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STUDY OF SITING CRITERIA FOR DEVELOPMENT OF A LOW-LEVEL RADIOACTIVE WASTE FACILITY

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PREFACE

In January 1980, Lee Sherman Dreyfus, Governor of Wisconsin, under Executive Order No. 30, created an Ad Hoc Radiation Waste Disposal Committee. One of the major problems identified by the Committee was the disposal of low-level radioactive waste. In December 1980, Congress passed the Low-Level Radioactive Waste Policy Act. This act requires each state, individually or in compact with other states, to provide for the disposal of low-level radioactive waste produced within its boundaries. The Ad Hoc Committee determined that Wisconsin did not have the resources or the time that it would take to adequately study and develop criteria on what should and should not be considered in locating a low-level radioactive waste disposal facility. The Geological and Natural History Survey was requested to seek funding from the U.S. Department of Energy to conduct a study to identify the criteria which have historically been considered in evaluating potential sites for the installation of a radioactive waste disposal facility.

In September 1980, a grant was awarded to M. E. Ostrom and M. G. Mudrey, Jr. of the Geological and Natural History Survey to undertake such a study. Ms. Stefanie Brouwer and Mr. Joe C. Yelderman, Jr. were hired to undertake the data collection and presentation, and prepare a preliminary draft of their findings. Brouwer and Yelderman prepared this final report, and were materially assisted by the colleagues acknowledged below.

The study was intended to be general, with emphasis on concerns critical to the Midwest. An extensive literature search was conducted to determine what geotechnical and other criteria are necessary to assess potential sites for disposal of low-level radioactive waste. A total of 177 criteria are identified and verified by relevant quotations from the literature. The importance of each criteria, and its relationship to other critera are briefly discussed. A few conclusions have also been drawn and, in the process, certain unresolved issues have also been identified and discussed.

This report was prepared with the support of the U.S. Department of Energy (DOE) Grant No. DE-FG-07-80ID12184. However, any opinions, findings conclusions, or recommendations expressed herein are those of the authors and do not necessarily reflect the views of DOE.

October, 1981

M. E. Ostrom, Director
State Geologist

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Mr. Craig Nern of EG and G, Inc., Idaho Falls, and Ms. Cathy Fore of the Radiation Effects Information Center at Oak Ridge National Laboratory, assisted us frequently in collecting many of the references for the literature survey.

Finally, the clerical skills of Judith Reinemann, Elizabeth Jane Ellis, Connie Miller, and Patricia Rydz were essential to the compilation of the data base and the preparation of the report. Special thanks goes to Dona Ireland, who single-handedly and with good humor, typed the entire final draft.

CONTENTS

I. SUMMARY

The purpose of this study is to identify criteria that should be considered in evaluating sites for shallow land burial of low-level radioactive waste. The Ad Hoc Radiation Waste Disposal Committee appointed by Lee Sherman Dreyfus, Governor of the State of Wisconsin, requested that the Wisconsin Geological and Natural History Survey undertake the study. Funding was requested from and granted by the U.S. Department of Energy through the Idaho Falls Operations Office. The study is designed to be general, with emphasis on concerns critical to the Midwest. Under the grant, an extensive literature search was conducted to determine what technical and nontechnical criteria are necessary to assess potential sites for disposal of low-level radioactive waste. The criteria are grouped under seven headings: waste characteristics; natural site considerations; sites impact to the environment; process considerations; external hazards; complexity; and human considerations. A total of 177 criteria are identified and verified by the presentation of relevant quotations from the literature. The importance of each criterion and its relationship to other criteria is discussed and conclusions are drawn. The major conclusions from the study are:

(1) The primary concern for any low-level radioactive waste facility is the health and safety of the public. The major criteria for assessing this concern are hydrogeology, demography, and transportation.

(2) The primary goal of disposal is to protect human health and safety which cannot be assessed accurately using any individual criterion as a limiting factor. The cumulative effect of all criteria as they relate to each other in an overall system more accurately assesses site suitability.

(3) There is pressing need for a generally accepted legal definition of low-level radioactive waste that can be used in the evaluation of any particular site. Proposed Nuclear Regulatory Commission Rule 10 CFR 61 is an approach in this direction; however, the proposed rule has significant technical problems and has not been promulgated.

(4) There is a general lack of information on ecological criteria important to the evaluation of any individual site. Such criteria have been developed for other siting problems, such as mine development and power plant siting; however, these criteria have not been commonly applied to siting of low-level waste disposal facilities.

(5) The geotechnical aspects of siting appear well-defined and the resolution of these criteria manageable; however, the socio-political and institutional problems are poorly defined and no problem resolution mechanism currently exists.

(6) A more effective role for state and local government and the concerned public should be defined. Proposed Rule 10 CFR 61 is a first approach, but is clearly inadequate in the political and social context of some regions of the county which have strong traditions of local involvement in major decisions.

(7) Evaluation of any particular site must consider the mitigation of possible social and economic impacts that development of a disposal site would have on a host community and its residents.

II. INTRODUCTION

Low-level radioactive wastes received national attention in the fall of 1979 when the sites at Beatty, Nevada, and Hanford, Washington, temporarily closed, leaving only the site at Barnwell, South Carolina, to accept nonmilitary wastes. These events pointed out the escalating problem of low-level radioactive waste disposal. Since the 1950s, low-level radioactive wastes have been produced by commercial and institutional activities, mainly through the generation of electricity in nuclear power plants and in medical and research facilities. In recent years industrial users have added to the increasing volume of commercial wastes that require disposal. Reports by the U.S. Department of Energy indicate that more waste will be produced by the mid-1980s than the existing facilities will be able to accommodate.

The federal agencies with major responsibility in the area of radioactive waste disposal are the Nuclear Regulatory Commission, as regulator and overseer, and the U.S. Department of Energy, as the implementor of federal policy. In early 1980, the U.S. Department of Energy was assigned the task of preparing a national plan for the management of radioactive wastes. The resulting document for low-level radioactive waste (Managing Low-Level Radioactive Wastes, August, 1980) outlines the national issues and problems and presents recommendations for their resolution.

On December 22, 1980, Congress passed the Low-Level Radioactive Waste Policy Act (Public Law 96-573). This law mandates that each state is responsible for providing for the disposal either within or outside of the state, of commercially-generated low-level radioactive waste generated within its borders. It furthermore authorizes the formation of interstate compacts to provide for the establishment and operation of regional disposal facilities.

In early recognition of the radioactive waste disposal problem, Lee Sherman Dreyfus, Governor of the State of Wisconsin, established by Executive Order Number 30 on January 22, 1980, an executive Ad Hoc Radiation Waste Disposal Committee. Among other activities, the Ad Hoc Committee was directed to review the adequacy of present and pending state and federal legislation on radioactive waste disposal. In addition, the Ad Hoc Committee was further directed to develop procedures for the State to deal effectively with the disposal of low-level radioactive waste.

By May 1980, the Ad Hoc Committee had clearly identified the problem of low-level radioactive waste as one of critical significance. As a first step, the Ad Hoc Committee requested that an inventory be made by the Wisconsin Department of Health and Social Services to determine the volume of low-level radioactive waste produced within Wisconsin and shipped out of state for disposal (Wisconsin Low-Level Radioactive Waste Survey - 1979, October, 1980). The Ad Hoc Committee members also felt that an increased understanding of the technical aspects, including disposal options and health and environmental effects, was necessary in making recommendations related to low-level radioactive waste issues.

Inasmuch as both the National Governors' Association (Low-Level Waste: A Program for Action, August, 1980) and the U.S. Department of Energy (Managing Low-Level Radioactive Waste, August, 1980) had proposed that regional compacts be developed, a recommendation was advanced by the Ad Hoc Committee that the

U.S. Department of Energy be approached for funding with the objective of identifying and evaluating those criteria that would be used in developing such a regional facility.

A definite analysis of the criteria necessary for evaluating a low-level radioactive waste site does not exist. This is in part historical in that no facilities have been established in over ten years, although technical knowledge has continued to advance. Although documents from the Nuclear Regulatory Commission do exist that relate to facility siting, the draft document (Licensing Requirements for Land Disposal of Radioactive Wastes, 10 CFR Parts 2, 19, 20, 21, 30, 40, 51, 61, 70, 73 and 170) does not clearly identify the critical technical and nontechnical criteria that should be considered in evaluating a low-level radioactive waste disposal site. Moreover, recommendations developed by other states (notably Pennsylvania, Texas, Massachusetts, and North Carolina) do not address some concerns critical to Wisconsin and the Midwest. (See "References Cited".)

As an aid to better understand what siting criteria have been applied and to evaluate their effectiveness in siting, the Geological and Natural History Survey was requested by the Ad Hoc Committee to undertake a study to identify the criteria which must be considered in evaluating potential sites for a radioactive waste disposal facility. This criteria study includes considerations of geologic, hydrologic, environmental, demographic, geographic, topographic, climatic, economic, transportation, socio-political, legal-institutional, cultural, and land use factors involved in and related to such siting. The criteria study has been designed to be general, and was not intended to concentrate on any specific issue. The conclusions and recommendations herein presented should be useful in the identification and consideration of sites for disposal of low-level radioactive waste.

This report solely concerns the disposal of low-level radioactive solid waste in shallow land burial facilities. Other disposal methods are also available (for example, ocean disposal and deep burial); however, most authors consider shallow land burial as the safest, most effective disposal method for the present and future. Although some low-level radioactive wastes are in the form of liquids or gases, most disposal sites and techniques require the waste to be in a solid form for disposal by shallow land burial. Therefore, most of the literature on this topic concerns techniques for shallow land burial of solid radioactive waste. The following quotations support our decision to concentrate on this disposal method.

> "Low-level solid waste will continue to be disposed of by shallow land burial. Upgrading of shallow land burial practices for LLW will focus on implementation of improved technology, making operations subject to comprehensive criteria, and stabilization of sites that are no longer needed."
>
> U.S. DOE (March, 1980) p. 20

> "Although alternative methods may be developed for disposal or management of some low-level radioactive wastes, shallow land burial will probably remain a primary management method for these wastes for the next ten to twenty years."
>
> Meyer (1979) p. 637

"Shallow land burial is intended to provide a waste emplacement with low probability for the release of radionuclides to the environment, and to provide a barrier against encroachment on the waste by man or his activities. Additionally, the emplacement conditions are designed to ensure that a potential release cannot result in unacceptable radionuclide concentrations in man's environment."

Wheeler and Smith (1979) p. 13

This document consists of eleven sections: I. Summary; II. Introduction; III. Procedures; IV. Criteria Listing; V. Discussion; VI. Conclusions; VII. Recommendations; VIII. Verification; IX. Appendix; X. Glossary and XI. References Cited. In section eight, the criteria listed in outline form in section four are verified by the presentation of quotations from the literature regarding each criterion topic. A text paragraph, explaining the importance of each criterion and in some cases its relationship to other criterion, precede the chosen quotations.

III. PROCEDURES

In this study a detailed literature survey was conducted to determine the technical and nontechnical criteria needed to assess a site for low-level radioactive waste disposal. Before creating even a preliminary criteria list, it was necessary first to define the term "low-level radioactive waste." Although the Nuclear Regulatory Commission has developed their own official definition, the authors surveyed in the literature do not agree on a general definition (See Appendix). The definition of low-level radioactive waste varies from one author to another, has changed over time, and varies even within a particular agency or organization. Therefore, to make the criteria list applicable now and in the future, we chose to use the most comprehensive definition for low-level radioactive waste: low-level radioactive waste is any non-high-level radioactive waste (see definition of high-level radioactive waste in Glossary). Our decision to use this definition is based also on the fact that, in the past, operating low-level disposal sites have handled a wide variety of radioactive materials, including transuranic wastes.

Documents Reviewed

To develop the list of criteria, references relating to all aspects of the disposal of low-level radioactive waste were reviewed. The publication Low-Level Radioactive Waste Technology: A Selected, Annotated Bibliography published by Oak Ridge National Laboratory in 1980, served as the basis for the literature search. In addition, a customized computer search of the shallow land burial data base compiled by the Oak Ridge Lab was obtained. Information was acquired on the topics of the disposal of low-level radioactive waste, shallow land burial, deeper burial of high-level waste and hazardous waste disposal. The listing contains an abstract for each citation. Other pertinent documents were located through references in reviewed material.

The first documents reviewed were those that contained specific suggestions for siting criteria for low-level radioactive waste facilities. These included documents and reports from the Nuclear Regulatory Commission, the U.S. Department of Energy, the U.S. Environmental Protection Agency, and the National Governors' Association. State reports on low-level radioactive waste management and criteria were also reviewed early in the data-gathering period. These reports include documents from the states of Pennsylvania, Massachusetts, Texas, North Carolina, Illinois and Michigan. Documents concerning the more general aspects of low-level radioactive waste management were also studied at this time. From the bibliographies of these more general documents, we compiled a list of more specific reports and articles. The oldest document reviewed was published in 1957 (See Hess et al. in References Cited); the most recent documents reviewed were published in August, 1981 (See State Planning Council Reports in References Cited).

This report is solely a literature survey and as such does not contain any original research. The conclusions and recommendations are derived from the documents, reports, and articles that have been reviewed. The greatest attention was given to the topics that are of specific concern in the Midwest. Note for example, that the criterion "hydrology" is discussed in considerable detail; other criteria, for example "earthquakes" and "volcanoes", being of less relevance in the Midwest, were treated more superficially.

The reader will also note that the report appears to be weighted heavily on the side of technical criteria. The reason for this is that more research and documentation exist on the technical aspects of low-level radioactive waste siting and disposal. Moreover, much of the information on human concerns, for example legal-institutional, social, and economic criteria, came not from the area of radioactive waste siting and management, but from related areas (for example, the siting of large-scale energy related facilities). Aside from some studies done at the Hanford Reservation, existing low-level radioactive waste disposal sites have not been studied from the perspective of social, economic, legal-institutional and other human concerns. More work needs to be done on all of these important aspects of locating disposal sites for low-level radioactive waste.

The limits of this report are obvious. As with any literature survey, a cut-off date had to be established beyond which no further references would be incorporated into the data base. Given the project deadlines, the data collection phase ended on August 1, 1981. This allowed time for compilation of the "Verification" section, preparation of the text portions of the report, and production of the first draft copy for review purposes. This report will necessarily lose some of its value over time, for new articles documenting new research are being published all the time. However, it is unlikely that the list of criteria will change significantly over time. Some of the topics may be expanded as new information becomes available, but it is doubtful that many new categories will appear. Our objective has been to collect and evaluate for siting purposes the literature that is available currently.

Criteria Selection and Verification

To select the criteria for site evaluation, each reference was reviewed critically. From each reference, quotations were selected that pertained to one, two or several of the criteria from a preliminary list of criteria. These quotations were assembled with the criteria topic (or topics) to which the information pertains and the author, date, and page of the reference (see sample card below). This information became the data base, the tool used to compile the Verification section.

