are transported from their point of origin by tractor trailers and are placed into trenches, which are backfilled. Records are kept of the locations and contents of each trench.

In some cases, fissile alpha-particle-emitting materials are stored in auger holes lined with stainless steel. The holes may vary in diameter--normally 20, 25, 30, or 76 centimeters (8, 10, 12, or 30 inches). Liners for these holes are rolled from 16-gauge 304 stainless steel, seam-welded, and with the bottoms welded in. All welds are dye checked. These holes are used to store radioactive waste contained in stainless steel 114- or 210-liter (30- or 55-gallon) drums, or in other suitable cylindrical containers. The holes are spaced no closer than 1 meter (3 feet) to each other, edge to edge.

After each cylinder is placed in a hole, a quantity of sand is placed on top for shielding purposes. The holes are provided with a concrete collar at the ground surface and capped with a stainless steel cap. If necessary for shielding, a stepped concrete plug is inserted in the top of the hole under the cap. When the hole is filled, it is plugged with a concrete plug. Each hole is provided with a metal tag for identification, and records are kept of the contents of each hole.

In cases where the radiation reading at the surface of the drums is less than 200 millirads per hour, the fissile-alpha-particle-emitting materials have been stored either in black iron or stainless steel drums or mild steel boxes above ground in a building specially designed for this purpose. This building is a semiopen corrugated metal structure designed for the specific purpose of temporary storage of this material, until such time as a suitable method of retrievable storage is developed. All drums so stored are identified by a metal tag, which provides information on the contents of the drum, and all of the pertinent information is recorded. This backlog and currently generated transuranium waste will be stored in specially constructed underground concrete vaults.

Criticality control of ORNL materials is accomplished by imposition of restrictions given in the following table, which specifies the maximum quantity of fissionable material permitted in each type of container. ("Fissionable material" means uranium-255, uranium-235, or plutonium-239.) Very small quantities of transuranium isotopes may be present, some of which are fissionable. Criticality restrictions are listed below.

Container Type	Maximum Permissible Fissionable Material (in grams per container)
114-liter (30-gallon) drum	20
210-liter (55-gallon) drum	36
Concrete cask (thin wall)	200
Intermediate cask (intermediate wall)	200
Concrete cask (thick wall)	96

These restrictions are consistent with the requirement that the concentration of fissionable materials shall not exceed 180 grams per cubic meter (5 grams per cubic foot), because, at that level, an infinite array of such containers has a neutron multiplication constant well below unity. In any case, where the amount of fissionable material to be stored exceeds 1 gram, it is necessary for the originator of the waste to obtain prior approval from the ORNL Criticality Safety Review Committee. Under certain circumstances this committee may, after consideration, modify the tabulated requirements for individual packages.

Fission non-alpha-particle-emitter waste, as previously described, is that which contains 1 gram or more of essentially non-alpha-particle-emitting fissionable material (almost exclusively uranium-235), regardless of concentration, or which contains more than 1 gram per cubic foot of the same material, regardless of quantity. The uranium-235, uncontaminated with fissile-alpha nuclides, is normally stored in unlined auger holes. Criticality restrictions apply here as well. The contents of these auger holes are logged and records are maintained. When filled, the holes are capped with concrete and a record kept of the location and contents. The restrictions on the amount of fissionable material that may be placed in a single container are the same as those given above.

A.7.3.2 Monitoring Experience The presence of leachate springs rising from SWSA No. 4 indicates that water is moving through the solid waste and carrying contaminants away from the disposal site. Work to date (U.S. Energy Research and Development Administration 1975a) indicates that this discharge does not have an appreciably adverse effect on the environment away from the vicinity of the burial ground. Work is continuing in order to confirm these findings.

A.8 SAVANNAH RIVER PLANT, AIKEN, SOUTH CAROLINA

(Operated for ERDA by E. I. DuPont de Nemours and Company, Inc.)

A.8.1 Nature of the Site

A.8.1.1 Location The Savannah River Plant (SRP) is in Aiken and Barnwell counties in South Carolina and consists of approximately 760 square kilometers (300 square miles) bounded on the southwest by the Savannah River and centered approximately 40 kilometers (25 miles) southeast of Augusta, Georgia (DuPont de Nemours [E. I.] and Company 1973b: 13).

A.8.1.2 Topography The Savannah River Plant is near the inner western edge of the Atlantic Coastal Plain physiographic province, at about 150 meters (500 feet) above mean sea level.) The topography is rolling and has a local relief of up to 75 meters (250 feet). Almost all of the site is drained by tributaries of the Savannah River and no part is very far from a continuously flowing stream.

A.8.1.3 Geology The area is underlain by a sequence of unconsolidated and partly consolidated sedimentary strata above the Precambrian basement. The unconsolidated sediments form a wedge-shaped mass that increases in thickness towards the southeast (U.S. Geological Survey 1967a: 11).

Immediately overlying the basement rocks is the Tuscaloosa Formation, which is 150 to 185 meters (500 to 600 feet) thick. This formation consists of sand and clay and contains several prolific water-bearing beds. Above this unit are approximately 100 meters (350 feet) of compact clays, sand, and sandy clays, with a few beds of clay and sand (in upward succession: Ellenton, Congaree, McBean, and Barnwell formations).

A.8.1.4 Tectonics The Savannah River Plant is located in an area where moderate damage might occur from earthquakes, according to earthquake predictions by the U.S. Coast and Geodetic Survey. On the basis of three centuries of recorded history of earthquakes, an earthquake above the intensity of VII (Modified Mercalli) would not be expected at the Savannah River Plant (DuPont de Nemours [E. I.] and Company 1973a: 93).

A.8.1.5 Climate The climate in the Savannah River area is relatively temperate with mild winters and long summers. This area, while subject to continental influences, is protected by the Blue Ridge Mountains from the more vigorous winters prevailing in the Tennessee Valley.

The average Augusta winter temperature is 8°C (48°F), the average summer temperature is 27°C (80°F), and the annual average is 19°C (65°F).

The average annual rainfall at the Savannah River Plant is 1,200 millimeters (47 inches) for the years 1952 through 1972. Rainfall is usually greatest in March and least in November. Snowfall and freezing rain are infrequent during the winter months in the Savannah River Plant area and any snow that does fall does not cover the ground for more than a few days.

Thirty-eight tornadoes caused damage in South Carolina in the 272 years of record, with an average frequency of one every 7 years. The Savannah River Plant is in an area where occasional tornadoes are to be expected. During the 21-year history of the Savannah River Plant, there has been no tornado damage to any production or support facility; however, there have been several unconfirmed sighting of tornadoes in unpopulated areas (Dupont de Nemours [E. I.] and Company 1973b: 65, 71, 86, 90, and 92).

A.8.1.6 Hydrogeology Almost all of the Savannah River Plant site is drained by tributaries of the Savannah River. Each of the tributaries is fed by small streams, and therefore no location on the site is very far from continuously flowing streams. In addition to the flowing streams, surface water is held in over 50 artificial impoundments, covering a total of over 1,200 hectares (3,000 acres).

The Tuscaloosa Formation is the principal aquifer in the Savannah River Plant area and is under artesian pressure over much of the area. The aquifer is recharged predominantly in the high areas around Aiken, South Carolina. Water movement in the aquifer at the plant site is towards the piezometric low along the Savannah River downstream from Augusta. Outcrop areas along the Savannah River and deeply incised stream valleys near the Savannah River Plant site are generally areas of discharge. The units above the Tuscaloosa yield only small to moderate groundwater supplies to wells. These formations are recharged in the topographically higher regions of the Savannah River Plant and discharge into the major drainageways on the Savannah River Plant site. Some water also discharges to the Savannah River and some migrates downdip to discharge by upward vertical leakage to overlying formations (DuPont de Nemours [E. I.] and Company 1973b: 23, 37, and 38).