> Papadopulos and Winograd (1971) p. 7
>
> "The site should have sufficient depth to water table to permit all burial operations to occur above the water table, or as an alternative the site should be suitable for producing an adequate water-table depth by flow system manipulation."
>
> Depth to Water Table

There are 35 major criteria topics identified in this document. The number of subcategories for each topic was determined by both the importance of the criterion and the amount of information available in the literature. For example, the criterion "hydrology" is of great importance in the Midwest and has also received considerable attention in the literature. The reader will note that there are four category levels for this criterion, as shown below:

HYDROLOGY (category level 1)

Subsurface Hydrology (category level 2)

Groundwater Flow or Gradient (category level 3)

direction of flow (category level 4)

Many other criteria of importance were not subdivided in as detailed a manner as shown above. This is due to either a lack of information in the literature on that topic or from the unavailability of such information for our critical review in the time frame of the project. To aid the reader, important sentences, phrases and words in the quotations are underlined to give them emphasis. References for the quotations are given by the author's last name, the date of the publication, and the page on which the reference is found. Some references are given in an abbreviated form because of the length of the author's name: the Comptroller-General of the United States is referred to as "GOA"; the International Atomic Energy Agency is referred to as "IAEA"; the Organization for Economic Cooperation and Development is referred to as "OECD"; the Texas Energy and Natural Resources Advisory Council is referred to as "TENRAC"; and the National Governors' Association Task Force on Low-Level Radioactive Waste Disposal is referred to as the "National Governors' Assn." Reports on low-level radioactive waste management prepared by the various states are also referred to in abbreviated form: the "Massachusetts Rept.", the "Tennessee Rept.", the "Illinois Rept.", and the "North Carolina Rept." The "Massachusetts Rept." was written by the Massachusetts Advisory Council on Radiation Protection; the "Tennessee Rept." was written by the Tennessee Department of Public Health; the "North Carolina Rept." was written by the Governor's Task Force on Waste Management; and the "Illinois Rept." was written by the Ad Hoc Committee on Low-Level Radioactive Waste, Illinois Commission on Atomic Energy.

The criteria listed and verified in this report are topics that are stated clearly, although not always frequently, in the literature. Efficient use of space required that only portions of paragraphs or statements be used as quotations; however, care was taken to preserve the meaning of the quotation in its original context. We tried to include all criteria that are generally agreed upon by the authors in the literature. At times, however, references to critera were made in the literature in such an indirect manner that to quote them was impractical. Therefore, the list of criteria represent minimum support rather than maximum support of the criteria documented in the literature. It is possible that criteria that are not mentioned still may be important for thorough evaluation of potential sites. Certainly all the criteria listed in this report should be given due consideration when evaluating sites for low-level radioactive waste disposal.

IV. CRITERIA LIST

The goal of all the siting criteria listed below is to isolate low-level radioactive wastes from the biosphere to the degree that is obtainable considering social, technical, and economic factors. The key consideration in this isolation is to assure protection of human health and the environment. Isolation of low-level radioactive wastes is achieved by the use of geologic and engineering barriers at the disposal site, as well as institutional control of the wastes and the disposal site. The following quotations support this goal:

> "The Task Force believes that site selection criteria should ensure maximum protection for the public's health and safety and the environment."
> North Carolina Rept. (Jan., 1980) p. 44

> "The overall goal of EPA with respect to radioactive waste management is to minimize the adverse health impact to present and future generations as well as to minimize degradation of environmental quality."
> U.S. EPA (Feb., 1977) p. 1.3

> "In simple terms the objectives of radioactive waste management are:
>
> 1. To assure that populations are adequately protected in relation to their air, water, and food supplies.
> 2. To assure that individuals (intruders) who might somehow come in contact with the disposed materials are adequately protected."
>
> Lieberman and Forbes, Feb., 1977, p. 1-10

> "...<u>the ultimate goal of radioactive waste management is total isolation of wastes from the biosphere to the degree that this is achievable considering technical, economic, and social factors</u>. Control of the potential impact on humans is essential; however, it is not in itself a totally sufficient condition because of the trustee responsibility each generation has to succeeding ones. For this reason, it is also necessary to prevent any unnecessary contamination of the environment which is reasonably achievable even though human interactions with the wastes could not be presently predicted. From these considerations, the goal for control of radioactive wastes should be to prevent its introduction into the biosphere over its hazardous lifetime."
> U.S. EPA (Feb., 1978) p. 22

The following critera are listed under seven major headings: Waste Considerations; Natural Site Considerations; Site Impacts to the Environment; External Hazards; Process Considerations; Complexity; and Human Considerations. These groupings and the ordering of the criteria topics within them reflect the information found in the literature and not the opinions of the authors of this report. In keeping with the objective of this study, the organization of the criteria is not intended to rank or prioritize the criteria in order of importance.

Waste Considerations

WASTE CHARACTERISTICS

Persistence

Concentration

Toxicity

Waste Form or Packaging

Volume

Mobility in Water

Waste Solubility

Precipitation of Waste

Reactivity of the Waste

BURIAL TECHNIQUES

Depth of Burial

Methods of Excavation

Backfill, Cover or Overburden Material

Method of Filling the Hole or Plugging

Sealing

Decommissioning

RETRIEVABILITY

Natural Site Considerations

HOST MATERIAL

Thickness

Size

Shape

Geochemistry

Porosity

Permeability

Corrosivity

Mineral Surface Area

Rock and Soil Mechanics

GEOLOGY

Geologic Investigation of the Site

Geologic Investigation of the Region

Mineralogy

Clay Content

Grain Size

Sorption

Ion Exchange

Salinity

Solubility

Subsidence

Dissolution Voids

Caverns and Karst

Fractures and Joints

Faulting

Folding

Structural Stability

Excavation Characteristics

Landslides

Creep

GEOPHYSICS

Seismicity

Earthquakes

Volcanoes

Tectonics

SOILS

<u>Premeability</u>

<u>Infiltration</u>

TOPOGRAPHY

CLIMATE

<u>Precipitation</u>

<u>Evapotranspiration</u>

<u>Temperature</u>

<u>Wind</u>

Direction

Velocity

<u>Trends</u>

<u>Cycles</u>

<u>Extremes</u>

HYDROLOGY

<u>Regional Hydrology</u>

<u>Site Hydrology</u>

<u>Surface Hydrology</u>

<u>Subsurface Hydrology</u>

Depth to Water Table

Seasonal Variations in Water Table

Importance or Significance of Aquifer

Size of Aquifer

Transmissivity

Diffusion Coefficient

Storage Coefficient

Hydraulic Conductivity and Permeability

Dispersion and Dispersivity Coefficients

Distribution Coefficients

Aquifer Boundary Conditions

Recharge Areas

Discharge Areas

Location of Aquifers

Groundwater Flow or Gradient

- direction of flow
- rate of flow
- volume of flow
- ability to control flow
- predictions of future flow conditions

Chemistry of the Groundwater

FLOODS

Erosion Due to Floods

Surface Water Contamination from Floods

Ponding and Infiltration from Floods

Groundwater Changes from Floods

EROSION

Types

- Water Erosion
- Wind Erosion
- Mass Wasting
- Glacial Erosion
- Catastrophic Erosion

Rates of Erosion

Depths of Erosion

WEATHERING

Site Impacts to the Environment

LAND

WATER

NOISE

AIR

ESTHETIC, CULTURAL, NATURAL, AGRICULTURAL, HISTORICAL AND RECREATIONAL VALUES

BIOLOGY

Food Chains

Plant Uptake

Wetlands

External Hazards

HUMAN INTRUSION

ANIMAL INTRUSION

PLANT INTRUSION

METEORITE IMPACT

GLACIATION

Process Considerations

RISK ANALYSIS

MONITORING

MODELING

Complexity

Human Considerations

HUMAN HEALTH AND SAFETY

Environmental Monitoring

Long-Term Care

DEMOGRAPHIC CRITERIA

<u>Population Size, Density, and Distribution</u>

<u>Anticipated Demographic Patterns</u>

<u>Immigrants and their Effects on Local Population</u>

SOCIAL CRITERIA

<u>Public Education and Opinion</u>

<u>Public Involvement and Acceptance</u>

<u>Risk Assessment and Perception</u>

<u>Ethical Considerations</u>

<u>Impact Mitigation</u>

<u>Incentives and Benefits</u>

<u>Compensation and Liabilities</u>

<u>Change in Local Community</u>

LEGAL-INSTITUTIONAL CRITERIA

<u>Institutional Control</u>

<u>Federal Authority</u>

<u>State Authority</u>

<u>Local Authority</u>

Zoning and Land Use Authority

Emergency Preparedness Planning

<u>Land Ownership</u>

<u>Legislation</u>

<u>Regulations</u>

<u>Public Policy Formation</u>

<u>Political Issues and Regionalization</u>

<u>Decision-Making Process</u>

ECONOMIC CRITERIA

Cost to Plan, Construct, Operate, Maintain and Decommission a Site

Cost-Benefit Analysis

Labor Availability

Perpetual Care Funds

Socioeconomic Issues

GEOGRAPHIC AND LAND-USE CRITERIA

Future Land Use

Resource Potential

Irrigation

Buffer Zone Availability

Distance from Restricted Land Use

Present Land Use

Location

Accessibility

Population

Distance to Nearest Water Use

Availability of Construction Material

Past Land Use

Dams

TRANSPORTATION

V. DISCUSSION

In section eight of this report, the criteria identified through the literature survey are supported by selected quotations from the references. In an introductory statement or paragraph for each criteria topic, the importance of each criterion and its relationship to other criteria are stated. While the criteria are not intentionally ranked or prioritized in this report, certain criteria, combinations of criteria, and issues related to the use of the criteria have emerged as being particularly significant. The purpose of this section is to discuss these issues and relationships as the authors of this report view them and as they pertain to the siting of low-level radioactive waste facilities in the Midwest. These discussion topics will then form a basis for the conclusions and recommendations presented in the following sections. The topics discussed below include: waste classification; hydrology; dispersion; radionuclide migration; definition of low-level radioactive waste; site evaluation; co-location or co-burial; burrowing animals; social, political and institutional problems of siting; state, local, and citizen involvement in the decision-making process; social and economic impacts of siting a low-level radioactive waste facility.

Waste Classification

In any discussion of waste disposal, it is imperative that the nature of the waste be defined, in as much as this determines not only the technologies that can be used, but also the nature of the geologic environment that would be amenable for a disposal facility. Many authors suggest classifying radioactive waste to enable inventory procedures to be more effective and to allow sites to accept only the wastes suited for disposal at each particular site. During the preparation of this report, the U.S. Nuclear Regulatory Commission offered for comment a low-level radioactive waste classification system based on stability (Licensing Requirements for Land Disposal of Radioactive Waste, Federal Register, July 24, 1981). Other options on classification exist, as shown by the following references. The authors of this report feel that the classification parameters of persistence and hazard should also be considered (See "Recommendations" section, number 8). The question of classification will be answered ultimately by formal rules from the Nuclear Regulatory Commission.

> "Segregation of waste, by half-life, activity, and/or other characteristics may provide a net advantage."
>
> EPA (Apr., 1977) p. 2-98

> "A classification system based on total hazard is preferable to the other alternatives because it provides the best assessment of the environmental protection that is needed. Such a system would offer guidance on the isolation needed for each category of waste. It should be designed to assist generators in separating wastes into the appropriate categories for disposal."
>
> EG and G., Idaho, Inc. (1980) p. 21

> "Thus, there is particular concern for long-lived radionuclides, radionuclides with high radiotoxicity, and radionuclides with high potential mobility. Methods to verify the physical characteristics of waste receipts and procedures for remedial action are needed."
>
> Jacobs, Epler, and Rose (1980) p. 35

"Although water is considered to be the primary vehicle for radionuclide migration from shallow land-burial facilities, other pathways of importance need to be identified and their significance established.

An over all evaluation should be undertaken to establish priorities for further research and development related to radionuclide migration. The critical radionuclides in wastes should be identified on the basis of such factors as quantities, concentrations, radiotoxicity, environmental mobility, and persistence."

Jacobs, Epler, and Rose (1980) p. 43

"Waste Classification needs resolution. For example, the formalized rule to determine cut-off limits for transuranics is needed to verify or replace the 10 nCi/g criterion assumed."

Wheeler and Smith (1979) p. 40

"The National Low-Level Waste Management Program is developing a system of classification of wastes according to degree of hazard. Both radioactive and nonradioactive components of the waste will be incorporated in the hazards analysis."

Radioactive Waste Technology Newsletter (Jan.- Mar., 1981) p. 13

"The second recommended item relates to the categorization of 'other than high-level waste.' I have purposely ignored the term 'low-level' waste, since I do not believe that such a broad term is appropriate for the kind of waste we are discussing. I believe that 'other than high-level,' waste could be categorized into 'intermediate-level' and 'low-level' waste. For discussion purposes I suggest the following:

Intermediate-Level: All treated waste (e.g. solidified waste or ion exchange resins), high specific activity waste (e.g. one curie per cubic foot or greater), and long half-life waste (30 years or greater).

Low-Level: All other waste, with the exception of waste resulting from disturbing the earth, such as mill tailings that do not fall into the above category."

Hardin (1979) p. 834

"Uniform and specific criteria are urgently desirable for categorizing wastes in this regard, principally according to type, quantity, and persistence of critical constituents."

Piper (1969) p. 5

"The approach used by Cherry et al. of classifying burial sites for low-level waste as (1) intermediate term sites, suitable for wastes that decay to a safe level within several decades and for which protection is mainly provided by the engineered structure in which the waste is buried, and as (b) long-term sites for wastes with a longer life, which depend mainly on geohydrologic conditions for protection, appears to be a rational approach to the site evaluation problem."

DeBuchananne (1974) p. 357

"Waste material disposed at the proposed site shall be limited to carbon-14 or material (except 'special nuclear material') with a half-life of 100 years or less, including waste from nuclear power plants but excluding irradiated nuclear reactor fuel and high-level waste as defined by federal regulations.

TENRAC (1980) p. 5

"To ensure that the disposal site receives only those materials which can be effectively disposed by shallow land burial, a clear, restrictive subclass of LLW to be accepted at the site should be established."

TENRAC (1980) p. 6

"Radioactive waste problems are dynamic, complex, and varied. Therefore, there can be no one simple solution to all problems. The different solutions will have to be imaginative, working primarily within the constraints dictated by the hydrogeologic environment at each proposed disposal site. The major factor will be to determine what types of radioactive wastes can be contained by the proposed site for the period of time required to isolate them from the biosphere and hydrosphere."

DeBuchananne (1978) p. 12 and 13

"Examples of possible disposal options for low-level wastes are controlled landfills, shallow land burial, intermediate-depth burial, and geologic repositories designed for high-level wastes. While most low-level wastes can be satisfactorily isolated through shallow burial under 4 to 10 feet of soil, a small portion may require greater isolation. The recommended approach is to use all disposal options in association with a waste classification system that will allow the disposal method to match the hazard of the waste."

EG and G., Idaho, Inc. (1980)

Hydrology

Hydrology is considered by most investigators to be one of the most important factors for evaluating low-level radioactive waste disposal sites. The hydrology of a given area is dynamic and will not necessarily remain as it is originally characterized at the time of site evaluation. This concept is especially true of long-term conditions. The most probable reasons for such changes are climatic effects, engineering activities during disposal, and land-use changes. The long-term prediction of changes in the hydrologic regime is in its infancy, and in some cases no credible models exist for such forecasting. Although hydrology is a developed science, there are still some areas where significant questions remain. Particular examples of importance to siting of low-level radioactive waste facilities are: flow-through fractured media; dispersion characteristics at a field scale; and modeling and testing of complex, nonuniform flow systems. The following quotations illustrate some thoughts from the literature on these topics:

"A more elaborate total aquifer and radionuclide migration model for evaluating a specific radioactive waste facility is needed. Such a model should include considerations for fractured rock aquifers and interactions of the various radionuclides."

Staley et al. (1979)

"As noted earlier, the flow of solutes through fractured rocks is not yet adequately understood. All verified transport models assume intergranular flow in the aquifer. However, where flow occurs in a fractured media these models are not applicable. Sound theory relating flow in fractured media to that in intergranular flow is presently lacking and must be developed before meaningful field tests can be made."

DeBuchananne (1978) p. 11

"Long-term care requirements can continue site control measures, and provide a continuing check on the containment capability. However significant changes in climate, hydrology, plant cover and land use which might alter the containment potential can occur in a time frame of tens to hundreds of years, and true 'perpetual care cannot be guaranteed'."

Wheeler and Smith (1979) p. 13

"Major climatic oscillations, with periods on the order of tens of thousands of years, have been a feature of global climate for at least the past million years and may be expected to continue. Therefore, existing paleo-climatological data need to be reviewed to judge the likelihood of the wastes being exposed during a future erosion cycle and/or transported as a result of change in the hydrologic regime."

Lipschutz (1980) p. 78

"Although a proposed site may at the present time be 'dry' and seem free of the effects of groundwater, it undoubtedly is, or at some time during the period of concern (up to one million years) will be, in fact, located within an active groundwater flow system."

Lipschutz (1980) p. 77

Dispersion

The methods used for determining subsurface hydrological conditions require a substantial amount of interpretation. For instance, there is considerable controversy in the literature regarding dispersion concepts, and the application of these concepts to models. Most of the literature on this topic deals with microscopic and small-scale laboratory experiments. When the same theories are applied to field-scale problems, in most cases, the results are not accurately predicted. Many researchers consider dispersion to be extremely important and directly applicable to low-level radioactive waste disposal. If this is true, then dispersion at a field-scale site needs to be better understood before it is used as one of the important criterion in site evaluation. (See "Recommendations" section, number 6.)

"There is considerable controversy in the literature at present regarding the extension of the dispersion concept to a field scale."

Ames and Rai (1978) p. 2-23

"From these simulation, it was concluded that although the attenuating effects of chemical and nuclear processes may be dramatic, they are not as important compared to transport by advection and dispersion, at least for radioactive wastes with half-lives of less than 30 years. The implication is that for site evaluation where few data are available, the worst possible case can be analyzed by considering only advective and dispersive transport."

Anderson (1979)

Radionuclide Migration

The goal of all criteria developed for siting a low-level radioactive waste facility is to isolate the waste from the biosphere. The key consideration in this isolation is to assure the protection of human health and the environment. The migration of radionuclides is not a criterion itself, but is the result of many criteria. One of the major concerns in evaluating a site is the ability of the site geology to prevent or retard radionuclides from migrating beyond defined limits until their toxicity has decayed to generally acceptable levels. To evaluate this, an understanding of radionuclide migration and the criteria affecting it in different environments is necessary. Presently, the migration of radionuclides is not fully understood, and may represent a significant stumbling block to the evaluation of some waste disposal sites. Quotations from the literature representing radionuclide migration are presented below.

> "For simple chemical reactions of short duration, under conditions of rapid flow, hydrologists have traditionally been able to ignore the kinetics of some major reactions. However, for predictions pertaining to radioactive waste disposal systems, involving tens of hundreds of years in systems where flow is slow, these reactions become important. Research is under way in the USGS to quantify them."
>
> DeBuchananne (1978) p. 12

> "The influence of different factors (such as pH, Eh, complexing ligands, competing ions, CEC, type and amount of soil minerals, solid phases of element) on the magnitude and extent of absorption of radionuclides by the geologic media need to be evaluated."
>
> Ames and Rai (1978) p. 4-7

> "The USGS has expressed the opinion that additional information in ion exchange capacity is needed for all sites (CG076). Such information may be useful, but would provide only a portion of that needed for understanding interactions and migration of radionuclides in the ground."
>
> Jacobs, Epler, and Rose (1980) p. 10

> "All of the major laboratories have continuing programs to study the mechanisms of radionuclide interactions in the ground. The basic studies on mechanisms of the interactions should continue but with more emphasis on the spectrum of conditions likely to be encountered in the field. The effects on pH, oxidation-reduction conditions, complexing agents, and biological activity on the behavior of specific radionuclides should be studied. It would be impossible to study all permutations for all radionuclides; thus, a list should be made of those radionuclides present in shallow-land burial operations which pose the most significant radiological health hazards and these should be given priority for detailed study. It is important that attention be given to the kinetics of reaction mechanisms as well as to equilibrium conditions."
>
> Jacobs, Epler, and Rose (1980) p. 29

> "Laboratory studies are needed on:
>
> 1) The effect of degree of saturation on radionuclide adsorption;
> 2) Physical transport of fine particles through porous and channeled media;
> 3) Sorption of solutes from solutions flowing through fissures and channels; and
> 4) Vapor phase transport of radionuclides.
>
> In addition, field measurement should be conducted to verify the significance of these transport conditions and the results should be considered in the development of predictive models."
>
> Jacobs, Epler, and Rose (1980) p. 31

"Theory for chemical reactions among water, waste, and earth materials, in the unsaturated zone must be developed. Research on this subject is underway at the present time. After development of adequate theoretical concepts, the next step would be field testing and verification of the theory."

DeBuchananne (1978) p. 12

"However, the data presented in Section 3 indicate that there is a general lack of systematic evaluation of various factors that determine element-solid matrix interactions, and no information at present is available to determine the magnitude of the various factors. At best, the available data suggest trends of the influence of some of the factors that control solution concentrations and interaction with solid matrices. This type of information would not be very useful for precisely predicting the general fate of radionuclides in the environment."

Ames and Rai (1978) p. 4-1

"The existing thermodynamics data on species are incomplete in many cases, and of dubious quality in other cases. The thermodynamic data should be confirmed by experimental evidence on radionuclide absorption and migration. Thermodynamic data on the radionuclide complexes with natural solid and water organic components are essentially nonexistent. Note in the table 4-1 that radionuclide reactions with organic material were reported for 12 of 19 radionuclides reviewed. Hence, what may prove to be a most important influence on radionuclide absorption and migration is one of the least understood."

Ames and Rai (1978) p. 4-1

"Although water is considered to be the primary vehicle for radionuclide migration from shallow land-burial facilities, other pathways of importance need to be identified and their significance established.

An overall evaluation should be undertaken to establish priorities for further research and development related to radionuclide migration. The factors as quantities, concentrations, radiotoxicity, environmental mobility, and persistence."

Jacobs, Epler, and Rose (1978) p. 43

Definition of Low-Level Radioactive Waste

Although the Nuclear Regulatory Commission has developed their own official definition for low-level radioactive waste, the authors surveyed in the literature do not agree on a general definition. As documented in the Appendix, definitions in the literature range from "non-high-level wastes" to very specific subsections of low-level waste. In the past, disposal sites have accepted a broad range of waste types and the general public may assume that new sites will contain similar wastes. This belief increases suspicion and decreases the credibility of groups that use limited subsets of non-high level waste as their definition. It is important, therefore, to define all radioactive wastes clearly so that the technical, economical, and political evaluation of potential sites can be made more accurately (See "Conclusion" section, number 3).

Site Evaluation

There is no generally agreed upon procedure for evaluating sites and no perfect way to use the criteria list provided in this report. Although a reconnaissance scheme may be helpful in locating potential candidate sites, a site-specific evaluation eventually will have to be performed for each proposed site (See "Recommendations" section, number 1). Depending upon the sites available, certain parts of the country may be able to dispose of only select groups of waste and conversely, the definition or classification accepted by a facility will determine the criteria necessary for proper evaluation. Sites that are not perfectly suited for disposal of low-level radioactive waste in their natural condition may be improved by engineering. However, where long-term isolation is the goal, engineering which requires maintenance should be minimal compared to natural features.

There are different opinions concerning individual criteria and how they should be used in evaluation. The authors of this report are convinced that the overall affect of all pertinent criteria as a system should be the deciding factor and not any one criterion by itself (See "Concusions" section, number 2). The following references were selected to give readers an example of opinions expressed in the literature.

> "Each site environment has inherent characteristics which must be studied and evaluated especially for that site."
>
> Morton (1968) p. 24

> "However, not all the outlined information is likely to be needed at all sites."
>
> Papadopulos and Winograd (1974) p. 19

> "Regulations with rigid specifications of geologic and hydrologic criteria for sites, such as to specify a minimum distance above the water table, are conceptually incorrect and cannot be applied to the entire United States, or even to an entire state in most cases. Strict application of some criteria, such as depth to water table, can actually lead to the selection of less suitable sites. Rather, regulations should provide performance standards that the disposal site must meet to be acceptable and should be applied on a site-by-site basis."
>
> Cartwright et al. (1981) p. 4

> "An assessment of the adequacy of multiple natural and engineered barriers, of a host rock and its environment, of conservative engineering practices, and of any particular waste form or container requires detailed and time consuming site specific evaluation. Genetic geologic studies and/or performance assessments of hypothetical sites, although useful for site selection and development of techniques, do not constitute a sufficient basis for some aspects of repository design or for final determination of site suitability. The natural variability of geohydrologic, geochemical, and tectonic conditions, as well as the heterogeneity of rock masses, reduces the reliability of transferring detailed geologic data from one location to another."
>
> Barnes (1979) p. 4

> "An ideal setting would be in an isotropic host rock situated in a seismically stable area that is totally free of fluids. Since this

situation is unlikely to exist, careful analyses will be necessary to determine that, despite the deviations from the ideal, the conditions that do prevail will, nonetheless, fulfill the regulatory objectives for the disposal program. In order to effect these analyses, regional investigations as well as site-specific studies are recommended."

Barnes (1979) p. 4

"The criteria are presented in three levels

Level I Eliminates broad areas within the State.

Level II Identifies candidate sites within the much larger broad areas, not eliminated by the Level I screening.

Level III Elminates candidate sites based on site specific assessments of individual factors."

Environmental Resources Management (1980) no pages given

"The geology of the site should be studied only in the detail necessary to provide the information required for the site design and to predict the fate of the waste by-products. For some sites, areal geologic mapping may be sufficient; other sites may require considerable drilling, field and laboratory testing, geophysics, and instrumentation using piezometers, pressure-vacuum lysimeters, and tensiometers and such."

Cartwright et al. (1981) p. 8

"(b) The disposal facility shall be designed and operated to enhance and improve the ability of the natural characteristics of the site to confine the waste after disposal. Such improvements may include measures to direct surface water away from disposal areas, to reduce infiltration of precipitation into disposal cells or to reduce the potential for erosion. Independent and diverse engineering barriers shall be provided, as necessary to complement natural barriers in avoiding contact of waste with percolating water, in reducing potential releases from the facility and in complying with the performance objectives of Subpart C."

U.S. NRC (Feb., 1981) p. 14-15

"Before a site can be determined to be suitable, the information must be complete on the full range of characteristics to allow comparison of chosen sites against all siting criteria. The ultimate suitability of an alternative site cannot be determined based on only one or two characteristics, such as tectonics or geochemistry; nor can it be expected that perfect locations will be found, where every characteristic is ideal. Geologic systems are found as they are, not engineered, so each candidate location will have distinctive advantages and disadvantages which will be compared in narrowing the range of alternatives or, ultimately, in selecting sites. Whereas one geologic area might be considered less favorable based on an evaluation of tectonic factors alone, the characteristics such as land use or geohydrology may be so favorable as to counterbalance the low degree of compliance of the tectonic factors with the criteria for tectonic environment."

NWTS Program Office (Feb., 1981) p. 3-4

"Both environmental barriers (geological and engineering controls may be necessary to provide the required protection to man the environment."

U.S. EPA (April, 1977) p. 2-94

Co-Location and Co-Burial

Some authors consider low-level radioactive waste as a portion of a larger group of hazardous wastes. For this reason, some of the literature for hazardous waste was considered applicable to the low-level radioactive waste problem and therefore is referenced in this report. In addition, the same similarities are often used to consider co-location or co-burial of non-radioactive with low-level radioactive waste. There is some real concern over the problems of co-burial where both low-level radioactive waste and hazardous wastes are buried together (See the reference by Cleveland below). However, another alternative is co-location but separate burial. Both of these concepts need further study, but progress will be severely hampered until a workable definition and classification scheme for low-level radioactive waste are developed (See "Recommendations" section, number 3). The following references may be helpful to readers interested in this topic.

> "This discussion has considered hazardous waste in general. Radioactive materials, mentioned several times in the report, represent a special type of hazardous waste that is often given special consideration. In our opinion, such special consideration is not necessary; the discussion in this report also applies to low-level radioactive waste disposal."
>
> Cartwright et al. (1981) p. 11

> "Coordination with Hazardous Chemical Wastes. In recent years, the federal and state governments have begun the task of managing the disposition of hazardous and chemical wastes. There are similarities between low-level radioactive waste and hazardous chemical waste in terms of some waste constituents (e.g., organic liquids) and waste treatment (e.g., incineration and burial). However, the administrative and regulatory environments governing these two types of waste are not currently integrated, and regulations which are still under development may not be consistent when promulgated. Prospects for co-disposal are uncertain due to these factors.
>
> "A related concept which has been proposed is to consider hazardous waste management in multi-state arrangements for low-level waste management. Reciprocal relationships between states involving other waste types and facilities may contribute cohesiveness and equity to multi-state compacts."
>
> Tennessee Rept. (Nov., 1980)

> "The most practical solution, therefore, is the third mode, processing and burial on the same site. Since sites geologically satisfactory for hazardous waste disposal have been found in Massachusetts, these sites or similar ones might be adequate for LLW disposal. Licensing for LLW incineration is a relatively short term (6 months - 1 year) effort so that incineration could proceed soon. While pursuing licensing for burial, a 1- to 3-year process, the incinerator residue could be transported for burial to the existing out-of-state sites. Such a solution demonstrates to these states that Massachusetts is taking appropriate action and, at the same time, is transporting and requesting burial for smaller volumes of much less leachable waste."
>
> Massachusetts Rept. (1980) p. 14

> "Hence it is important that all organic matter in transuranium wastes be destroyed in order to prevent the formation of stable, potentially mobile complexes of plutonium. Moreover, ground water in the area should be free

of strongly complexing legands. For this reason, it is highly inadvisable to locate a chemical waste disposal site adjacent to a radioactive waste disposal site."

Cleveland (June, 1981) p. 1509

Burrowing Animals

The potential for problems created by burrowing animals is mentioned by several authors, but is not well explained. Different types of burrowing animals represent different potentials for damage. For instance, it is not known whether numerous small burrowing animals may be more or less threatening than a few large burrowers. In addition, further explanation of the impact from burrowing animals is needed to understand whether there is potential for transport of radionuclides to the surface or whether there is only a threat to the stability of the surface. The effects of burrowing on infiltration along trenches is especially important (See "Recommendations" section, number 5).

"Transport by burrowing animals may well result in measurable (but not necessarily hazardous) concentration at the surface, particularly if such burrowing occurs shortly after the completion of a trench. Further work is needed to establish the long-term significance of this release mechanism."

Wheeler and Smith (1979) p. 24

Social, Political, and Institutional Problems of Siting

The reader will notice that the majority of quotations from the literature in this report concern the geotechnical and hydrogeologic factors of siting. This is not to negate the importance of all criteria listed under the heading of "human considerations": human health and safety, demography, social criteria, legal-institutuional criteria, economic criteria, and transportation. It does indicate that to date, significantly more research and documentation have occurred concerning the technical aspects of low-level radioactive waste siting and disposal. In particular, citations from the U.S. Department of Energy and other federal agencies relate almost exclusively to these geotechnical and hydrogelogic criteria. The social, political, economic, human health, transportation, demographic and institutional criteria, on the other hand, have been brought to the front by non-federal governmental organizations, including state agencies, environmental groups, and concerned citizens. Throughout the country, particularly in areas with long traditions of input from concerned citizens, these issues may in fact be the more important.

Many authors feel that the technical knowledge to create safe low-level radioactive disposal facilities is available, but that the institutional and sociopolitical mechanisms for siting, operating and maintaining these sites are poorly defined (See "Conclusions" section, number 5). With the passage of the "Low-Level Radioactive Waste Policy Act" in December 1980, states were given full responsibility for finding or developing disposal facilities for their own low-level radioactive wastes. By 1986, states will either have to create their own in-state sites or join regional compacts for shared disposal sites. While regional meetings for the formation of compacts are occurring, few states have adequate legislation or problem-solving mechanisms in place to deal with the consequences of siting. The resolution of institutional issues, particularly those on the local level, may be more difficult than solving the remaining technical problems of disposal. Issues affecting human health and safety and specific local concerns, such as long-term care programs and compensation to a host community, will need serious consideration prior to siting. The following quotations support this viewpoint.