A.8.1.7 Hydrogeology of Burial Sites for Solid Waste Originally, approximately 34 hectares (83 acres) located near the center of the plant between two chemical separations areas served as the burial ground. Subsequently, this was expanded to about 77 hectares (190 acres). It is situated between two tributaries of the Savannah River, Upper Three Runs Creek on the north and Four Mile Creek on the south. Surface relief in the burial ground is low with a maximum difference in elevation of 6.6 meters (22 feet). No flowing streams cross the area. Annual rainfall is 1,140 to 1,300 millimeters (45 to 50 inches). Surface runoff is through three drainage ditches. Underlying sediments consist of sandy clay and clay beds with a predominance of sandy clays. The depth of these unconsolidated deposits above the hard metamorphic basement rocks ranges from 270 to 300 meters (900 to 1,000 feet). The average depth of the water table in the burial area is 12 meters (40 feet). There are also some small water-saturated zones, usually not more than 60 or 90 meters (200 or 300 feet) in extent, perched above the normal water table on supporting clay beds (Fenimore 1964: 229, 230).

Groundwater movement is complex because of great variations in permeability. In general, water moves slowly away from the groundwater divide and then at an accelerating rate down gradient to outcrop at the spring swamps and beds of the two streams. Drainage from the burial ground and seepage basins is to Four Mile Creek (DuPont de Nemours [E. I.] and Company 1973b: 41).

Infiltration into the burial trenches probably moves downward through the trenches to the zone of saturation and then through the local flow systems to discharge into the valleys of Upper Three Runs Creek and Four Mile Creek. The base of this local flow system has not been defined, and some of this infiltration may move into a larger flow system. There is some evidence of perched water in the base of the burial trenches, but it is not known whether this perching is the result of increased infiltration through the top of the trenches or because of the formation of a permeability barrier along the sides and base of the trenches and base when it was excavated. Studies of the movement of groundwater and contaminants are outlined in the section on current research (see Section C.6.2).

A.8.1.8 Hydrogeologic Monitoring Monitoring of groundwater is done in 13 boreholes, 22 trench wells, and 42 grid wells within the burial ground and in 14 peripheral permanent wells. To date, tritium has not migrated in groundwater significantly beyond the landfill boundaries. Additional monitoring is done to establish the distribution of radioactive materials in the trenches. Radioactivity has not been detected more than 3 meters (10 feet) below the bottoms of the trenches. Surface waters are monitored in the tributary creeks of the Savannah River and in the river.

A.8.2 Current Experience

The major radionuclides that are buried or stored in many forms at the Savannah River plant include the following:

Tritium	2,900,000 curies
Cobalt-60	150,000 curies
Strontium-90	4,000 curies
Cesium-137	4,000 curies
Plutonium-238	309,000 curies
Plutonium-239	1,000 curies
Curium-244	40,000 curies

About 85 percent of the total buried radioactive waste contains tritium. Some of the tritium and most of the plutonium-238 have come from other operations. Most of the tritium comes from local programs and is contained in large masses of lithium-aluminum alloy melts, within steel liners from extraction crucibles. These have been buried without other containment. The release of tritium (as HTO or tritiated water) from these items by soil interaction is a slow process.

About 11,300 cubic meters (400,000 cubic feet) of alpha-particle-emitting waste were buried before 1965 and about an equal volume since then. The earlier burials were not encapsulated in concrete; they contain about 200 curies of plutonium-239. Since 1965, there have been some low-level alpha disposals without encapsulation, but the location of these burials is well known and trial exhumations have been undertaken.

A development program is being conducted at SRP to improve the accuracy of the current assay of radioactivity in the burial ground. The program will have two objectives: (1) to develop methods to make a rapid and accurate assay or estimate of the contents of waste packages, and (2) to develop methods to obtain an estimate of the radionuclide distribution in existing trenches. The program will include the development and evaluation of detection devices for quantifying the contents of a package prior to storage or disposal in the burial ground, development of sampling and measurement techniques to produce accurate inventories of existing trenches, and development of improved recording and monitoring methods for burial ground operations.

Development of operational methods is needed to improve the safety of the burial ground operation further by minimizing environmental effects from radionuclide migration and uptake by vegetation. Present programs to evaluate burial ground covers must determine the need for shallow-rooted vegetation at the burial sites. Improved trench design and placement configurations to minimize infiltration of water, leaching, and vegetative uptake will be developed.

Two phases are envisioned for the future of the burial ground at SRP. The first phase is during the life of the SRP and for a limited time following plant shutdown. During this time, custody and normal surveillance of the burial ground will continue. The second phase follows for an indefinite period and requires minimal surveillance and control of the site. Appropriate measures to prepare the burial ground for minimal surveillance will need to be incorporated into future burial ground operation programs. Transuranium waste presently encapsulated in concrete containers, and possibly much of the unencapsulated transuranium waste, would be removed.

APPENDIX

B BURIAL SITES

B.1 GENERAL COMMENTS

When compared with present burial ground practices, early practices were poorly organized and rather careless. Poor records were kept and little is now known about the type and exact location of the materials that were buried. Sites were chosen for convenience, rather than for environmental safety, which resulted in a large number of small disposal sites located close to the origins of the particular waste. However, these practices may not have created as serious a problem as one might expect. At the Oak Ridge National Laboratory, only small amounts of fissionable material were available, so it was assiduously recovered and little was likely to have reached the burial grounds (F. T. Binford and J. R. Gissel 1974, unpublished report: A Review of Solid Radioactive Waste Storage at Oak Ridge National Laboratory; Union Carbide Company, Oak Ridge, Tennessee).

B.2 HYDROGEOLOGIC RESEARCH

Most of the hydrogeologic and water quality investigations that have been, and still are being, carried out at the various ERDA sites are directed towards obtaining an understanding of the hazards involved in liquid waste disposal operations. Fortunately, this information is usually applicable to the solid low-level waste disposal operations as well.

B.2.1 Older Investigations

The general geology and hydrogeology of the various ERDA land burial sites have been described in some detail. Monitoring points have been installed in underlying aquifers and nearby surface waters and data have been collected from these installations for many years. As noted previously, much of this work has been directed toward monitoring the movement of contaminants from disposal sites for liquid waste. However, there have been some investigations specifically directed toward the solid low-level radioactive waste disposal operations.

At the Savannah River Plant solid waste disposal site, these studies were primarily concerned with arriving at an estimate of the time taken for contaminants to be transported from the disposal trenches downward to the top of the zone of saturation, and then with the groundwater to nearby streams.

At the Oak Ridge National Laboratory, leachate was observed on the surface at SWSA No. 4 and investigations have been made of the environmental effects of this leachate. Detectable strontium-90 in the groundwater from burial ground SWSA No. 4 increases the amount of strontium-90 in White Oak Creek, which flows into the Clinch River. However, offsite release of radioactive material into the Clinch River is 1 percent of the allowable level for unrestricted use of river water (U.S. Energy Research and Development Administration 1975a).

At the Idaho National Engineering Laboratory, a rather detailed study has been made of infiltration through the INEL solid waste burial grounds, and at Los Alamos and Hanford, investigations have been directed to studies of infiltration and moisture in the vadose zone.

B.2.2 Current Investigations

In many respects, the current investigations carried out at these sites are extensions of past investigations. At the Savannah River Plant, the monitoring system is being upgraded and leaching studies are being conducted in test lysimeters.

The monitoring system at the Oak Ridge National Laboratory is also being upgraded and efforts are being directed towards determining how the leachate problems which were encountered at SWSA No. 4 can be avoided in the new burial grounds.

At the Idaho National Engineering Laboratory, work is continuing on investigations of infiltration through the burial ground, and at Hanford lysimeter studies are continuing on the mechanisms involved in moisture transport in the vadose zone.

Future work at the Savannah River Plant and the Oak Ridge National Laboratory will include the construction of predictive mathematical models that will describe the migration of contaminants from the low-level solid waste disposal sites.

APPENDIX

C HYDROGEOLOGICAL RESEARCH: A REVIEW OF THE PERTINENT TECHNICAL LITERATURE

A considerable amount of research has been done at the various ERDA sites and elsewhere on hydrogeologic problems related to solid waste disposal operations. The following sections present a brief outline of some of this research with comments on the principal findings. Some of the more general papers related to solid waste disposal may be of particular interest and are also noted.

C.1 GENERAL PAPERS

A general seminar, sponsored by the AEC, was held in Cincinnati, Ohio, in 1955 to discuss the sanitary engineering aspects of the atomic energy industry. The report of this conference (U.S. Atomic Energy Commission 1956: TID-7517) includes papers on the geology and hydrology of the various waste disposal sites as well as discussions of the disposal practices current at that time.

Morgan, Jamieson, and Stevenson (U.S. Atomic Energy Commission 1962) edited a series of papers presented at a conference on ground disposal of radioactive waste held at Chalk River, Canada, in 1961. These two volumes include papers describing the hydrology and geology at various waste disposal facilities and some discussion of waste disposal practices. Another paper at the same meeting (Christenson and Thomas 1962) discussed the general problems of the movement of plutonium through soil, using Los Alamos tuff as an example.

A National Academy of Sciences-National Research Council Committee on Geologic Aspects of Waste Disposal (an earlier counterpart of this present Panel and Committee) prepared a report for the U.S. Atomic Energy Commission in 1966 (National Research Council 1966). This is a critical review of the U.S. Atomic Energy Commission's research and development activities with respect to radioactive waste disposal in the ground, including a discussion of the safety of the then current and proposed operations, insofar as they were affected by geologic considerations.

In 1973, an International Conference on Land for Waste Management was held in Ottawa, Canada. A paper presented at that meeting (Cherry et al. 1974) discussed radioactive waste disposal sites and practices in Canada and outlined the hydrogeologic characteristics that would be significant for intermediate-term burial sites and long-term burial sites.

Winograd (1974) discussed the hydrogeologic aspects of radioactive waste burial in the arid zone and related them to burial of waste in other hydrogeologic environments.

Papadopulos and Winograd (U.S. Environmental Protection Agency 1974b) reviewed the general problems of burial of low-level radioactive waste, with particular emphasis on the hydrogeological and hydrochemical data required to evaluate properly the suitability of specific sites. A description of the Maxey Flats (Kentucky) burial site for low-level waste was given for illustration.

C.2 LOS ALAMOS SCIENTIFIC LABORATORY

A series of papers have described the results of investigations of the movement of water and radioactive contaminants from the waste disposal facilities at Los Alamos (Abrahams et al. 1961; U.S. Geological Survey 1963a, 1975b). These works indicated that moisture beneath liquid waste disposal sites has moved to a depth of 28 meters (92 feet), while plutonium was detected at least 8.5 meters (28 feet) below the disposal pits. This penetration took place along fissures. These studies also indicated that, where the normal soil is undisturbed, there would be little or no recharge of water to the zone of saturation as a result of precipitation on the surface of the plateau.

Purtymun and Kennedy (University of California 1971) summarized the existing work on the geology and hydrogeology of the waste disposal sites and described the various waste disposal areas at Los Alamos.

Baltz, Abrahams, and Purtymun (U.S. Geological Survey 1963b) wrote a preliminary report primarily concerned with the movement of surface and groundwater in Mortandad Canyon, with emphasis on the stream of liquid waste that discharges into this canyon.

Purtymun (University of California 1973) reported on the underground movement of tritium from shafts used for the storage of solid wastes at Los Alamos. This investigation was accomplished by analyzing the moisture distilled from tuff samples that were recovered from borings adjacent to the storage shafts. It was found that tritium had moved laterally from the shafts along the contact between ashflows and through joints for a distance of 32 meters (105 feet) in 4 years. This report led to the spraying of the walls of the disposal shafts with asphalt.

C.3 IDAHO NATIONAL ENGINEERING LABORATORY (formerly the National Reactor Testing Station [NRTS])

C.3.1 Papers

Barraclough et al. (U.S. Geological Survey 1967b) reported in detail on the programs measuring water quality and monitoring water levels at the National Reactor Testing Station (NRTS) and on the hydrogeology of the site. Their paper gave special emphasis to the sites for disposal of liquid waste, but the disposal sites for solid waste were not discussed.

Schmalz (U.S. Atomic Energy Commission 1972) discussed the distribution of radionuclides in the soil mantle as a result of the disposal of wastes at the NRTS. He included the results of studies of the hydrogeology of the burial grounds for solid waste. It was concluded that rainfall at the NRTS is insufficient to saturate the soil except where ponding occurs and that radioactive contaminants could not move an appreciable distance from the disposal site for solid waste. There was evidence that infiltration from snowmelt on frozen ground does occur. Field evidence indicated that, even with ponding, radioactive nuclides would not move a significant distance from the disposal trenches.

Robertson (U.S. Geological Survey 1974a) describes the mathematical model that has been developed for the NRTS to predict the effect of present operations for disposal of liquid waste and of various future practices for disposal of waste.

Robertson et al. (U.S. Geological Survey 1974b) wrote a long report describing the meteorology, surface and groundwater hydrology, and geology of the NRTS area, as well as the geochemistry of the groundwater and the effects to date of the various operations for disposal of liquid waste. The report included a description of the monitoring wells on the site, their construction and the procedures used to obtain representative samples, and a list of selected references. This publication is concerned only with the operations at the NRTS for the disposal of liquid waste.

Several current papers related to the geological conditions and migrations of radionuclides from waste disposal areas at the INEL are those by Nace et al. (U.S. Geological Survey 1975b) and by Barraclough, Robertson, and Janzer (see citation to their unpublished paper in A.5.1.8).

C.3.2 Current Research

Current hydrogeological research at the INEL includes a detailed study of the burial ground for solid waste. The sediments beneath the burial grounds to the top of the zone of saturation have been described in detail, with particular emphasis being placed on the distribution and properties of thin fine-textured sedimentary units interbedded within the basalt. The infiltration of precipitation and surface water through the burial grounds is also being investigated.

Results to date suggest that water is perched on sediment layers in the vadose zone and that there may have been some leaching and downward movement of radionuclides from the buried solid waste. These investigations are continuing.

C.4 HANFORD WORKS

C.4.1 Papers

A detailed environmental statement (U.S. Energy Research and Development Administration 1975b: ERDA-1538) on the waste management operations has recently appeared in final form. It includes a comprehensive description of the hydrogeology of the Hanford area. A considerable amount of information is given on the operations for disposal of liquid waste, including maps showing the distribution of contaminants from liquid waste in the underlying groundwater. Management operations for solid waste are described; however, there is little or no information on studies of the hydrogeology of the solid waste disposal sites themselves.

Isaacson et al. (Atlantic Richfield Hanford Company 1974) reported on their study of the transport processes for soil moisture in the arid soils at the Hanford site. Use was made of the distribution of fallout tritium, temperature, water potentials, and soil moisture changes in lysimeters. Tentative conclusions were reached that annual precipitation does not reach the water table but is removed by evaporation and evapotranspiration during the summer.