> "An effective radioactive waste management program in this country requires more than the solution of outstanding technical problems; it is equally dependent on the resolution of institutional issues."
>
> State Planning Council (Feb., 1981) p. iii

> "The Task Force has concluded that the remaining issues are not technical, but matters of public policy and political decisionmaking."
>
> National Governors' Association (Aug. 1, 1980) p. 28

> "The biggest problem, I believe, in the entire rad waste siting business is the institutional gap, or the absence of appropriate institutions...
>
> Who can guarantee that needed protective and accountability arrangements will survive shifting government priorities and budget cuts for a generation or more? How do we arrange these structures that I claim we need to protect those bearing special risks in the national interest? How do we avoid the Indian treaty analogy when making commitments to local areas?
>
> Perhaps contractual arrangements will provide the institutional certainty that is needed to enable resolution of this dilema."
>
> Subcommittee on Rural Development (Peelle Testimony) (Aug. 26, 1980) p. 5 - 6

> "The credible resolution of locally-held citizen concerns will determine successful facility siting and licensing. This resolution should occur publicly, for the most part, for while the process may move somewhat slowly, it will have far greater potential for success than a process largely concealed from the public."
>
> Murphy and Goldsmith (Feb., 1981) p. ii

> "Expeditious development of regional low-level nuclear waste facilities will likely depend on the quality and quantity of incentives and benefits available to state and local units of government.
>
> National Governors' Association (Aug., 1980) p. 17-18

Some authors feel that, prior to siting, each state should develop a facility siting process with adequate planning resources. The process would provide for public understanding of radioactive waste issues and ensure technical understanding for local officials; assess the technical adequacy of potential sites; determine the potential risk of the facility and response capability to protect nearby communities; ensure adequate and safe transportation of waste materials; and develop an extended care plan for the site (See "Recommendations" section, number 9).

> "...it is necessary to create three entities within a state to establish an environment for a participatory low-level siting process. They should be temporary in duration and should be dissolved or become dormant upon

completion of their siting responsibilities, being reactivated only when a second regional site is being assessed sometime in the future. The three are:

- a local municipal review committee authorized by state legislation;
- a waste siting council;
- a waste management planning committee."

Murphy and Goldsmith (Feb., 1981) p. 8

"In particular, it is recommended that an education program be instituted to give everyone the opportunity to understand the L-LW problem and the proper management of L-LW and, hence, to support constructively, the implementation of this necessary program."

Massachusetts Rept. (1980) p. 1

Some authors feel that the state should have final authority in siting regardless of local opinion. Other authors suggest that the success of regional siting efforts will depend on the enactment of siting legislation by the individual states. The following quotations represent these ideas:

"The siting of such a facility is best addressed as a state and local matter. This may be a preferable and more successful approach than a solution instituted by the federal government."

Tennessee Rept. (Nov., 1980) p. 5-6

"It is in the best interest of the citizens of the State to ensure that sites are available for these facilities. If this approach is not successful, however, the state must be in a position to make a final decision on a site location."

North Carolina Rept. (Jan. 12, 1980) p. 44-45

"Enactment of siting legislation will assure other states within the region that each state is approaching regional siting efforts with the intention of meeting its responsibilities. Siting efforts coordinated among states will help in answering requirements of Federal regulations and the local concern of 'why my town?'"

Murphy and Goldsmith (Feb., 1981) p. ii

State, Local, and Citizen Involvement in the Decision-Making Process

Many authors stress that the decision-making process for siting of low-level radioactive waste facilities must involve the public, state, and local governments. (See "Conclusions" section, number 6 and "Recommendations" section, number 10.) In siting of low-level radioactive waste facilities, the most critical decisions will be made by the citizens who inhabit the potential host communities. Their decisions will primarily be social ones, involving risks, negative impacts, social benefits, and other quality of life issues. Some authors suggest that the decision-making process can be improved by increasing both the quantity and quality of public participaion.

"There was a clear consensus among Workshop participants that the public, and state and local governments, should be involved in the decision-making process on radioactive waste criteria and other such future regulation and criteria-forming efforts."

U.S. EPA (Feb., 1977) p. xv

"Low level waste repository siting is clearly a quality of life issue, for a sound decision-making process can contribute significantly to how people feel about their ability to control important impacts on their lives.

Murphy and Goldsmith (Feb., 1981) p. 2

"...one needs to achieve sufficient public participation, and participation of sufficiently high quality, that no citizen feels that his or her viewpoint has been omitted, overlooked, or ignored. I stress the quality of public participation because it is so important and so frequently neglected by managers."

Montague (Jan., 1979) p. 3

Mitigation of Social and Economic Impacts of Siting a Low-Level Radioactive Waste Facility

In selecting sites for low-level radioactive waste facilities, authors state that consideration must be given to the social and economic impacts on communities and the region hosting the site (See "Conclusions" section, number 7 and "Recommendations" section, number 11). The disposal facility should be located so that adverse impacts from construction and operation of the facility can be mitigated. Mitigation can take various forms, for example a financial incentives program to assist a community in accepting and supporting the facility. To be effective, authors stress that a mitigation plan must be tailored to each host facility.

"The site shall be selected giving due consideration to social and economic impacts on communities and regions affected by the repository."

NWTS Program Office (Feb., 1981) p. 11

"It is also essential to keep in mind that there is, perhaps, no ideal general mitigation strategy, but rather that strategies must be tailored to the local area's needs and preferences if they are to be successful and acceptable.

Subcommittee on Rural Development (Murdock Testimony)
(Aug. 26, 1980) p. 11-12

VI. CONCLUSIONS

It is impossible for the authors of this report to make conclusionary statements about all of the criteria topics found in the literature. With the exception of a few topics, the authors of the reviewed documents are often in disagreement about the significance of individual criterion. Opinions frequently differ on whether criterion should be viewed as limiting factors to siting, individually or in combination with other criteria. A good example is the criterion "depth to water table." There are two different opinions about the water table and its effect on low-level radioactive waste: 1) disposal should not occur in the water table portion of any host material; and 2) disposal can occur in the water table portion of any host material, if the hydraulic conductivity and flow rates are low enough to preclude migration of nuclides beyond the site, before their half-lives render them harmless. The authors agree in their opinion of the criterion "surface water," however. They feel that surface water should never come into contact with radioactive waste, nor should it directly affect a disposal site.

The conclusions presented below represent concepts that are generally agreed upon in the literature. They are the conclusions solely of the authors of this report, formulated after a thorough review of the content, number, and variety of references in the literature. They are supported by the quotations presented in the "Verification" section.

1. The primary concern for any low-level radioactive waste disposal site is the health and safety of the public. The major criteria necessary for assessing their effect are hydrogeology, demography, and transportation. These criteria appear often in the literature and are mentioned by many authors. The criterion of hydrogeology, discussed at length in section five, is of particular significance because of the danger of radionuclide migration into groundwater. Demography is a critical criterion about which there is some disagreement in the literature. Some authors favor remote areas with low population density for siting because of the reduced potential for exposure to large populations. Other authors favor siting closer to urban, industrial areas to reduce the chances of exposure to large populations through transportation accidents. They also stress that rural areas are often the least prepared to act as host communities and are most vulnerable to adverse socioeconomic impacts. All authors agree, however, that studies of current and projected population size, density, and distribution should be conducted prior to siting. All authors also agree that transportation is a critical criterion in evaluating sites for low-level radioactive waste facilities. The risks of transportation accidents via poor routing constitutes a major hazard to human health and safety. Therefore, sites and routes should be selected to avoid population centers and low-level radioactive waste sites should be located with access to major all-weather highway and rail routes.

2. The cumulative effect of all applicable criteria as they relate to each other in an overall system more accurately assesses site suitability. The primary goal of disposal is to protect human health and safety which cannot be assessed accurately using any individual criterion as a limiting factor.

3. There is a pressing need for a legal accepted definition of low-level radioactive waste that can be used in evaluating disposal sites. The definition problem as it relates to siting criteria for low-level radioactive waste sites is disussed in the "Procedures" section, the "Discussion" section, and the "Appendix."

4. There is a general lack of information on ecological impact criteria important to the evaluation of any individual site. Such criteria have been developed for other siting problems, such as mine development and power plant siting, however, these criteria have not been commonly applied to siting of low-level radioactive waste disposal facilities.

5. The geotechnical aspects of siting low-level radioactive waste sites appear well-defined and the resolution of these criteria manageable; however, the socio-political and institutional problems of siting are poorly defined and no problem resolution mechanism currently exists.

6. A more effective role for state and local government and the concerned public should be defined. Proposed Rule 10 CFR 61 is a first approach, but is clearly inadequate in the political and social context of some regions of the country, which have strong traditions of local involvement in major decisions. Some authors recommend that each state develop a facility siting process which has adequate planning resources.

7. Evaluation of any particular site must consider the possible mitigation of social and economic impacts that development of a disposal site would have on a host community and its residents. The authors feel that mitigation plans should be tailored to the needs and preferences of each local community. Moreover, local residents should be involved in the formulation of these strategies.

8. The research should continue. Many questions remain unanswered concerning the critical criteria that need to be considered in evaluating potential sites for low-level radioactive waste facilities. Enough information exists at present, however, to adequately evaluate potential sites for certain low-level radioactive wastes with little hazard and short half-lives. The disposal of low-level radioactive wastes with longer half-lives and greater hazard may require more information. Two specific areas in which further research is needed are fracture hydrology and hydrogeology of the unsaturated zone above the water table. Fracture hydrology is not well understood. The hydrogeology of a potential low-level radioactive waste site may be controlled by the fractures of the host material, even if the site is located in fine-grained material. To accurately assess certain sites, more research is needed to properly understand fracture flow. Further study is needed also on the topic of the hydrogeology of the unsaturated zone above the water table. The authors reviewed in this literature survey do not discuss determining characteristics or monitoring in this zone.

VII. RECOMMENDATIONS

The authors of this report spent a year reviewing the literature and obtained additional insights which they wish to share with the readers. The following suggestions are offered as help in evaluating sites for disposal of low-level radioactive waste. These ideas are those solely of the authors of this report, but many of them represent the views of other authors.

1. Regional and site specific studies should be conducted in the evaluation of low-level radioactive waste disposal sites.

2. A concept of multiple barriers should be considered in site evaluations. As many man-made barriers as practicable should be used in addition to natural barriers to minimize the potential for migration of wastes.

3. Co-burial and co-location of low-level radioactive waste with other hazardous waste should be studied carefully for each specific combination of wastes and the relationship with the proposed host material.

4. More study should be done regarding monitoring design requirements and more emphasis should be placed upon the unsaturated zone.

5. The potential effects of burrowing animals on low-level radioactive waste disposal sites should be studied more completely.

6. More laboratory and especially more field studies should be conducted on dispersion effects.

7. More studies regarding chemical reactions between host material and waste should be conducted. This includes the effects of the entire waste and its container; not just the radionuclides involved. Field verification is especially important.

8. Low-level radioactive waste should be classified to enable inventory procedures to be more effective and to allow sites to accept only the wastes suited for disposal at each particular site. Two classification parameters that should be considered are persistence and hazard.

9. Prior to siting, each state should develop a facility siting process which has adequate planning resources. In addition it should provide for public understanding of radioactive waste issues and ensure technical understanding for local officials; assess the technical adequacy of potential sites; determine the potential risk of the facility and response capability to protect nearby communities; ensure adequate and safe transportation of waste materials; and develop an extended care plan for the site.

10. Mechanisms should be developed to provide ample opportunity for state, local, and citizen involvement in ongoing policy development and decisions concerning proposed facilities.

11. A socioeconomic impact assessment should be undertaken to provide credible information regarding the potential effects of a low-level facility on a local community.

VIII. VERIFICATION

Waste Considerations

WASTE CHARACTERISTICS

Since the criteria used in establishing a site depend upon the waste characteristics, it may be critical to determine these characteristics prior to burial.

Even though this report specifically concerns low-level radioactive waste, the definition of low-level radioactive waste varies (see Appendix) and hence the characteristics of the wastes may vary.

> "The future condition of burial sites, and the hazards they may present are strongly dependent on the nature of low-level waste presently generated, and the techniques used for its disposal."
>
> Wheeler and Smith (1979) p. 16

> "Knowledge of the radiological, chemical, and physical characteristics of the contents of waste packages is required to facilitate the optimum disposal of solid radioactive wastes."
>
> Jacobs, Epler, and Rose (1980) p. 7

> "The effectiveness of the disposal depends upon the specific retention properties of the some hundred metres of dry calcareous clays, sands, and gravels (locally called 'soils') existing at the sites. A description of a waste that has been discharged to a trench is helpful in understanding this disposal technique."
>
> Pearce et al. (1960) p. 348

> "Landfills designed to meet performance standards should take into account six factors: (1) the type of waste to be disposed; (2) the site hydrogeology that governs the direction and rate of contaminant travel; (3) the attentuation of contaminants by geochemical interactions with the geologic materials; (4) the release rate of unattenuated pollutants to surface or ground water; (5) character of the receiving waters; and (6) construction problems which may be encountered."
>
> Cartwright et al. (1981) p. 5

> "In considering and evaluating applications for alternative methods of disposal not specifically covered by subparts D-F, the Commission will be guided by the specific requirements set out in these subparts. In particular, any such application should include:
>
> (a) A description of the hydrological, geological and other characteristics of the site;
>
> (b) A description of the disposal facility design and methods of operation and waste emplacement;
>
> (c) A description of the characteristics and properties of the waste;
>
> (d) A description of the use and reliance on institutional controls during operations and after site closure; and

(e) An analysis to demonstrate that the performance objectives in subpart C will be met."

U.S. NRC (Feb., 1981) p. 10-11

Additional references include: Dillon, Blantz, and Pahwa, 1978; Galley, 1972, p. 119-120; Jacobs, Epler, and Rose, 1980, p. 35, 38; Papadopulos and Winograd, 1974, p. 22; Tennessee Rept., Nov., 1980.

The following references illustrate the importance of understanding waste characteristics in the selection of appropriate site criteria. As the last quote implies, some sites may be suitable for certain wastes but not others.

"The hazardous materials that are frequently present in general municipal refuse pose problems resulting from a lack of knowledge of either the composition or volume."

Cartwright et al. (1981) p. 5

"Differing radionuclides may behave in very different ways in the environment; they can also have widely differing radiotoxicities. For these reasons it is of little or no value to know the total amount of radioactivity released if information is lacking on which nuclides are present and in what relative proportions."

OECD (1972) p. 93

"Thus, there is particular concern for long-lived radionuclides, radionuclides with high radiotoxicity, and radionuclides with high potential mobility. Methods to verify the physical characteristics of waste receipts and procedures for remedial action are needed."

Jacobs, Epler, and Rose (1980) p. 35

"The short-term problem Tennessee and the nation will face is reduced disposal capacity for liquid organic radioactive wastes possibly beginning as soon as mid-1981. This situation is due not to a lack of disposal capacity, but rather to changing waste acceptance criteria.

a. Liquids are considered undesirable in a shallow land burial site because their mobility is potentially disruptive to the buried waste and the chemical hazard from many organic liquids is more significant than the hazard from the usually small amount of radiation present. Solidification of organic liquids presents special problems, and many experts feel incineration will ultimately be the best 'disposal' method for these wastes."

Tennessee Rept. (Nov., 1980) p. 3

No additional references.

WASTE CHARACTERISTICS

Persistence

One of the most critical criteria involved with waste characteristics is persistence, or, "how long will the waste persist in the hazardous state?"

The radioactivity hazard thus is related to half-life and the chemical toxicity to chemical or biological breakdown. The type of site and type of disposal are intimately related to the persistence of the waste.