LaSala and Doty (U.S. Geological Survey 1975c) have recently discussed the hydrology of the burial grounds for solid waste at the Hanford site.

C.4.2 Current Research

Current research directly related to solid waste disposal operations at Hanford consists of a continuation of the soil moisture studies described by Isaacson (Atlantic Richfield Hanford Company 1974).

C.5 OAK RIDGE NATIONAL LABORATORY

C.5.1 Papers

Stockdale (U.S. Atomic Energy Commission 1951) reported the hydrogeologic conditions at the Oak Ridge National Laboratory as they related to operations for the disposal of both solid and liquid waste. Fifty-one borings were drilled, 1,400 meters (4,500 feet) of core were taken, and pressure tests were run on one well, to define permeable zones. Based on these data, a map of the top of the zone of saturation was constructed. The report recommended that monitoring of the waste disposal operations be continued and that future burial of contaminated solid waste should be in the Conasauga shale belt of Melton Valley.

Two reports, known as ORNL I and ORNL II, were prepared respectively by Cowser, Lomenick, and McMaster and by Lomenick and Cowser (U.S. Atomic Energy Commission 1961a, 1961b). ORNL I described previous hydrogeologic work at Oak Ridge and discussed the criteria employed in selecting a site, the findings of site evaluations, the design and preliminary findings of new trench construction and the conclusions relative to expected improvements in a new burial ground. This includes information on pressure testing of deep wells, a discussion of old burial procedures, and the result of a study of a burial trench with asphalt lining and an asphalt cover. ORNL II is primarily concerned with conditions at burial ground No. 4 and monitoring of groundwater at that site.

Duguid (U.S. Energy Research and Development Administration 1975a) has presented the result of a study of the movement of radioactive contaminants from burial ground No. 4 and estimates based on reconnaissance studies of contaminant movement from the other burial grounds at Oak Ridge. The report concluded that off-site radioactive releases into the Clinch River are less than 1 percent of the upper limit allowable for unrestricted use of the water by a population. It discussed methods of reducing this discharge to yet lower levels and of the construction of a mathematical model to assist in predicting future discharges.

A review of the hydrological conditions at the ORNL burial grounds has been prepared by Webster (David A. Webster 1976, unpublished report: A Review of the Burial Grounds and Related Hydrology at Oak Ridge National Laboratory, Tennessee; U.S. Geological Survey).

C.5.2 Current Research

Current research at ORNL consists of a continuation of the hydrogeologic investigation described in Duguid (U.S. Energy Research and Development Administration 1975a). This includes the construction of a mathematical model and monitoring of burial ground No. 4 and other active burial grounds.

C.6 SAVANNAH RIVER PLANT

C.6.1 Papers

Fenimore (1964) discussed the experience in land burial of solid radioactive waste over a 10-year period. He described the hydrogeologic research that had been carried out up to 1964 at the burial grounds for solid wastes at the SRP. The paper also includes the results of a field study in which samples of the materials beneath the buried waste were obtained and tracer studies were conducted to determine flow velocities in the vadose zone and below the top of the zone of saturation. Based on these studies, it was concluded that there is little possiblity of buried radioactive waste migrating to public areas.

Hawkins and Horton (1967) described the results of a study of the effectiveness of bentonite as a surface seal to reduce the infiltration of precipitation into the burial trenches. The authors concluded that bentonite could be used for this purpose.

Siple (U.S. Geological Survey 1967a) presented a comprehensive description of hydrogeologic conditions in the vicinity of the Savannah River Plant. He noted that although radioactive materials were detected in the groundwater in monitoring wells, the disposal of radioactive waste has not seriously affected the quality of the groundwater in the area discussed in the report.

Fenimore (1968) briefly described the disposal operations for solid waste, low-level liquid waste, and high-level liquid waste at the Savannah River Plant site. His report discussed the general site hydrogeology, injection tests, point dilution tests, and soil moisture studies that had been carried out in the past to determine the velocity with which water moves away from the burial sites to its point of discharge. It also included discusssion of then current work and of future work to be carried out in the area. The report concluded that the solid waste burial practices that were then being used at the Savannah River site were safe.

C.6.2 Current Research

Current hydrogeologic research at the Savannah River Plant includes the construction of a three-dimensional mathematical model to predict waste transport, studies of the leaching of tritium from melts in a test lysimeter, and the installation of a number of new well points to expand the groundwater monitoring program and to gather additional information to use with the predictive model.

APPENDIX

D BIBLIOGRAPHY OF PUBLISHED REPORTS OF THE COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT

Copies of all seven reports in this list are on file at the Library of the National Academy of Sciences. They may be obtained on request through interlibrary loan. If necessary, photocopies of out-of-print reports can be made by the NAS Library, but will be charged for at the current service rate. The Library is located at 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

1. Interim Storage of Solidified High-Level Radioactive Wastes, Committee on Radioactive Waste Management, Panel on Engineered Storage, National Research Council, Washington, D.C., 1975. Available from Printing and Publishing Office, National Academy of Sciences, ISBN 0-309-02400-5; viii + 82 pp., paperbound, $8.50 (see NOTE 1).
2. Transportation of High-Level Nuclear Wastes, Committee on Radioactive Waste Management, Panel on Transportation of Radioactive Wastes, National Research Council, November, 1974. (Published by the U.S. Energy Research and Development Administration as ERDA-8, UC-71, as a letter report. 4 pp. (Out-of-print, to be available from NTIS) (see NOTE 2).
3. An Evaluation of the Concept of Storing Radioactive Wastes in Bedrock below the Savannah River Plant Site, Committee on Radioactive Waste Management, Panel on Bedrock Disposal, National Academy of Sciences, Washington, D.C., 1972. Available from Printing and Publishing Office, National Academy of Sciences, ISBN 0-309-02035-2; viii + 88 pp., paperbound, $3.25 (see NOTE 1).

4. Radioactive Waste Management: An Interim Report of the Committee on Radioactive Waste Management, National Academy of Sciences-National Research Council, February 17, 1970. (A 9-page letter report, out-of-print, to be available from NTIS) (see NOTE 2).
5. Disposal of Solid Radioactive Wastes in Bedded Salt Deposits, Committee on Radioactive Waste Management, Panel on Disposal in Salt Mines, November 1970. 28 pp. Published by U.S. Government Printing Office, Washington, D.C. (out-of-print, to be available from NTIS) (see NOTE 2).
6. Report to the Division of Reactor Development and Technology, U.S. Atomic Energy Commission, NAS-NRC Committee on Geologic Aspects of Radioactive Waste Disposal, May 1966. National Research Council, May 1966, 92 pp. (Out-of-print, to be available from NTIS) (see NOTE 2).
7. The Disposal of Radioactive Waste on Land, Report of the NRC Committee on Waste Disposal of the Division of Earth Sciences, National Academy of Sciences-National Research Council, Washington, D.C., September 1957. Publication 519. 126 pp. (Out-of-print, to be available from NTIS) (see NOTE 2).

NOTE 1: Printing and Publishing Office, National Academy of Sciences. 2101 Constitution Ave., N.W., Washington, D.C. 20418 (orders for books must be prepaid).

NOTE 2: NTIS is the National Technical Information Service, operated by the U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

APPENDIX

E

June 9, 1970

Honorable Frank Church
United States Senate

Dear Frank:

Since receiving your letter of May 1, 1970, Commissioner Thompson and members of the AEC staff have had the opportunity to meet with you and your assistants to discuss waste management activities at the National Reactor Testing Station.

Among matters discussed were some of the recommendations of the recently issued report of the Federal Water Quality Administration. As you were informed, AEC is not in accord with a number of the FWQA report findings and recommendations. We have recently completed detailed comments on that report and have furnished you a copy.

As you know, the AEC has long supported an active research and development program on methods for managing and disposing of radioactive wastes. This program has resulted in the development of several effective processes for reducing the volume of high-level liquid wastes and converting them into solid forms suitable for shipment and long-term storage. Just about a year ago the Commission announced a proposed policy that would require high-level wastes from commercial fuel reprocessing plants to be solidified on-site and to be shipped to a Federal repository for storage. Such a policy is possible because of the successful technological developments resulting from AEC's R&D program. That program has also included extensive R&D on the best methods for long-term storage of solid wastes. After years of study and experiment, the Commission has concluded that a salt mine would provide effective long-term isolation of solid radioactive wastes from fresh water aquifers and from the biosphere. In FY 1972, AEC will seek authority to establish a demonstration radioactive waste repository in salt which will store both high-level solid wastes from fuel reprocessing plants and low-level alpha particle emitting wastes (alpha wastes) such as the Pu-contaminated wastes from the Rocky Flats Plant.

When the salt mine repository is fully operative, AEC plans to store not only currently generated alpha wastes but also to excavate, process and ship such wastes which are being temporarily stored at NRTS. A number of years will be required to complete the transfer of such wastes from NRTS which we hope to start within the decade. The proposed transfer of such wastes is not because of any near-term hazard to the aquifer which underlies NRTS, the public or NRTS employees. Transferral to an underground repository appears to be the best method for attaining the very long-term isolation of these wastes from the biosphere.

We will keep you fully informed as our waste management plans continue to develop and will be happy to discuss them with you.

Cordially,

[signed]
GLENN T. SEABORG, Chairman
United States Atomic Energy Commission
Washington, D.C.

APPENDIX F

May 31, 1973

Dr. Cyrus Klingsberg
National Research Council
2101 Constitution Avenue
Washington, D. C. 20418

Dear Dr. Klingsberg:

The Atomic Energy Commission (AEC) requests the Committee on Radioactive Waste Management (CRWM) to advise the AEC concerning its practices of ground burial of solid wastes contaminated with radioactivity. This is in accord with our agreement at the September 26, 1972, meeting of the CRWM.

Where observed, undesirable existing conditions and practices should be identified. Appropriate corrective actions should also be identified, such as changes in current burial practices, changes in conditioning of materials for burial (including special packaging), and special treatment of the ground prior to waste burial.

Appropriate briefings, plant tours, or site visits will be arranged by AEC staff. All available reports on the subject will be provided to the CRWM, or its designated panel, should the Committee decide to establish a panel for this review.

Sincerely,

[signed]
FRANK K. PITTMAN, Director
Division of Waste Management and Transportation
United States Atomic Energy Commission
Washington, D.C.

cc: Dr. John C. Frye, Chairman, CRWM

REFERENCES

Abrahams, J. H., Jr., J. E. Weir, Jr., and W. D. Purtymun (1961) Distribution of moisture in soil and near-surface tuff on the Pajarito Plateau, Los Alamos County, New Mexico, pp. D-142-D-145. In Short Papers in Geologic and Hydrologic Sciences. U.S. Geological Survey Professional Paper 424-C, No. 559. Washington, D.C.: U.S. Government Printing Office.

Atlantic Richfield Hanford Company (1974) Soil Moisture Transport in Arid Site Vadose Zones, by R. E. Isaacson, L. E. Brownell, R. W. Nelson, and E. I. Roetman. Report ARH-SA-169. Prepared under U.S. Atomic Energy Commission contract AT(45-1)-2130 for presentation at the International Atomic Energy Agency Symposium on Isotope Techniques in Groundwater Hydrology, March 11-15, 1974, Vienna, Austria. Springfield, Va.: National Technical Information Service. 25 pp.

Cherry, J. A., G. E. Grisak, and R. E. Jackson (1974) Hydrogeologic factors in shallow subsurface radioactive waste management in Canada, pp. 131-146. In Proceedings of the International Conference on Land for Waste Management, Ottawa, Canada, October 1-3, 1973. Department of the Environment and the National Research Council of Canada. Ottawa: The Agricultural Institute of Canada. 27 pp.

Christenson, C. W. and R. G. Thomas (1962) Movement of plutonium through Los Alamos Tuff, pp. 248-281. In Ground Disposal of Radioactive Wastes, Second Conference Proceedings Held at Atomic Energy of Canada Lts., Chalk River, Canada, September 26-29, 1961, Book 10. U.S. Atomic Energy Commission Report TID-7628. Springfield, Va.: National Technical Information Service.

De Laguna, W. (1956), Some geologic factors that influence disposal of radioactive wastes into pits, pp. 426-456. In Sanitary Engineering Aspects of the Atomic Energy Industry. U.S. Atomic Energy Commission Report TID-7517 (Pt. Ia). Springfield, Va.: National Technical Information Service.

DuPont de Nemours (E. I.) and Company (1973a) Development Program for Long Term Storage of Savannah River Plant Solid Radioactive Wastes, E. L. Albenesius to C. H. Ice (August 21, 1973). Savannah River Laboratory Report DPST-73-352. Aiken, S.C. [Now out-of-print.]

DuPont de Nemours (E. I.) and Company (1973b) The Savannah River Plant Site, by T. M. Langley and W. L. Marter. Prepared under U.S. Atomic Energy Commission contract AT(07-2)-1. Report DP-1323. Springfield, Va.: National Technical Information Service. 160 pp.

Fenimore, J. W. (1964) Land burial of solid radioactive waste during a 10-year period. Health Physics 10:229-236.

Fenimore, J. W. (1968) Tracing soil moisture and ground water flow at the Savannah River plant. Presented at the Clemson University Council on Hydrology Conference on Hydrology in Water Resources Management, March 28-29, 1968. Prepared under U.S. Atomic Energy Commission contract AT(07-2)-1. Savannah River Laboratory Report DP-MS-68-23. Aiken, S.C.: E. I. duPont de Nemours and Company, Inc. 10 pp.

Hawkins, R. H. and J. H. Horton (1967) Bentonite as a protective cover for buried radioactive waste. Health Physics 13:287-292.

Idaho Nuclear Corporation (1968) ICPP Fissionable Isotope Monitor, Status Report, by G. L. Booman, J. P. Morgan, W. J. Maeck, H. R. Beard, F. L. Lisman, and J. E. Rein. Report IN-1211. Prepared under U.S. Atomic Energy Commission contract AT(10-1)-1230. Springfield, Va.: National Technical Information Service. 51 pp.

National Research Council (1966) Report to the Division of Reactor Development and Technology, U.S. Atomic Energy Commission. Committee on Geologic Aspects of Radioactive Waste Disposal. Washington, D.C.: National Academy of Sciences. 92 pp.

Soule, H. F. (1970) Radiation standards and radioactive waste. In Proceedings, Fifth Annual Midyear Topical Symposium, Vol. III, pp. 656-666. Idaho Falls, Idaho: Eastern Idaho Chapter, Health Physics Society.

Theis, C. V. (1956) A review of the groundwater geology of the major waste-producing sites, pp.116-131. In Sanitary Engineering Aspects of the Atomic Energy Industry. U.S. Atomic Energy Commission Report TID-7517 (Pt. Ia). Springfield, Va.: National Technical Information Service.

U.S. Atomic Energy Commission (1951) Geologic Conditions at the Oak Ridge National Laboratory (X-10) Area Relevant to the Disposal of Radioactive Waste, by P. B. Stockdale. Oak Ridge Operations Office Report ORD-58. Oak Ridge, Tenn.: Technical Information Service. 87 pp.