> "In evaluating waste for disposal by landfill, the toxicity of the waste must be related to its decomposition/decay rate. Geologic conditions in Illinois may be unsuitable for landfill disposal of some wastes that have slow decomposition/decay rates and for certain constituents that are extremely toxic."
>
> Cartwright et al. (1981) p. 6

> "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."
>
> Panel on Land Burial (1976) p. 66-67

> "An important parameter in the disposal of radioactive wastes is the half-life of the radioactive atoms, or radionuclides, with which the waste is contaminated."
>
> EG & G, Inc. (1980) p. 5

> "Criteria must then be established to minimize long-term environmental impact. These will be governed by three parameters: the waste form and packaging, the half-lives of the radionuclides involved, and the length of time that the burial site can be monitored and remain under operational control."
>
> Steger (1979) p. 671

> "Contaminant severity. Contaminant severity is a composite term; it includes qualitative weighting of toxicity, concentration and volume, mobility in the water, and persistence."
>
> LeGrand (1980) p. 28

"Uniform and specific criteria are urgently desirable for categorizing wastes in this regard, principally according to type, quantity, and persistence of critical constituents."

Piper (1969) p. 5

Additional references include: Barnes, 1979, p. 14, 56; GAO Rept., 1976; Frye et al., 1978, p. 10; LeGrand, 1980, p. 15; EG & G, Inc., 1980, p. 5.

Concentration

The concentration of the waste is important because it relates to the toxicity and to the amount that will be left after a certain number of half-lives. It also affects the potential concentration of leachate.

> "Contaminant severity. Contaminant severity is a composite term; it includes qualitative weighting of toxicity, concentration and volume, mobility in the water, and persistence."
>
> LeGrand (1980) p. 28

> "Low-level wastes may contain potentially hazardous quantities of radioactive materials in a wide range of concentrations; some are also chemically toxic. Most of these materials lose much of their radioactivity within a few months or years; others in several hundred years. In general, low-level wastes emit very little heat, and most require little or no radiation shielding for handling by people."
>
> EG & G, Inc. (1980) p. 5

> "Chemistry of water in aquifers and confining beds and of leachate from the waste trenches."
>
> GAO Rept. (1976) p. 43

No additional references.

Waste Considerations

WASTE CHARACTERISTICS

Toxicity

Handling, sampling, disposal method, and site selection are all dependent upon knowledge of the waste toxicity.

> "In evaluating waste for disposal by landfill, the toxicity of the waste must be related to its decomposition/decay rate. Geologic conditions in Illinois may be unsuitable for landfill disposal of some wastes that have slow decomposition/decay rates and for certain constituents that are extremely toxic."
>
> Cartwright et al. (1981) p. 6

> "Low-level wastes may contain potentially hazardous quantities of radioactive materials in a wide range of concentrations; some are also chemically toxic. Most of these materials lose much of their radioactivity within a few months or years; others in several hundred years. In general, low-level wastes emit very little heat, and most require little or no radiation shielding for handling by people."
>
> EG & G. Inc. (1980) p. 5

> "Contaminant severity. Contaminant severity is a composite term; it includes qualitative weighting of toxicity, concentration and volume, mobility in the water, and persistence."
>
> LeGrand (1980) p. 28

No additional references.

Waste Considerations

WASTE CHARACTERISTICS

Waste Form or Packaging

"The choice of the form of the waste, its container, the properties of the specific host rock, the composition of the available water, the ambient temperature and pressure, the nature of any intentionally added materials, and the equilibrium constants of the possible chemical reactions define a complex interacting chemical system that determines the rate at which dissolved species become available for hydrological transport."

Frye et al. (1978) p. 12

"Waste form is an important factor in minimizing radionuclide releases. The mobility of liquid and gaseous wastes makes them undesirable waste forms for shallow land burial ground operators who are not authorized to bury liquid or gaseous wastes, but they often receive wastes with free-standing liquid. Recently Richland and Beatty were closed by action of the respective state governors because the packaging did not meet acceptable standards for transport."

Jacobs, Epler, and Rose (1980) p. 8

"The second problem highlighted by the Maxey Flats and West Valley experience, is poor waste form. Uncompacted organic material decomposed in the trenches at both sites, causing settling and cracking of the trench caps. Stable waste forms should be required; the Nuclear Regulatory Commission draft regulations concerning the shallow land burial sites (10CFR 61) contain these requirements."

U.S. DOE (Mar. 13, 1981) p. 26-27

"Criteria must then be established to minimize long-term environmental impact. These will be governed by three parameters; the waste form and packaging, the half-lives of the radionuclides involved, and the length of time that the burial site can be monitored and remain under operational control."

Steger (1979) p. 671

Additional references include: Barnes, 1979, p. vi, vii, 6, 30, 31, 46; Donohue and Associates, 1980, p. 1; Jacobs, Epler, and Rose, 1980, p. 38; Klingsberg and Duguid, 1980, p. 2, 3, 26; EG & G, Inc., 1980, p. 5; Lipschutz, 1980, p. 75; Massachusetts Rept., 1980, p. 18; Piper, 1969, p. 5; U.S. DOE, Mar., 13, 1981, p. 30-31.

Waste Considerations

WASTE CHARACTERISTICS

Volume

The projected total volume of waste is important in evaluating waste disposal sites both economically and technically.

If a variety of waste is accepted, it may be important to know the volume of each type of waste also. For more information see the "Host Material-Size" and "Economics" sections.

> "The size of the site required for a low-level waste burial facility will depend on the volume of LLW in the state or in the region to be served, the desired length of time the facility will be operational and the desired exclusion area surrounding the active site. Typical sites may range from less than a hundred acres to several hundred acres, depending on how much land is already available for a buffer zone. The space requirements for a waste volume reduction/solidification facility would be much less, and the licensing effort for this type of processing plant would be significantly less than that for a burial site whether on the same site or elsewhere. For this reason most of the discussion below pertains to the siting of waste burial facilities."
>
> Massachusetts Rept. (1980) p. 17

> "Contaminant severity. Contaminant severity is a composite term; it includes qualitative weighting of toxicity, concentration and volume, mobility in the water, and persistence."
>
> LeGrand (1980) p. 28

> "Uniform and specific criteria are urgently desirable for categorizing wastes in this regard, principally according to type, quantity, and persistence of critical constituents."
>
> Piper (1969) p. 5

> The hazardous materials that are frequently present in general municipal refuse pose problems resulting from a lack of knowledge of either the composition or volume."
>
> Cartwright et al. (1981) p. 5

> "In summary, it is expected that at least 148,000 cubic metres of low-level waste will be generated annually by the year 1990, significantly exceeding the capacity of the existing three commercial disposal sites. The regional distribution of this waste indicates a need for a system of five or six disposal sites geographically distributed."
>
> U.S. DOE (Mar. 13, 1981) p. 13

Additional references include: Illinois Rept., 1980, p. 5; Massachusetts Rept., 1980, p. 1; Murphy and Goldsmith, 1981, p. 22; North Carolina Rept., Jan., 12, 1980, p. 17; Subcommittee on Rural Development, Aug. 26, 1980, p. 2; U.S. DOE, Mar., 13, 1981, p. 2, 4.

Waste Considerations

WASTE CHARACTERISTICS

Mobility in Water

Water is one of the most important ways that radionuclides can enter the biosphere and migrate from the waste site. Therefore, it is important to understand the mobility of the waste in water.

Although this criterion appears identical to the following category of solubility, it is slightly different in two respects. First, solubility includes concern for the waste container and second, some wastes (such as oily substances) actually may not dissolve in water, but are carried by its movement.

> "Granted the importance of the total solution concentrations of the element, the nature of the predominant solution species are important since they affect 1) adsorption through their charge; 2) adsorption because of changes in the nature of the species due to alteration in solution properties such as pH, Eh, competing ions and complexing ions; 3) movement through the soil and rock matrix because of their physical size; and 4) plant uptake."
>
> Ames and Rai (1978) p. 2-2

> "It is always necessary to establish local base level concentrations to avoid disposal or storage of the radioisotope of an element in environments with high concentrations of stable isotopes of the same element. Such an environment could enhance mobility of the radionuclide."
>
> Ames and Rai (1978) p. 2-2

> "Contaminant severity. Contaminant severity is a composite term; it includes qualitative weighting of toxicity, concentration and volume, mobility in the water, and persistence."
>
> LeGrand (1980) p. 28

> "Criteria used by Cherry for intermediate-term burial sites include:
>
> 1. burial site devoid of surface water except snowmelt and rainfall
> 2. burial trenches sufficiently above fractured bedrock to prevent migration of radionuclides through the bedrock
> 3. predicted rate of waste solvents movement provides decades of delay time before radionuclides can reach undesirable areas
> 4. water table, naturally or artificially, below bottom of burial trenches
> 5. Site hydrologically suitable to monitoring and to waste containment by groundwater flow manipulation by pumping."
>
> DeBuchananne (1974) p. 357

No additional references.

Waste Considerations

WASTE CHARACTERISTICS

Waste Solubility

The solubility of the waste may have a significant effect upon the management and site selection alternatives.

If a waste is easily soluble in water, it is more important to prevent water from contacting the waste. This criterion includes the container or packaging and is slightly different from mobility in water (see previous criterion).

> "The panel notes that release into the biosphere of radionuclides from a deep repository would be constrained by several circumstances that serve as barriers: (a) a low-leach solid form of the waste; (b) low permeability of the repository medium; (c) a long path of travel by groundwater; and (d) delay by sorption, ion exchange, or other reaction between radionuclides and aquifer materials. Selection of a site and construction of a repository should be guided by efforts to make these barriers as effective as possible."
>
> Panel on Hanford Wastes (1978) p. 4

> "The dissolution of wastes and transport of radionuclides by groundwater is influenced by the following factors: (1) solubility of the waste form and its container at repository geochemical conditions including temperatures and pressures; (2) rate and volume of ground-water flow; (3) the mineral surfaces along the ground-water flow path; (4) the chemical properties of the ground-water including its pH, oxidation potential, ionic strength, complexing agents present, and chemical changes associated with emplaced wastes."
>
> Klingsberg and Duguid (1980) p. 26

No additional references.

Precipitation of Waste

The ability or potential for the waste to precipitate back out of solution may have a significant effect on the distances and rates in which contamination can occur.

> "If the waste is dissolved it will presumably be transported back to the biosphere unless it is 'fixed' by either the host rock or backfill. If the radionuclides react with the solution to form precipitates their migration rate will be greatly reduced."
>
> Barnes (1979) p. 7

No additional references.

Waste Considerations

WASTE CHARACTERISTICS

Reactivity of the Waste

"Reactivity of the waste materials with the host rock is extremely important. It is possible that reactions between the host and waste materials may alter the physical nature of the enclosing material. This in turn could lead to leakage and contamination of adjacent formations. Materials which generally have low reactivity with corrosive substances include anhydrite, salt, and shale or clay. Materials which have strong sorptive properties are desirable; clays are attractive hosts for this reason. Anhydrite and salt are generally unsuitable for near-surface storage because of their high solubility in water."

TENRAC (1980) p. 60

No additional references.

Waste Considerations

BURIAL TECHNIQUES CRITERIA

The burial techniques used in the disposal of low-level radioactive waste may have a significant effect on the success of the site.

The natural conditions of the site - geologic, topographic, soil, etc. - may determine the technique of burial employed (for example, the extent of host material may limit burial depth). Some sites may be suited for only certain types of burial. The most commonly mentioned criteria for burial techniques include: depth of burial; backfill, cover, or overburden material; method of filling the hole (or plugging); sealing; and decommissioning. These are discussed below with representative quotations.

Depth of Burial

"Thickness must be adequate for construction and system requirements, and the depth must be sufficient for the overburden to protect the repository from surficial events."

Klingsberg and Duguid (1980) p. 66

"The minimum depth of the repository waste emplacement area shall be such that credible human activities and natural processes acting at the surface will not unacceptably affect system performance."

NWTS Program Office (Feb., 1981) p. 6

"As several members of the nuclear waste population (TC - 99, I-129, Cs - 135, N-237, Pu - 242) have half lives in the million year range, we must consider what depth is safe with respect to erosion.

Barnes (1979) p. 56

Additional references include: Barnes, 1979, p. vi, vii, 56.

Waste Considerations

BURIAL TECHNIQUES CRITERIA

Methods of Excavation

The method used for excavation of the disposal site may have an influence on the effectiveness of the site. This is especially true where fractures are a concern.

> "Excavation characteristics of the host material provide a measure for determining the expense of operating a particular site. Blasting, for example, would be an unnecessary expense if sites were available where no blasting was required for excavation. Also, blasting generally yields unwanted fractures which readily transport groundwater or other fluids."
>
> TENRAC (1980) p. 61

> "The reader is reminded that a complete safety analysis of a low-level radioactive burial site would also have to explicitly consider the following matters: a) introduction of radionuclides to the atmosphere and surface water through long-term erosion and catastrophic erosion due to floods and earthquakes; b) uptake of radionuclides from the solid zone by plants; c) identification of critical nuclides within, and of the critical population group in the vicinity of proposed burial sites; d) long-term monitoring of the site to prevent vandalism and blundering by unaware descendants; and e) methods of trench construction and waste emplacement designed to reduce or exclude entry of water into the trenches."
>
> Papadopulos and Winograd (1974) p. 22

> "The future condition of burial sites, and the hazards they may present are stongly dependent on the nature of low-level waste presently generated, and the techniques used for its disposal."
>
> Wheeler and Smith (1979) p. 16

Additional references include: Donohue and Associates, 1980, p. 1; U.S. NRC, Feb., 1981, p. 10, 14, and 15.

BURIAL TECHNIQUES CRITERIA

Backfill, Cover or Overburden Material

The properties of the material used to fill the trench or hole are important.

Due to economic considerations, the material at the site and often the host material itself is usually used. However, sometimes this will not support plant growth and a soil cover must therefore be added. This cover may be different from the backfill material, which must contain the waste in a fashion similar to the host material. Barnes (1979) mentions buffer material and overburden several times in his report. Although there are few other references related to criteria on this particular subject, it can be very important depending on the burial technique. While the reference below concerns high-level waste, it expresses a concept that is applicable to site design at a low-level radioactive waste site.

> "The Canadian Waste disposal program is based on a concept of multiple barriers: waste dilution and solidification; its containment in an inert canister; this container then surrounded by special backfill material and sealed in an excavation created 1000 m or deeper in the geological subsurface environment. Thus, each barrier should provide a degree of containment should leaching of the waste occur."
>
> Barnes (1979) p. vi

No additional references.

Method of Filling the Hole or Plugging

While related to the previous criterion, this criterion differs in its close connection to the method of burial. It also involves the relationship between the host material, the backfill material, and the next criterion - sealing. These quotations also concern high-level waste, but convey the importance of filling the trench hole to prevent the migration of radionuclides.

> "...a geological system should be selected that can be satisfactorily plugged and sealed when the repository is closed, and suitably monitored to ensure that the behavior of the overall hydrogeological system will continue to function satisfactorily after closure."
>
> Frye et al. (1978) p. 10

> "The sequence of overlying rock units, the host rock, and the plugs and seals of the shafts are among the most critical of the barriers inhibiting the migration of the radionuclides to the biosphere. The plugs and seals should be credibly expected to stay secure against leakage without maintenance or repair for a long time relative to the half-lives of the waste radionuclides."
>
> Frye et al. (1978) p. 10

Additional references include: Barnes, 1979, p. 58-59; D'Appolonia, Jan., 1979, abstract; Martin, June, 1975, abstract; Moore et al., Aug., 1979, abstract; U.S. DOE, Oct., 1980, p. 268.

Waste Considerations

BURIAL TECHNIQUES CRITERIA

Sealing

A good seal is important to the long-term isolation of the waste.