U.S. Atomic Energy Commission (1956) Sanitary Engineering Aspects of the Atomic Energy Industry. A seminar sponsored by the U.S. Atomic Energy Commission and the Public Health Service, held at the Robert A. Taft Center, Engineering, Cincinnati, Ohio, December 6-9, 1955. U.S. Atomic Energy Commission Report TID-7517 (Pt. Ia). Springfield, Va.: National Technical Information Service.

U.S. Atomic Energy Commission (1961a) Status Report on Evaluation of Solid Waste Disposal at ORNL: I, by K. E. Cowser, T. F. Lomenick, and W. M. McMaster. Oak Ridge National Laboratory Report ORNL-3035. Prepared under contract W-7405-eng-26. Springfield, Va: National Technical Information Service. 38 pp.

U.S. Atomic Energy Commission (1961b) Status Report on the Evaluation of Solid Waste Disposal at ORNL: II, by T. F. Lomenick and K. E. Cowser. Oak Ridge National Laboratory Report ORNL-3182. Prepared under contract W-7405-eng-26. Springfield, Va.: National Technical Information Service. 38 pp.

U.S. Atomic Energy Commission (1962) Ground Disposal of Radioactive Wastes, Second Conference Proceedings Held at Atomic Energy of Canada Lts., Chalk River, Canada, September 26-29, 1961, edited by J. M. Morgan, Jr., D. K. Jamieson, and J. D. Stevenson. U.S. Atomic Energy Commission Report TID-7628. Springfield, Va: National Technical Information Service. 2 Vol.

U.S. Atomic Energy Commission (1968) Design and Evaluation of a Delayed-Neutron Leached-Hull Monitor, by J. E. Strain, W. J. Ross, G. A. West, and J. W. Landry. Oak Ridge National Laboratory Report ORNL-4135. Oak Ridge, Tenn.

U.S. Atomic Energy Commission (1970) Sorting of Solid Wastes, by P. D. Fairchild, J. L. Lawless, P. Ruhter, H. F. Soule, J. A. Teal, and M. M. Thorpe. A Report to the General Manager's Task Force on AEC Operational Radioactive Waste Management. Washington, D.C. [Now out-of-print]

U.S. Atomic Energy Commission (1972) Radionuclide Distribution in Soil Mantle of the Lithosphere as a

Consequence of Waste Disposal at the National Reactor Testing Station, compiled by B. L. Schmalz. Idaho Operations Office Report IDO-10049. Springfield, Va.: National Technical Information Service. 80 pp.

U.S. Atomic Energy Commission (1973a) Plan for the management of AEC-Generated Radioactive Wastes, by F. K. Pittman. Division of Waste Management and Transportation. Report WASH-1202 (73) UC-70. Washington, D.C. 48 pp.

U.S. Atomic Energy Commission (1973b) Transuranium Solid Waste Development Facility, Los Alamos Scientific Laboratory, New Mexico (Environmental Statement). Report WASH-1527. Washington, D.C. 77 pp.

U.S. Atomic Energy Commission (1974a) Management of Commercial High-Level and Transuranium-Contaminated Radioactive Waste (Draft Environmental Statement). Report WASH-1539. Washington, D.C. [Now out-of-print]

U.S. Atomic Energy Commission (1974b) Projected Shipments of Special Nuclear Material and Wastes by the Nuclear Power Industry, by J. O. Blomeke, C. W. McKee, and O. R. Salmon. Oak Ridge National Laboratory Report ORNL-TM-4631. Prepared under U.S. Atomic Energy Commission contract W-7405-eng-26. Springfield, Va.: National Technical Information Service.

U.S. Atomic Energy Commission (1974c) Radioactive Waste Facilities, Oak Ridge National Laboratory, Oak Ridge, Tennessee (Environmental Statement). Report WASH-1532. Washington, D.C. 48 pp. + appendix. (Preliminary draft)

U.S. Atomic Energy Commission (1974d) Transuranic waste disposal: exemption and continuing regulatory authority (10CFR Part 150). Federal Register 39(178):32922-32923.

U.S. Energy Research and Development Administration (1975a) Status Report of Radioactivity Movement from Burial Grounds in Melton and Bethel Valleys, by J. O. Duguid. Oak Ridge National Laboratory Report ORNL-5017. Prepared under contract W-7405-eng-26. Springfield, Va.: National Technical Information Service. 70 pp.

U.S. Energy Research and Development Administration (1975b) Waste Management Operations, Hanford Reservation, Richland, Washington (Final Environmental Statement). Report ERDA-1538. Washington, D.C. 2 Vols.

U.S. Environmental Protection Agency (1974a) Radiation Data and Reports. Vol. 15, No. 12. Report PB-240091. Springfield, Va.: National Technical Information Service.

U.S. Environmental Protection Agency (1974b) Storage of Low-Level Radioactive Wastes in the Ground: Hydrogeologic and Hydrochemical Factors with an Appendix on The Maxey Flats, Kentucky, Radioactive Waste Storage Site: Current Knowledge and Data Needs for a Quantitative Hydrogeologic Evaluation, by S. S. Papadopulos and I. J. Winograd. Open-File Report 74-344. Washington, D.C. 49 pp. Also published as USEPA Report 520/3-74-009 (1974).

U.S. Geological Survey (1963a) Physical Properties of and Movement of Water in the Bandelier Tuff, Los Alamos and Santa Fe Counties, New Mexico, by J. H. Abrahams, Jr. Unpublished Report. Prepared in cooperation with the U.S. Atomic Energy Commission and Los Alamos Scientific Laboratory of the University of California. Washington, D.C.: U.S. Department of the Interior. 84 pp.

U.S. Geological Survey (1963b) Preliminary Report on the Geology and Hydrology of the Mortandad Canyon near Los Alamos, New Mexico, with Reference to the Disposal of Liquid Low Level Radioactive Waste, by E. H. Baltz, J. H. Abrahams, Jr., and W. D. Purtymun. Open-File Report, March. Prepared in cooperation with the U.S. Atomic Energy Commission and the Los Alamos Scientific Laboratory, University of California. Washington, D.C.: U.S. Department of the Interior. 105 pp.

U.S. Geological Survey (1967a) Geology and Ground Water of the Savannah River Plant and Vicinity, South Carolina, by G. E. Siple. Water-Supply Paper 1841. Prepared in cooperation with the U.S. Atomic Energy Commission. Washington, D.C.: U.S. Government Printing Office. 113 pp.

U.S. Geological Survey (1967b) Hydrology of the National Reactor Testing Station, Idaho, 1966, by J. T. Barraclough, W. E. Teasdale, J. B. Robertson, and R. G. Jensen. U.S. Atomic Energy Commission Report IDO-22049. Springfield, Va.: National Technical Information Service. 95 pp.

U.S. Geological Survey (1974a) Digital Modeling of Radioactive Chemical Waste Transport in the Snake River Plain Aquifer at the National Reactor Testing Station, Idaho, by J. B. Robertson. U.S. Atomic Energy Commission Report IDO-22054. Springfield, Va.: National Technical Information Service. 41 pp.

U.S. Geological Survey (1974b) The Influence of Liquid Waste Disposal on the Geochemistry of Water at the National Reactor Testing Station, Idaho, 1952-1970, by J. B. Robertson, R. Shoen, and J. T. Barraclough U.S. Atomic Energy Commission Report ID-22053. Springfield, Va.: National Technical Information Service. 231 pp.

U.S. Geological Survey (1975a) Evaluation of Monitoring of Radioactive Solid Waste Burial Sites at Los Alamos, New Mexico, by T. E. Kelly. Open-File Report 75-406. Washington, D.C.: U.S. Department of the Interior.
U.S. Geological Survey (1975b) Generalized Geologic Framework of the National Reactor Testing Station, Idaho, by R. L. Nace, P. T. Voegeli, J. R. Jones, and M. Deutsch; ed. by S. Subitzky. Professional Paper 725-B. Prepared in cooperation with the U.S. Atomic Energy Commission. Washington, D.C.: U.S. Government Printing Office. 53 pp.
U.S. Geological Survey (1975c) Hydrology of Radioactive Solid Waste Burial Grounds at the Hanford Reservation, Washington, by A. M. LaSala, Jr., and G. C. Doty. Open-File Report 75-625. Washington, D.C.: U.S. Department of the Interior.
University of California (1971) Geology and Hydrology of Mesita del Buey, by W. D. Purtymun and W. R. Kennedy. Los Alamos Scientific Laboratory Report LA-4660. Prepared under U.S. Atomic Energy Commission contract W-7405-eng-36. Springfield, Va.; National Technical Information Service.
University of California (1973) Underground Movement of Tritium from Solid-Waste Storage Shafts, by W. D. Purtymun. Los Alamos Scientific Laboratory Report LA-5286-MS. Springfield, Va.: National Technical Information Service.
Winograd, I. J. (1974) Radioactive waste storage in the arid zone. EOS, Transactions of the American Geophysical Union 55(10):884-894.

BIBLIOGRAPHIC ADDENDUM (July 29, 1976)

Several recent publications have appeared after this report was written, but before editing was completed. These publications were not read by the Panel or cited in the report, but are listed here for their relevance to the body of the report.

Committee on Government Operations, 94th Congress, Second Session (1976) Low-level Radioactive Waste Disposal. Hearings, February 23, March 12, and April 6, 1976. Washington, D.C.: U.S. Government Printing Office.
Committee on Government Operations, 94th Congress, Second Session (1976) 26th Report. Low-level Nuclear Waste Disposal. June 30, 1976. Washington, D.C.: U.S. Government Printing Office.
Comptroller General of the United States (1976) Report to the Congress. Improvements Needed in the Land

Disposal of Radioactive Wastes--A Problem of Centuries. Washington, D.C.

Joint Committee on Atomic Energy, Congress of the United States, 94th Congress, First Session (1975) Storage and Disposal of Radioactive Waste. Hearings, November 19, 1975. Washington, D.C.: U.S. Government Printing Office.

U.S. Energy Research and Development Administration (1976) Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle, Report ERDA-76-43 (UC-70). Washington, D.C. 5 Vols.

GLOSSARY

actinide series: The series of elements beginning with actinium, element No. 89, and continuing through lawrencium, element No. 103, which together occupy one position in the periodic table. The series includes uranium, element No. 92, and all the man-made transuranium elements. The group is also referred to as the "actinides."

activation: The process of making a material radioactive by bombardment with neutrons, protons, or other nuclear particles. Also called radioactivation.

activity: A measure of the rate at which a material is emitting nuclear radiations; usually given in terms of the number of nuclear disintegrations occurring in a given quantity of material over a unit of time; the standard unit of activity is the curie (Ci), which is equal to 3.7×10^{10} disintegrations per second.

air sampling: The collection and analysis of samples of air to measure its radioactivity or to detect the presence of radioactive substances.

alpha waste: Waste material that is contaminated by radionuclides that emit alpha particles, particularly the transuranium elements.

aquifer: A subsurface formation or geological unit containing sufficient saturated permeable material to yield significant quantities of water.

cladding waste: Fuel rods in most nuclear reactors today are made up of fissionable materials clad in a protective alloy sheathing that is relatively resistant to radiation and the physical and chemical conditions that prevail in a reactor core. The spent fuel rods, after removal from the reactor and storage to permit radioactive decay of the short-lived fission products, are removed and in certain fuel cycle systems are chopped up, and the residues of the fissionable materials are leached out chemically. The remaining residues, principally the now radioactivated cladding material (zirconium alloys, etc.) and insoluble residues of nuclear fuel, fission products, and transuranium nuclides, are left behind as cladding waste, which is a special category of transuranium radioactive waste.

critical: The condition in which a material is undergoing nuclear fission at a self-sustaining rate; the critical mass of a material is the amount that will self-sustain nuclear fission when placed in an optimum arrangement in its present form; the minimum critical mass is the amount of a fissile isotope that will self-sustain nuclear fission when placed in optimum conditions.

curie (Ci): A unit of radioactivity defined as the amount of a radioactive material that has an activity of 3.7×10^{10} disintegrations per second (d/s); millicurie (mCi) = 10^{-3} curies; microcurie (μCi) = 10^{-6} curies; nanocurie (nCi) = 19^{-9} curies; picocurie (pCi) = 10^{-12} curies; femtocurie (fCi) = 10^{-15} curies.

decommissioning: The process of removing a facility or area from operation and decontaminating and/or disposing of it or placing it in a condition of standby with appropriate controls and safeguards.

decontamination: The selective removal of radioactive material from a surface or from within another material.

disposal: The planned release or placement of waste in a manner that precludes recovery.

engineered storage: The storage of radioactive wastes, usually in suitable sealed containers, into any of a variety of structures especially designed to protect them from water and weather and to help keep them from leakage to the biosphere by accident or sabotage. They may also provide for extracting heat of radioactive decay from the waste.

environmental surveillance: A program to monitor the impact on the surrounding region of the discharges from the industrial operations.

fertile material: A material, not itself fissionable by thermal neutrons, that can be converted into a fissile material by irradiation in a reactor. There are two basic fertile materials, uranium-238 and thorium-232. When these fertile materials capture neutrons, they are partially converted into fissile plutonium-239 and uranium-255, respectively.

fissile material: While sometimes used as a synonym for fissionable material, this term has also acquired a more restricted meaning, namely, any material fissionable by neutrons of all energies, including (and especially) thermal (slow) neutrons as well as fast neutrons; for example, uranium-235 and plutonium-239.
fission: The splitting of a heavy nucleus into two approximately equal parts (which are nuclei of lighter elements), accompanied by the release of a relatively large amount of energy and generally one or more neutrons. Fission can occur spontaneously, but usually is caused by nuclear absorption of gamma rays, neutrons, or other particles.
fissionable material: Commonly used as a synonym for fissile material. The meaning of this term also has been extended to include material that can be fissioned by fast neutrons only, such as uranium-238. Used in reactor operations to mean fuel.
fission products: The nuclei (fission fragments) formed by the fission of heavy elements, plus the nuclides formed by the fission fragments' radioactive decay.
fuel (nuclear, reactor): Fissionable material used as the source of power when placed in a critical arrangement in a nuclear reactor.
fuel cycle: The complete series of steps involved in supplying fuel for nuclear power reactors. It includes mining, refining, the original fabrication of fuel elements, their use in a reactor, chemical processing to recover the fissionable material remaining in the spent fuel, reenrichment of the fuel material, refabrication into new fuel elements, and management of radioactive waste.
fuel separation (fuel reprocessing): Processing of irradiated (spent) nuclear reactor fuel to recover useful materials as separate products, usually separation into plutonium, uranium, and fission products.
groundwater: Water that exists or flows below the surface (within the zone of saturation).
half-life: The time in which half the atoms of a particular radioactive substance disintegrate to another nuclear form. Measured half-lives vary from millionths of a second to billions of years. After a period of time equal to 10 half-lives, the radioactivity of a radionuclide has decreased to 0.1 percent of its original level.
health physics: The science concerned with recognition, evaluation, and control of health hazards from ionizing and nuclear radiations.
high-efficiency particulate air filter (HEPA): An air filter capable of removing at least 99.97 percent of the particulate material in an air system.