"Sealing" can be thought of as capping off the waste trench or borehole. It may involve artificial or natural material and the relationship of the material to the host material.

> The plugging and sealing of shafts, tunnels, and boreholes are discussed in detail in an Office of the Nuclear Waste Isolation (ONWI) document (ONWI 1979)."
>
> U.S. DOE (Oct., 1980) V.3, p. 268

> "The sequence of overlying rock units, the host rock, and the plugs and seals of the shafts are among the most critical of the barriers inhibiting the migration of the radionuclides to the biosphere. The plugs and seals should be credibly expected to stay secure against leakage without maintenance or repair for a long time relative to the half-lives of the waste radionuclides."
>
> Frye et al. (1978) p. 10

Additional references include: Barnes, 1979, p. 46; D'Appolonia, Jan., 1979, abstract; Martin, June, 1975, abstract.

Waste Considerations

BURIAL TECHNIQUES CRITERIA

Decommissioning

The process of decommissioning removes all operational facilities (for example, buildings) and prepares the site for long-term maintenance and monitoring. In this phase, personnel are not continuously required to be at the site.

> "...a geological system should be selected that can be satisfactorily plugged and sealed when the repository is closed, and suitably monitored to ensure that the behavior of the overall hydrogeological system will continue to function satisfactorily after closure."
>
> Frye et al. (1978) p. 10

> "Sites should be selected in areas that may be decommissioned with the least impact on the environment."
>
> Illinois Rept. (1980) p. 17

> "However, erosional and vegetative transport vectors, vulnerability to natural events, decommissioning and ease in monitoring the site should also be considered."
>
> Steger (1979) p. 669

Additional references include: Barnes, 1979, p. 46; D'Appolonia, Jan. 1979, abstract; TENRAC, 1980, p. 43; U.S. DOE, Oct., 1980, p. 421.

Waste Considerations

RETRIEVABILITY CRITERIA

> "Disposal of wastes implies a terminal solution. Once wastes are disposed of, they are presumably unretrievable. However, there is always the chance that the disposal technology might prove unsafe or inadequate. Thus, disposal with retrievability implies that, for a limited period, the wastes can be removed from their place in interment, substituting either a better disposal method or further storage."
>
> Lipschutz (1980) p. 56

Retrievability is an option that may or may not be desirable for disposal of low-level radioactive wastes. However, it should be considered in the siting process because it may affect the specific waste form and disposal technique. The following quotes give reasons for including retrievability as one of the criteria to be considered in selecting a low-level radioactive waste disposal site.

> "A waste management system provides for retrievability of the waste if it incorporates a designed provision for recovery of the waste materials. The necessity of such a feature is obvious for any phase of the management system prior to disposal.
>
> The principal reasons in favor of retrievable waste management systems are:
>
> a. They offer an opportunity for correction of unanticipated failures of the isolation methodology.
> b. They may allow future societies the prerogative of applying advanced knowledge to improve upon earlier efforts in waste disposal.
> c. They permit recovery of the waste as a resource, if uses for it should develop in the future.
>
> The disadvantage of retrievability is that it necessarily increases the probability that the waste will not remain isolated from humans. Systems with designed provisions for recovery of the radioactive materials in general cannot be as secure from intrusion as those which lack such features."
>
> U.S. EPA (Feb., 1978) p. 44-45

> "Retrievability of radioactive wastes has been advocated because of: (1) the possibility of developing better disposal methods in the future, and (2) the possibility that what is 'waste' today may have some intrinsic value in the future. Criteria for long-range waste management, to be of any practical utility, must provide guidelines for resolving these uncertainties."
>
> Schiager, K.J. (Apr., 1977) p. 2.49

Additional references include: Barnes, 1979, p. 21-22, 46; Boch and Kibbe, 1978; Lipschutz, 1980, p. 77; U.S. EPA, Apr., 1977, p. 2.16, 2.95; U.S. EPA, Feb., 1978, p. 45.

Natural Site Considerations

HOST MATERIAL

Low-level radioactive wastes are disposed of in host material. This material is most commonly called "host rock," but it may not actually be rock. Clays and other sorptive properties can serve as host material. While this criterion appears similar to that of "Geology," it does not include geologic processes or the surrounding geologic formations. "Host Material" is simply a description of the material in which the wastes will be buried. It includes the following subdivisions: thickness; size; shape; geochemistry; porosity; permeability; corrosivity; mineral surface area; and rock and soil mechanics.

> "Reactivity of the waste materials with the host rock is extremely important. It is possible that reactions between the host and waste mateials (sic) may alter the physical nature of the enclosing material. This in turn could lead to leakage and contamination of adjacent formations. Materials which generally have low reactivity with corrosive substances include anhydrite, salt, and shale or clay. Materials which have strong sorptive properties are desirable; clays are attractive hosts for this reason. Anhydrite and salt are generally unsuitable for near-surface storage because of their high solubility in water."
>
> TENRAC (1980) p. 60

> "An assessment of the adequacy of multiple natural and engineered barriers, of a host rock and its environment, of conservative engineering practices, and of any particular waste form or container requires detailed and time consuming site specific evaluations. Generic geologic studies and/or performance assessments of hypothetical sites, although useful for site selection and development of techniques, do not constitute a sufficient basis for some aspects of repository design or for final determination of site suitability. The natural variability of geohydrologic, geochemical, and tectonic conditions, as well as the heterogeneity of rock masses, reduces the reliability of transferring detailed geologic data from one location to another."
>
> Klingsberg and Duguid (1980) p. 2-3

> "The choice of the form of the waste, its container, the properties of the specific host rock, the composition of the available water, the ambient temperature and pressure, the nature of any intentionally added materials, and the equilibrium constants of the possible chemical reactions define a complex interacting chemical system that determines the rate at which dissolved species become available for hydrological transport."
>
> Frye et al. (1978) p. 12

Additional references include: Barnes, 1979, p. vi, vii, 6, 14; GAO Rept., 1976, p. 43; Hawley and Gallaher, 1981, p. 561; Morton, 1968, p. 29.

Natural Site Considerations

HOST MATERIAL

Thickness

"The thickness of the host material is important since it must accommodate a site large enough for long term usage. In addition, a thick buffer zone of the material should be available above, below, and laterally around the storage site."

TENRAC (1980) p. 60-61

"Surficial materials. There should be a sufficient thickness of suitable surficial geologic materials in which to construct the disposal trenches, provide attenuation capacity for released leachate from the waste, and limit the migration of leachates."

Cartwright et al. (1981) p. 12-13

"(ii) For sites located in predominately course grained materials, the following criteria should be met:

(A) low saturated hydraulic conductivity.
(B) low groundwater resource value and inadequate yields for groundwater use in the unconfined and underlying confined aquifers.
(C) sufficient depth to the water table such that the groundwater intrusion, perennial or otherwise, into the waste will not occur.
(D) an area which does not provide significant recharge to the unconfined or underlying confined aquifers.
(E) an absence of discharge areas such as perennial streams, seeps, springs, and wetlands.
(F) sufficient thickness and lateral extent to permit burial of the waste entirely within the unit and to promote retardation, low groundwater flux, and long groundwater travel time to the water table."

U.S. NRC (Feb., 1981) p. 13-14

Additional references include: Donohue and Associates, 1980, p. 11; IAEA, 1979, p. 5; TENRAC, 1980, p. 59, 61.

Natural Site Considerations

HOST MATERIAL

Size

"In addition to the natural factors outlined above, geographic factors, such as location, size and shape of the area, communications, population density and distribution, and water use downstream from the site, must be considered."

Morton (1968) p. 29

"DOE estimates that the minimum economically feasible LLW site would accept 1.2 million cubic feet per year for 40 years, with 325,000 cubic feet of waste per acre. In fact, site size may vary according to regulatory requirements and to agreements."

Murphy and Goldsmith (Feb., 1981) p. 22

"The thickness of the host material is important since it must accommodate a site large enough for long term usage. In addition, a thick buffer zone of the material should be available above, below, and laterally around the storage site."

TENRAC (1980) p. 60-61

"Hydrological transmissivity of water flow, for example, may be significantly greater parallel to stratification than across it; therefore, the areal extent of undisturbed strata of repositories in tabular bodies would commonly require special consideration of tabular or discoid shapes. Equidimensional and irregular bodies may include a variety of igneous intrusions plus plugs, domes, or diapirs of gypsum, anhydrite, mud, or salt. Such bodies are commonly relatively isotropic with respect to transmissivity and other pertinent properties and would require appropriate shapes of buffer zones and barrier envelopes."

Frye et al. (178) p. 4-5

Additional references include: IAEA, 1979, p. 5; U.S. AEC, 1974, p. G-7.

Shape

"In addition to the natural factors outlined above, geographic factors, such as location, size and shape of the area, communications, population density and distribution, and water use downstream from the site, must be considered."

Morton (1968) p. 29

"Hydrological transmissivity of water flow, for example, may be significantly greater parallel to stratification than across it; therefore, the areal extent of undisturbed strata of repositories in tabular bodies would commonly require special consideration of tabular or discoid shapes. Equidimensional and irregular bodies may include a variety of igneous intrusions plus plugs, domes, or diapirs of gypsum, anhydrite, mud, or salt. Such bodies are commonly relatively isotropic with respect to transmissivity and other pertinent properties and would require appropriate shapes of buffer zones and barrier envelopes."

Frye et al. (1978) p. 4-5

No additional references.

Natural Site Considerations

HOST MATERIAL

Geochemistry

The chemistry of the host material and its environs is important in assessing the potential for leachate migration. Any leachate that escapes from the burial site will be a combination of both the geologic material and the waste.

> "The study of rock-waste interactions should include the geochemistry. Mobility of a number of radionuclides is strongly affected by the geochemistry (particularly the oxidation-reduction potential of the repository and ground water) and by the potential presence of complexing agents. These should be included in the proposed research program."
>
> U.S. DOE (Oct., 1980) V.3, p. 258

> "It is therefore clear that burial grounds should be chosen only on the basis of extensive geological, hydrogeological and geochemical investigations. Contact between the radioactive materials and percolating ground water must be prevented. Arid areas are best suited in this connection. Where such areas are not available, the water table should be well below the bottom of the trenches or wells. Leaching can be prevented if the geological structure is impermeable. However, if leaching should occur, the ion exchange capacity of the geological materials should be adequate to restrict the migration of radionuclides."
>
> OECD (1972) p. 160

> "The site shall have geochemical characteristics compatible with waste containment, isolation, and retrieval."
>
> NWTS Program Office (Feb., 1981) p. 7

> "Site suitability for radioactive materials disposal depends on its ability to retain such materials and prevent the radioactivity from becoming a public hazard. Properly assessing this ability requires that qualified geologists, geochemists. and hydrologists study and define the site's earth science characteristics (geology, geochemistry, hydrology, soil, water chemistry, and climatology). Such studies may require 2 to 5 years of data before interpretations can be made."
>
> GAO Rept. (1976) p. 9

Additional references include: Ames and Rai, 1978, p. 2-2; Barnes, 1979, p. 67; Cartwright et al., 1978, p. 5; Klingsberg and Duguid, 1980, p. 2-3; Morton, 1968, p. 29; NWTS Program Office, Feb., 1981, p. 7-8; Relyea, J. R., D. Rai, and R. J. Searne, 1979, Abstract.

Natural Site Considerations

HOST MATERIAL

Porosity

Porosity is the amount of void space in the host material and is usually expressed as a percent of the total volume of material. This represents the space that can normally be filled by liquids and hence is related to permeability.

> "The specific hydrological parameters are the dispersivity and the ground water flow rates, which are largely determined by factors such as porosity, permeability, fractures, and hydraulic heads and gradients in the geological environment."
>
> Frye et al. (1978) p. 10

> "The principal mechanism that prevents or retards water-borne movement of radionuclides that may be leached from wastes buried in the ground is sorption on soil and mineral particles. For this reason accurate information is needed on the composition, permeability, porosity, and sorptive (ion exchange) properties of the overburden and bedrock at the burial site under construction."
>
> Morton (1968) p. 29

> "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 should be measured at different water contents and suctions."
>
> GAO Rept. (1976) p. 43

Additional references include: Barnes, 1979, p. 7, 56; Galley, 1972, p. 119-120; Klingsberg and Duguid, 1980, p. 27; Lipschutz, 1980, p. 75-76.

Fractures contribute to porosity, but represent a special consideration. Since construction can fracture the host material, it is important to know the effect of construction on the porosity of the host material.

> Excavation "may produce significant displacements" which "may alter significantly the porosity and permeability of the rock mass." In addition, solution or deposition along fractures may alter the attenuation capacity of the fracture plane surfaces. If fractures form sometime after the repository is constructed, it will be difficult, if not impossible to assess their impact.
>
> Barnes (1979) p. 36

Natural Site Considerations

HOST MATERIAL

Permeability

The terms "permeability" and "hydraulic conductivity" are often used synonymously; however, permeability is only a function of the host material. Since it has a direct effect on flow rates, permeability is an important criterion in evaluating potential low-level waste disposal sites.

> "Since containment is the primary goal, a minimal permeability of the rock formations should be the first property assessed. The ideal condition would be an entirely impermeable material."
>
> TENRAC (1980) p. 60

> "The principal mechanism that prevents or retards water-borne movement of radionuclides that may be leached from wastes buried in the ground is sorption on soil and mineral particles. For this reason accurate information is needed on the composition, permeability, porosity, and sorptive (ion exchange) properties of the overburden and bedrock at the burial site under construction."
>
> Morton (1968) p 29

> "Suggested geologic and hydrologic criteria for shallow burial of hazardous waste in New Mexico include: (1) rock type and permeability;... (2) absence of known aquifers below or adjacent to site and minimum depths to the water table exceeding 100-200 feet (31 to 62 m); (3) surface stability in terms of water and wind erosion, with minimum land-surface ages in the 10,000 to 100,000-year range; the site should also be stable in terms of seismic and solution subsidence processes; (4) absence of known mineral and geothermal resources whose development could be affected by disposal operations."
>
> Hawley and Gallaher (1981) p. 561

Additional references include: Barnes, 1979, p. vi, vii, 7, 19, 56; Cartwright et al., 1981, p. 3; Galley, 1972, p. 119-120; LeGrand, 1980, p. ii, 17; Lipschutz, 1980, p. 75-76; TENRAC, 1980, p. 59-60.

Because fractures can affect permeability (and construction often produces fractures), the impact of construction on permeability must be assessed.

> "Fractures or bedding planes may cause local high permeability zones in otherwise impervious materials."
>
> TENRAC (1980) p. 60

> Excavation "may produce significant displacements" which "may alter significantly the porosity and permeability of the rock mass." In addition, solution or deposition along fractures may alter the attenuation capacity of the fracture plane surfaces. If fractures form sometime after the repository is contructed, it will be difficult, if not impossible to assess their impact.
>
> Barnes (1979) p. 36

Natural Site Considerations

HOST MATERIAL

Corrosivity

"Reactivity of the waste materials with the host rock is extremely important. It is possible that reactions between the host and waste mateials (sic) may alter the physical nature of the enclosing material. This in turn could lead to leakage and contamination of adjacent formations. Materials which generally have low reactivity with corrosive substances include anhydrite, salt, and shale or clay. Materials which have strong sorptive properties are desirable; clays are attractive hosts for this reason. Anhydrite and salt are generally unsuitable for near-surface storage because of their high solubility in water."

TENRAC (1980) p. 60

Additional references include: Lipschutz, 1980, p. 75-76; TENRAC, 1980, p. 59.

Mineral Surface Area

"The rock should show good ion exchange properties. Most of these processes will involve exchange in the outer few layers of the surfaces of minerals. Thus, rocks with the greatest mineral surface areas, fine grained rocks, should be best. It is not too difficult to estimate which minerals are the most likely to exchange with and dilute a radioactive species. Clay minerals and zeolites are likely to be the best general cation exchangers. One wishes to present the solutions with a maximum array of sites, both chemically and structurally. Highly zeolitized volcanics or black pyritic shale could easily be good candidates on this basis.