high-level liquid waste: The aqueous waste resulting from the operation of the first-cycle extraction system, equivalent concentrated wastes from subsequent extraction cycles, or equivalent wastes from a process not using solvent extraction, in a facility for processing irradiated reactor fuels. This is the legal definition used by ERDA; another definition used at the ERDA Hanford Reservation for its waste, is: fluid materials, disposed of by storage in underground tanks that are contaminated by greater than 100 microcuries/milliliter of mixed fission products or more than 2 microcuries/milliliter of cesium-137, strontium-90, or long-lived alpha emitters.

hot spot: A surface area of higher-than-average radioactivity. Also a part of a fuel element surface that has become overheated.

intermediate-level liquid waste: Fluid materials, disposed as a result of Hanford operations, which contain from 5×10^{5} microcuries/milliliter to 100 microcuries/milliliter of mixed fission products, including less than 2 microcuries/milliliter of cesium-137, strontium-90, or long-lived alpha emitters.

ion exchange: A chemical process involving the reversible interchange of various ions between a solution and a solid material, usually a plastic or a resin. It is used to separate and purify chemicals, such as fission products, rare earths, in solution.

ionizing radiation: Any radiation displacing electrons from atoms or molecules, thereby producing ions. Examples: alpha, beta, and gamma radiation, short-wave ultraviolet light. Ionizing radiation may produce severe skin or tissue damage.

isotope: One of two or more atoms with the same atomic number (the same chemical element) but with different atomic weights. An equivalent statement is that the nuclei of isotopes have the same number of protons but different numbers of neutrons. Isotopes usually have very nearly the same chemical properties, but somewhat different physical properties.

licensed material: Source material, special nuclear material, or by-product material received, possessed, used, or transferred under a general or special license issued by the U.S. Energy Research and Development Administration or a state.

loess: A homogeneous, nonstratified, unindurated sediment, largely silt, deposited primarily by the wind.

long-lived isotope: A radioactive nuclide that decays at such a slow rate that a quantity of it will exist for an extended period, usually radionuclides whose half-life is greater than 3 years.

low-level liquid waste: Fluid materials that are contaminated by less than 5×10^{-5} microcuries/milliliter of mixed fission products.

man-rem: A unit used in health physics to compare the effects of different amounts of radiation on groups of people. It is obtained by multiplying the average dose equivalent to a given organ or tissue (measured in rems, which see) by the number of persons in that population.

nuclide: A species of atom having a specific mass, atomic number, and nuclear energy state. These factors determine the other properties of the element, including its radioactivity.

partitioning: The process of separating liquid waste into two or more fractions.

pH: A measure of the relative acidity or alkalinity of solution; a neutral solution has a pH of 7; acids have pH's of 7 to 1; bases have pH's of 7 to 14.

plutonium: A heavy, radioactive, man-made, metallic element with atomic number 94. Its most important isotope is fissionable plutonium-239, produced by neutron irradiation of uranium-238. It is used for reactor fuel and in weapons.

rad (acronym for radiation absorbed dose): The basic unit of absorbed dose of ionizing radiation. A dose of 1 rad means the absorption of 100 ergs of radiation energy per gram of absorbing material.

radiation: The emission and propagation of energy through matter or space by means of electromagnetic disturbances, which display both wave-like and particle-like behavior; in this context the "particles" are known as photons. Also, the energy so propagated. The term has been extended to include streams of fast-moving particles (alpha and beta particles, free neutrons, cosmic radiation, etc.). Nuclear radiation is that emitted from atomic nuclei in various nuclear reactions, including alpha, beta, and gamma radiation and neutrons.

radiation survey: Evaluation of an area or object with instruments in order to detect, identify, and quantify radioactive materials and radiation fields present.

radioactive contamination: Deposition of radioactive material in any place where it may harm persons, spoil experiments, or make products or equipment unsuitable or unsafe for some specific use. The presence of unwanted radioactive matter. Also radioactive material found on the walls of vessels in used-fuel processing plants, or radioactive material that has leaked into a reactor coolant. Often referred to only as contamination.

radioactivity (often shortened to "activity"): The spontaneous decay or disintegration of an unstable atomic nucleus, usually accompanied by the emission of ionizing radiation. The word radioactivity is often used to refer to radioactive materials or radioactive nuclides, but this usage is not, strictly speaking, correct. Radioactivity is a process, not a substance.

radioisotope: A radioactive isotope. An unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation. More than 1,300 natural and artificial radioisotopes have been identified.

radwaste: Waste materials that are contaminated with radioactive materials.

rem: A unit of measure for the dose of ionizing radiation that gives the same biological effect as 1 roentgen of X rays; 1 rem equals approximately 1 rad for X, gamma, or beta radiation.

roentgen (abbreviation r): A unit of exposure to ionizing radiation. It is that amount of gamma or X rays required to produce ions carrying 1 electrostatic unit of electrical charge (either positive or negative) in 1 cubic centimeter of dry air under standard conditions. Named after Wilhelm Roentgen, German scientist who discovered X rays in 1895.

seepage pond: An artificial body of surface water formed by discharge of liquid waste.

short-lived isotope: A radioactive nuclide that decays so rapidly that a given quantity is transformed into its daughter products within a short period (usually those with a half-life of days or less).

smear: A means of measuring loose surface contamination on an object by wiping it with paper, gauze, etc., and then measuring the disintegrations per minute on the wipe with an instrument.

solid wastes (radioactive): Either solid radioactive material or solid objects that contain radioactive material or bear radioactive surface contamination.

special nuclear material (SNM): Plutonium, uranium-255, uranium-235, or uranium enriched to a higher percentage than normal of the 255 or 235 isotopes.

surface contamination: The deposition and attachment of radioactive materials to a surface.

survey meter: Any portable radiation detection instrument especially adapted for surveying or inspecting an area to establish the existence and amount of radioactive material present.

tank farm: An installation of interconnected underground containers (tanks) for storage of high-level waste.

tank: A large metal container located underground for storage of liquid wastes.

tectonic: Of, pertaining to, or designating the rock structures resulting from deformation of the earth's crust.

transmissivity: A coefficient relating the volumetric flow through a unit width of groundwater to the driving force (hydraulic potential); a function of both the porous medium, fluid properties, and saturated thickness of the aquifer.

transuranium: Nuclides having an atomic number greater than that of uranium (i.e., greater than 92). The principal transuranium radionuclides of concern in radioactive waste management are tabulated below with their half-lives:

Nuclide	Half-Life (Years)	Principal Decay Modes
Neptunium-237	2,140,000	alpha
Plutonium-238	86	alpha, spontaneous fission
Plutonium-239	24,390	alpha, spontaneous fission
Plutonium-240	6,580	alpha, spontaneous fission
Plutonium-242	379,000	alpha
Americium-241	458	alpha
Americum-243	7,950	alpha
Curium-245	9,300	alpha
Curium-246	5,500	alpha, spontaneous fission

The transuranium nuclide produced in largest amounts is plutonium-239; americum-241 is also produced in significant amounts. One system of classification used at Oak Ridge includes uranium-255 (162,000 year half-life, alpha decay) among the transuranium isotopes, although strictly speaking this is not accurate.

uranium: A radioactive element with the atomic number 92 and, as found in natural ores, an average atomic weight of approximately 238. The two principal natural isotopes are uranium-235 (0.7 percent of natural uranium), which is fissionable, and uranium-238 (99.3 percent of natural uranium), which is fertile. Natural uranium also includes a minute amount of uranium-234. Uranium is the basic raw material of nuclear energy.

vadose zone: The unsaturated region of soil between the ground surface and the water table.

water table: Upper boundary of an unconfined aquifer surface below which saturated groundwater occurs; defined by the levels at which water stands in wells that barely penetrate the aquifer.