Barnes (1979) p. 55-56

No additional references.

Rock and Soil Mechanics

Although not directly connected to radionuclide migration, the rock and soil mechanics of the host material may affect human health and safety. This could occur through the effect of rock and soil mechanics on: 1) construction and operation practices and 2) the fracture condition of the host material. Topics mentioned in the literature for this criterion include: failure criteria; rock bursts; joint failures; underground opening stability; stress resistance; strength; plasticity; and dehydration.

Additional references include: Barnes, 1979, p. 14, 46, 53, 67; Lipschutz, 1980, p. 75-76; Price, 1980, p. 209.

Natural Site Considerations

GEOLOGY

Geology is one of the most important criteria in the evaluation of a low-level radioactive waste disposal site.

As a criterion, geology involves: 1) mapping and describing the geologic material surrounding the host material and 2) identifying the geologic processes of the site and area. The geology of the site and the region should both be studied to determine the effects of the geology on the waste, as well as the effects of the waste on the geology. In this report the criterion "geology" is divided into nineteen sections: geologic investigation of the site; geologic investigation of the region; mineralogy; clay content; grain size; sorption; ion exchange; salinity; solubility; subsidence; dissolution voids; caverns and karst; fractures and joints; faulting; folding; structural stability; excavation characteristics; landslides; and creep.

> "The site shall have geologic characteristics compatible with waste containment, isolation, and retrieval."
>
> NWTS Program Office (Feb., 1981) p. 8

> "It is therefore clear that burial grounds should be chosen only on the basis of extensive geological, hydrogeological and geochemical investigations. Contact between the radioactive materials and percolating ground water must be prevented. Arid areas are best suited in this connection. Where such areas are not available, the water table should be well below the bottom of the trenches or wells. Leaching can be prevented if the geological structure is impermeable. However, if leaching should occur, the ion exchange capacity of the geological materials should be adequate to restrict the migration of radionuclides."
>
> OECD (1972) p. 160

> "Site suitability for radioactive materials disposal depends on its ability to retain such materials and prevent the radioactivity from becoming a public hazard. Properly assessing this ability requires that qualified geologists, geochemists, and hydrologists study and define the site's earth science characteristics (geology, geochemistry, hydrology, soil, water chemistry, and climatology). Such studies may require 2 to 5 years of data before interpretations can be made."
>
> GAO Rept. (1976) p. 9

> "In view of the high costs of constructing and operating a successful waste-management facility, and especially in view of the crises to be faced in the event of failure, it is obvious that full geologic and hydrologic investigations must be conducted before the disposal site is acquired."
>
> Galley (1972) p. 123

> "A special detailed investigation of the geology of the site area and the site vicinity should be conducted to identify tectonic structures that might localize earthquakes in the site area, to establish a basis for

determining the age of movement of faults that may be present, to identify geological hazards, such as karstic phenomena or subsidence, that may affect safety, and to determine seismic energy transmission characteristics of the site area."

IAEA (1979) p. 6

"Although not a key issue in the selection of a temporary site for interim storage, the geology must be considered in the selection of any site."

Illinois Rept. (1980) p. 16

"Geologic mapping of new waste burial pits is routinely conducted to collect structural geology data on the area and to make sure that there are no large unsealed fractures in the walls, as open fractures would provide potential migration pathways."

Johnson et al. (June, 1977) p. 7

Additional references include: Illinois Rept. 1980, p. 16; Barnes, 1979, p. 46, 67; Cartwright et al. 1981, p. 5; DeBuchananne, 1974, p. 361; Donohue and Associates, 1980, p. 1; Galley, 1972, p. 123; Gibbs, 1980, p. 488; Hawley and Gallaher, 1981, p. 561; IAEA, 1966, p. 416; IAEA, 1979, p. 5; Jacobs, Epler, and Rose, 1980, p. 38; Klingsberg and Duguid, 1980, p. 2-3; Macbeth et al., 1979, p. 29; NWTS Program Office, Feb., 1981, p. 8-9; Papadopulos and Winograd, 1974, p. 1-2; Steger, 1979, p. 669; Tennessee Rept., Nov., 1980, p. 34; TENRAC, 1980, p. 15; U.S. AEC, 1974, p. G-5; U.S. EPA, Feb., 1977, p. 2-28; U.S. NRC, Feb., 1981, p. 10.

Natural Site Considerations

GEOLOGY

Geologic Investigations of the Site

"Each site environment has inherent characteristics which must be studied and evaluated especially for that site."

Morton (1968) p. 29

"An assessment of the adequacy of multiple natural and engineered barriers, of a host rock and its environment, of conservative engineering practices, and of any particular waste form or container requires detailed and time consuming site specific evaluations. Generic geologic studies and/or performance assessments of hypothetical sites, although useful for site selection and development of techniques, do not constitute a sufficient basis for some aspects of repository design or for final determination of site suitability. The natural variability of geohydrologic, geochemical, and tectonic conditions, as well as the heterogeneity of rock masses, reduces the reliability of transferring detailed geologic data from one location to another."

Klingsberg and Duguid (1980) p. 2-3

"However, not all the outlined information is likely to be needed at all sites."

Papadopolus and Winograd (1974) p. 19

"Regulations with rigid specifications of geologic and hydrologic criteria for sites, such as to specify a minimum distance above the water table, are conceptually incorrect and cannot be applied to the entire United States, or even to an entire state in most cases. Strict application of some criteria, such as the depth to water table, can actually lead to the selection of less suitable sites. Rather, regulations should provide performance standards that the disposal site must meet to be acceptable and should be applied on a site-by-site basis."

Cartwright et al. (1981) p. 4

"An ideal setting would be in an isotropic host rock situated in seismically stable area that is totally free of fluids. Since this situation is unlikely to exist, careful analyses will be necessary to determine that, despite the deviations from the ideal, the conditions that do prevail will, nonetheless, fulfill the regulatory objectives for the disposal program. In order to effect these analyses, regional investigations as well as site-specific studies are recommended."

Barnes (1979) p. 4

Additional references include: Environmental Resources Management, 1980, no pages given; Lipschutz, 1980, p. 171; EG&G, Idaho, Inc., 1980, no pages given.

Natural Site Considerations

GEOLOGY

Geologic Investigations of the Region

The text suggests that "a well documented knowledge of the regional geology is imperative" to convince the public that a thorough study has been conducted and to give a more complete picture than a site specific study.

Barnes (1979) p. 4

"An ideal setting would be in an isotropic host rock situated in a seismically stable area that is totally free of fluids. Since this situation is unlikely to exist, careful analyses will be necessary to determine that, despite the deviations from the ideal, the conditions that do prevail will, nonetheless, fulfill the regulatory objectives for the disposal program. In order to effect these analyses, regional investigations as well as site-specific studies are recommended."

Barnes (1979) p. 4

Additional references include: IAEA, 1979, p. 5.

Mineralogy

The criterion of mineralogy is important for understanding the chemical reactions that might take place between the waste and the host material, as well as aiding in geologic interpretations.

"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 should be measured at different water contents and suctions."

GAO Rept. (1976) p. 43

"Characterization of the subsurface setting will include all pertinent physical, structural, mineralogical, and geochemical features of the rock units, the geologic conditions shall be shown to not unacceptably affect system performance."

NWTS Program Office (Feb., 1981) p. 8

No additional references.

Natural Site Considerations

GEOLOGY

Clay Content

Clay affects the permeability and the sorption of leachate. The type, quantity and location of clay at a potential low-level waste site must therefore be assessed.

"The following hydrogeologic features are considered favorable for management of contaminants near the land surface.

1. Sufficient permeability of surface soils to allow infiltration and thus prevent overland movement of contaminants.
2. Sufficient clay in the path that contaminants will take so that retention or sorption of contaminants is favorable.
3. A deep water table, which allows for sorption of contaminants on earth materials, slows subsurface movement of contaminants, and facilitates oxidation or other beneficial 'die-away' effects.
4. A great distance between wells and waste sites so that advantages of the above factors can accumulate.
5. A gradient of the water table beneath a waste site away from nearby wells.

LeGrand (1980) p. 17-18

Additional references include: Lipschutz, 1980, p. 75-76.

Grain Size

The grain size of the host material is closely related to the clay content of that material. The size of grains affects both the permeability and sorption properties.

"The native soil at the disposal site should have good ion exchange and sorptive properties, which usually accompany fine-textured material.

Macbeth et al. (1979) p. 29

"The rock should show good ion exchange properties. Most of these processes will involve exchange in the outer few layers of the surfaces of minerals. Thus, rocks with the greatest mineral surface areas, fine grained rocks, should be best. It is not too difficult to estimate which minerals are the most likely to exchange with and dilute a radioactive species. Clay minerals and zeolites are likely to be the best general cation exchangers. One wishes to present the solutions with a maximum array of sites, both chemically and structurally. Highly zeolitized volcanics or black pyritic shale could easily be good candidates on this basis."

Barnes (1979) p. 55-56

Additional references include: IAEA, 1979, p. 28-29.

Natural Site Considerations

GEOLOGY

Sorption

"The ability of earth materials to sorb, or otherwise immobilize or slow down the movement of water-borne radioactive waste, is the principal reason some environments are acceptable for the disposal of low-level radioactive waste."

DeBuchananne (1974) p. 359

"Since the sorption characteristics and reactivity of host rocks to radioactive solutes are among the most important properties of the multiple barrier concept, they should be more clearly developed. In this connection, shales could be superior to other proposed rock types provided that there is not large-scale lateral migration of ground water through the shale."

U.S. DOE (Oct., 1980) V.3 p. 431-432

"The native soil at the dispoal site should have good ion exchange and sorptive properties, which usually accompany fine-textured material."

Macbeth et al. (1979) p. 29

"The annual precipitation at ORNL is the highest of all of the burial sites and the only significant barrier to radionuclide migration is the adsorptive property of the soil (USERDA 76b)."

Jacobs, Epler, and Rose (1980) p. 6

"For the purposes of waste management, knowledge of the adsorption properties of the soil and of the ground-water contamination is required for assuring the continued safe disposal of radioactive wastes; knowledge of the exact location of the radioisotopes fixed on a given soil column is not considered to be essential."

Pearce et al. (1960) p. 359

"Granted the importance of the total solution concentrations of the element, the nature of the predominant solution species are important since they affect 1) adsorption through their charge; 2) adsorption because of changes in the nature of the species due to alteration if solution properties such as pH, Eh, competing ions and complexing ions; 3) movement through the soil and rock matrix because of their physical size; and 4) plant uptake."

Ames and Rai (1978) p. 2.2

Additional references include: DeBuchananne, 1974, p. 359; Cartwright et al., 1981, p. 5; Klingsberg and Duguid, 1980, p. 27; LeGrand, 1980, p. ii, 15, 17; Massachusetts Rept., 1980, p. 19; Morton, 1968, p. 3, 4, 29; Panel on Hanford Wastes, 1978, p. 4; Relyea, Rai and Serne, 1979, Abstract; Steger, 1979, p. 670.

Natural Site Considerations

GEOLOGY

Ion Exchange

"Ion exchange is one of the major interactions of the radionuclides with the formation. However, the presence of fissures in the geologic unit may short circuit opportunities for ion exchange of radionuclides mobilized during leaching in infiltrating water."

Jacobs, Epler, and Rose (1980) p. 9

"The soil provides good ion exchange characteristics to minimize percolation of radioactivity which may be leached from the solid waste to the groundwater. There is no nearby use of groundwater or well water downstream from the site. The site and its vicinity have the characteristically slow water movement through the soil in a direction in which there is little or no land use."

U.S. Atomic Energy Commission (1974) p. G-7

"4. Sorption and Ion Exchange - the distribution coefficient and the partial ion-exchange capacity of each soil and rock type must be determined for the appropriate radionuclides."

Steger (1979) p. 670

"The rock should show good ion exchange properties. Most of these processes will involve exchange in the outer few layers of the surfaces of minerals. Thus, rocks with the greatest mineral surface areas, fine grained rocks, should be best."

Barnes (1979) p. 55-56

Additional references include: Ames and Rai, 1978, p. 2-13; Barnes, 1979, p. 55; Jacobs, Epler, and Rose, 1980, p. 10; Morton, 1968, p. 29; Naeser, 1961, Abstract.

Natural Site Considerations

GEOLOGY

Salinity

"In general, the rocks should be salt free, for it is well known that high salt concentrations in the fluid will tend to block or compete with ion exchange on mineral surfaces to complex many metals.

Barnes (1979) p. 55

No additional references.

Solubility

"Reactivity of the waste materials with the host rock is extremely important. It is possible that reactions between the host and waste mateials (sic) may alter the physical nature of the enclosing material. This in turn could lead to leakage and contamination of adjacent formations. Materials which generally have low reactivity with corrosive substances include anhydrite, salt, and shale or clay. Materials which have strong sorptive properties are desirable; clays are attractive hosts for this reason. Anhydrite and salt are generally unsuitable for near-surface storage because of their high solubility in water."

TENRAC (1980) p. 60

Excavation "may produce significant displacements" which "may alter significantly the porosity and permeability of the rock mass." In addition, solution or deposition along fractures may alter the attenuation capacity of the fracture plane surfaces. If fractures form sometime after the repository is constructed, it will be difficult, if not impossible to assess their impact.

Barnes (1979) p. 36

Additional references include: Lipschutz, 1980, p. 75-76; TENRAC, 1980, p. 59.

Natural Site Considerations

GEOLOGY

Subsidence

"The criteria are based on: (1) thickness, excavation characteristics, permeability, solubility, and reactivity of the host material with the waste products; (2) hydrologic parameters including depth of water table, seasonal variation in water table level, and rate of liquid movement; (3) nature of erosion; and (4) potential for subsidence."
TENRAC (1980) p. 59

"Suggested geologic and hydrologic criteria for shallow burial of hazardous waste in New Mexico include: (1) rock type and permeability;... (2) absence of known aquifers below or adjacent to site and minimum depths to the water table exceeding 100-200 feet (31 to 62 m); (3) surface stability in terms of water and wind erosion, with minimum land surface ages in the 10,000 to 100,000-year range; the site should also be stable in terms of seismic and solution subsidence processes; (4) absence of known mineral and geothermal resources whose development could be affected by disposal operations."
Hawley and Gallaher (1981) p. 561

"The geology should be studied to determine other potential problems such as dislocation due to earth tremors, or mine subsidence."
Illinois Rept. (1980) p. 16

"The site should be located where faults, liquefaction, land slides, volcanoes, or land subsidence will not jeopardize site performance."
Falconer (1981) no pages given

Additional references include: IAEA, 1979, p. 2, 6, 31; TENRAC, 1980, p. 43.

Natural Site Considerations

GEOLOGY

Dissolution Voids

"Existing solution features must be analyzed to identify the rate of dissolution. The effects of further dissolution or of new dissolution features on system performance must be evaluated."

NWTS Program Office (Feb., 1981) p. 7

"The site shall be located so that subsurface rock dissolution that may be occurring, or is likely to occur, can be shown to have no unacceptable impact on system performance."

NWTS Program Office (Feb., 1981) p. 7

Additional references include: IAEA, 1979, p. 31.

Caverns and Karst

"A special detailed investigation of the geology of the site area and the site vicinity should be conducted to identify tectonic structures that might localize earthquakes in the site area, to establish a basis for determining the age of movement of faults that may be present, to identify geological hazards, such as karstic phenomena or subsidence, that may affect safety, and to determine seismic energy transmission characteristics of the site area."

IAEA (1979) p. 6

Additional references include: IAEA, 1979, p. 2, 31.

Natural Site Considerations

GEOLOGY

Fractures and Joints

Areas with large or numerous fractures are generally poor sites.

Fractures are extremely important in evaluating potential disposal sites for low-level radioactive waste because they can affect so many other criteria. Fractures allow for directionally channelized flow that is difficult to model and monitor. They reduce the ability of the host material to retard the waste and decrease the structural stability of the site, especially if blasting is used during excavation.

> "Much of the regional work essentially revolves around locating major faults and fractures and identifying their characteristics. A comprehensive study of these structures is essential because their characteristics may cause a rejection of a site for two reasons. Firstly, they serve as potential pathways for groundwater movement and secondly, they may be reactivated, resulting in seismic activity. Understanding the evolution, or paleotectonic function(s), of faults and fractures is an important first step in assessing the probability of future earthquake activity along them. In this regard it would be advisable in evaluating a site for waste disposal to attempt to determine the age of the latest fault movements. The reason is that if it can be demonstrated that no movements have occurred in recent geological time then a good possibility exists that natural tectonic processes will not disrupt the satisfactory retardation of radionuclides to the biosphere."
>
> Barnes (1979) p. 5

> "The burial zone should be separated from fractured bedrock by an interval of geologic deposits sufficient to prevent migration of radionuclides into the fractured zone."
>
> Papadopulos and Winograd (1974) p. 6

> "Fractures or bedding planes may cause local high permeability zones in otherwise impervious materials."
>
> TENRAC (1980) p. 60

> "If granite bodies are to be used as receptacles for toxic waste materials, the presence or absence of barren fractures and the virgin stresses in the granite are of fundamental importance."
>
> Price (1980) p. 209

> "Ideally, precipitation at the potential site should be low; the distance to any aquifers should be long; aquifer flows and utilization should be low; and underlying strata should be neither highly fractured nor contain voids and flow channels."
>
> Macbeth et al. (1979) p. 29

> "Ion exchange is one of the major interaction of the radionuclides with the formation. However, the presence of fissures in the geologic unit may short circuit opportunities for ion exchange of radionuclides mobilized during leaching in infiltrating water."
>
> Jacobs, Epler, and Rose (1980) p. 9

"Geologic mapping of new waste burial pits is routinely conducted to collect structural geology data on the area and to make sure that there are no large unsealed fractures in the walls, as open fractures would provide potential migration pathways."

Johnson et al. (June, 1977) p. 7

"The specific hydrological parameters are the dispersivity and the ground water flow rates, which are largely determined by factors such as porosity, permeability, fractures, and hydraulic heads and gradients in the geological environment."

Frye et al. (1978) p. 10

Additional references include: Barnes, 1979, p. 36, 51-53, 61; DeBuchananne, 1974, p. 357; Lipschutz, 1980, p. 75, 76; U.S. DOE, Oct., 1980, V.3, p. 248-249; U.S. NRC, Feb., 1981, p. 15.

Fractures have a significant impact on hydrogeology, as illustrated by the following quotations.

"That particular research emphasis must be placed on those technical areas where fundamental scientific questions remain unanswered. Fracture hydrology, hydrogeochemistry and geophysical monitoring systems are examples of such areas."

Barnes (1979) p. xi-xii

"In addition there is a need to assist the hydrogeologists in their determinations of the flow of water through fractured rock media. Emphasis is thus being given to geophysical methods of determining water flows and regional aquifer characteristics as well as evaluations of the nature of fractures intersected by drill-holes."

Dence and Scott (1980) p. 190

Except in unusual circumstances the direction and rate of groundwater flow as well as the retardation effects are very difficult or impossible to predict in ground-water regimes in fractured rocks. This lack of predictability necessitates that fractured rock be regarded as a major hazard in terms of subsurface radioactive waste management. In fact, it is doubtful if contaminated ground water could be effectively detected and monitored in some types of fractured rock."

Papadopulos and Winograd (1974) p. 6

Additional references include: Waters, Palmer, and Farrell, 1978, Abstract.

Barnes considers the following characteristics of fractures and joints to be important: apertures, intersects, geometry, attitude, spacing, and continuity (Barnes, 1979, p. 19, 51, 52, 53).

Natural Site Considerations

GEOLOGY

Faulting

Areas with capable faults should be avoided for siting because the migration of waste could increase as a result of seismic activity.

"Faults along which rupture could occur must be avoided."
Frye et al. (1978) p. 7

"Faults, which are natural fractures commonly extending at a high angle through several formations and along which the rocks on one side have been displaced relative to those on the other side, are to be avoided because they are potential escape routes for injected fluids."
Galley (1972) p. 122

"The site should not be located near a capable fault such that the migration of waste could increase as a result of seismic activity."
Massachusetts Rept. (1980) p. 19

"The site should be located where faults, liquefaction, land slides, volcanoes, or land subsidence will not jeopardize site performance."
Falconer (1981) no pages given

"Potentially hazardous geologic elements, including faults of any age, volcanoes, and anomalous geothermal gradients, must be sufficiently investigated to allow determination of their potential effects on system performance and to show that these effects will not unacceptably affect system performance."
NWTS Program Office (Feb., 1981) p. 8-9

"A special detailed investigation of the geology of the site area and the site vicinity should be conducted to identify tectonic structures that might localize earthquakes in the site area, to establish a basis for determining the age of movement of faults that may be present, to identify geological hazards, such as karstic phenomena or subsidence, that may affect safety, and to determine seismic energy transmission characteristics of the site area."
IAEA (1979) p. 6

"Regarding, jointing, faulting, and fracturing, one commenter recommended the addition of the following sentence: 'They increase the time and cost of investigations, complicate the representative quantitative modeling necessary for design, and decrease confidence that all conditions are known.'"
U.S. DOE (Oct., 1980) V.3, p. 248-249

Additional references include: Barnes, 1979, p. 61; IAEA, 1979, p. 2, 5; Lipschutz, 1980, p. 75, 76, 105; Massachusetts Rept., 1980, p. 19; Papadopulos and Winograd, 1974, p. 1-2; U.S. EPA, Feb., 1977, p. 2-28; U.S. NRC, Feb., 1981, p. 15.

Specific aspects of faulting that should be investigated include: 1) length 2) age 3) dip 4) strike 5) depth 6) type 7) style and 8) density. These topics are mentioned in Barnes (1979, p. 4), IAEA (1979, p. 5) and Lipschutz (1980, p. 75-76).

Natural Site Considerations

GEOLOGY

Folding

The folding of geologic strata can change a waste disposal site radically. The change might include shape, size, density, and groundwater flow paths.

> The site should be relatively stable structurally and geomorphically. Areas where tectonic processes such as faulting, folding, seismic activity or volcanism may adversely affect the ability of the site to isolate the wastes shall be avoided."
>
> U.S. NRC (Feb., 1981) p. 15

Additional references include: IAEA, 1979, p. 5.

Structural Stability

> "Site Characteristics
>
> (5) Geomorphic and structural stability. The site should be relatively stable structurally and geomorphically. Areas where tectonic processes such as faulting, folding, seismic activity or volcanism may adversely affect the ability of the site to isolate the wastes shall be avoided. Areas where surface geologic processes such as mass wasting, erosion, slumping, landsliding, or weathering occur with such frequency and extent so as to significantly affect the ability of the site to isolate the waste or to preclude defensible modeling and prediction of long term impacts shall be avoided."
>
> U.S. NRC (Feb., 1981) p. 15

> "Geologic mapping of new waste burial pits is routinely conducted to collect structural geology data on the area and to make sure that there are no large unsealed fractures in the walls, as open fractures would provide potential migration pathways."
>
> Johnson et al. (June, 1977) p. 7

> "Much of the regional work essentially revolves around locating major faults and fractures and identifying their characteristics. A comprehensive study of these structures is essential because their characteristics may cause a rejection of a site for two reasons. Firstly, they serve as potential pathways for groundwater movement and secondly, they may be reactivated, resulting in seismic activity. Understanding the evolution, or paleotectonic function(s), of faults and fractures is an important first step in assessing the probability of future earthquake activity along them. In this regard it would be

advisable in evaluating a site for waste disposal to attempt to determine the age of the latest fault movements. The reason is that if it can be demonstrated that no movements have occurred in recent geological time then a good possibility exists that natural tectonic processes will not disrupt the satisfactory retardation of radionuclides to the biosphere."

Barnes (1979) p. 5

"Characterization of the subsurface setting will include all pertinent physical, structural, mineralogical, and geochemical features of the rock units. The geologic conditions shall be shown to not unacceptably affect system performance."

NWTS Program Office (Feb., 1981) p. 8

Additional references include: Barnes, 1979, p. 14, 51, 52, 53; IAEA, 1979, p. 5; Lipschutz, 1980, p. 75, 76.

Barnes (1979, p. 51-53) mentions the following specific aspects of structural stability: 1) peak strength 2) residual strength 3) cohesion 4) angle of friction and 5) in situ stresses, including magnitude, direction, and variation with depth.

Natural Site Considerations

GEOLOGY

Excavation Characteristics

"Excavation characteristics of the host material provide a measure for determining the expense of operating a particular site. Blasting, for example, would be an unnecessary expense if sites were available where no blasting was required for excavation. Also, blasting generally yields unwanted fractures which readily transport groundwater or other fluids."

TENRAC (1980) p. 61

"Landfills designed to meet performance standards should take into account six factors: (1) the type of waste to be disposed; (2) the site hydrogeology that governs the direction and rate of contaminant travel; (3) the attenuation of contaminants by geochemical interactions with the geologic materials; (4) the release rate of unattenuated pollutants to surface or ground water; (5) character of the receiving waters; and (6) construction problems which may be encountered."

Cartwright et al. (1980) p. 5

"The criteria are based on: (1) thickness, excavation characteristics, permeability, solubility, and reactivity of the host material with the waste products; (2) hydrologic parameters including depth of water table, seasonal variation in water table level, and rate of liquid movement; (3) nature of erosion; and (4) potential for subsidence."

TENRAC (1980) p. 59

Excavation 'may produce significant displacements' which 'may alter significantly the porosity and permeability of the rock mass.' In addition, solution or deposition along fractures may alter the attenuation capacity of the fracture plane surfaces. If fractures form sometime after the repository is constructed, it will be difficult, if not impossible to assess their impact."

Barnes (1979) p. 36

"The facility should not be located in an area where surface geologic processes such as erosion, landsliding or weathering could significantly enhance the hydrogeological transport of LLW from the site."

Massachusetts Rept. (1980) p. 19

"The site should be located where faults, liquefaction, land slides, volcanoes, or land subsidence will not jeopardize site performance."

Falconer (1981) no pages given

Areas where surface geological processes such as mass wasting, erosion, slumping, landsliding, or weathering occur with such frequency and extent so as to significantly affect the ability of the site to isolate the waste or to preclude defensible modeling and prediction of long term impacts shall be avoided."

U.S. NRC (Feb., 1981) p. 15

"Terrain characteristics provide clues to the long term stability of a particular location. These characteristics include steepness of slopes, general topographic character, and surface drainage density. Steep slopes and rugged topography with a high density drainage network indicate relatively high erosion rates. As a result, a repository may be breached by incised drainage, land sliding, or soil creep."

TENRAC (1980) p. 61

No additional references.

Creep

"Terrain characteristics provide clues to the long term stability of a particular location. These characteristics include steepness of slopes, general topographic character, and surface drainage density. Steep slopes and rugged topography with a high density drainage network indicate relatively high erosion rates. As a result, a repository may be breached by incised drainage, land sliding, or soil creep."

TENRAC (1980) p. 61

"Topography. The slope of the land should not allow surface runoff to enter the disposal site; the site should not be located in areas of potential landslide, earth creep, or high rates of erosion.

Cartwright et al. (1981) p. 13

Additional references include: Barnes, 1979, p. 53; GAO Rept. 1976, p. 44.

Natural Site Considerations

GEOPHYSICS

> "Geophysics clearly has a role to play in establishing criteria that must be met by any acceptable disposal site, in developing approaches and techniques for evaluating sites under consideration and in monitoring selected locations during and following waste disposal."
>
> Dence and Scott (1980) p. 190

> "There is thus, little doubt that the use of electrical geophysical methods in attempting to find very dry environments, is one of the most sensitive tools available to us."
>
> Barnes (1979) p. 61

> "In addition there is a need to assist the hydrogeologists in their determinations of the flow of water through fractured rock media. Emphasis is thus being given to geophysical methods of determining water flows and regional aquifer characteristics as well as evaluations of the nature of fractures intersected by drill-holes."
>
> Dence and Scott (1980) p. 190

Additional references include: Barnes, 1979, p. 67.

Natural Site Considerations

GEOPHYSICS

Seismicity

The criterion of "Seismicity" is referenced for two reasons. First, it is important to know what seismic activity might occur at a site and how it would affect site stability. Second, seismic methods are often used to detect faults.

> "The area should be free from seismic activity and likely to remain so."
>
> Gibbs (1980) p. 488

> "The site should be relatively stable structurally and geomorphically. Areas where tectonic processes such as faulting, folding, seismic activity or volcanism may adversely affect the ability of the site to isolate the wastes shall be avoided."
>
> U.S. NRC (Feb., 1981) p. 15

> "They may also change the direction of groundwater flow which, as described below constitutes the principle envisaged means of transporting waste to the biosphere. Thus, it is recommended that a potential site be located in an area historically, and presently, characterized by no or only low level, seismicity."
>
> Barnes (1979) p. 6

> "The site should not be located near a capable fault such that the migration of waste could increase as a result of seismic activity."
>
> Massachusetts Rept. (1980) p. 19

> "The geology should be studied to determine other potential problems such as dislocation due to earth tremors, or mine subsidence."
>
> Illinois Rept. (1980) p. 16

> "There should be extensive testing and subsequent monitoring of sites to observe the seismicity before and after excavation."
>
> Barnes (1979) p. 65

> "Nevertheless, there is evidence that seismic velocities can provide information about the presence or absence of faults and fissures."
>
> Barnes (1979) p. 61

Additional references include: Barnes, 1979, p. 4, 5, 6, 14, 61; Cherry et al., 1979, p. 1024-1025; Hawley and Gallaher, 1981, p. 561; IAEA, 1979, p. 4, 5.

Natural Site Considerations

GEOPHYSICS

Seismicity

Earthquakes

"Earthquakes, whether natural or induced, pose a significant risk to the disposal of toxic wastes by burial or fluid injection in the crust."

Berry and Hasegawa (1980) p. 195

"The site shall be located so that ground motion associated with the maximum credible earthquake will not have unacceptable impact on system performance."

NWTS Program Office (Feb., 1981) p. 9

"All available earthquake information derived from instrumental recordings in the region should be collected."

IAEA (1979) p. 4

"Potential mechanisms through which critical radioelements in low-level solid wastes may be released from a burial site and introduced into the hydrosphere, atmosphere or biosphere are: a) transport of dissolved nuclides by water to wells, gaining streams, or springs; b) transport upward to the soil zone by capillary flow followed by concentration of the nuclides in plants; and c) exposure and overland transport by normal erosion processes (water and wind), erosion due to floods, or erosion following disruption of landscapes by earthquakes."

Papadopolus and Winograd (1974) p. 5

Additional references include: Barnes, 1979, p. 4, 30, 31; IAEA, 1979, p. 6; Lipschutz, 1980, p. 105; Papadopulos and Winograd, 1974, p. 22.

Natural Site Considerations

GEOPHYSICS

Seismicity

Volcanoes

"The site should be relatively stable structurally and geomorphically. Areas where tectonic processes such as faulting, folding, seismic activity or volcanism may adversely affect the ability of the site to isolate the wastes shall be avoided."

U.S. NRC (Feb., 1981) p. 15

"The site should be located where faults, liquefaction, landslides, volcanoes, or land subsidence will not jeopardize site performance."

Falconer (1981) no pages given

"Potentially hazardous geologic elements, including faults of any age, volcanoes, and anomalous geothermal gradients, must be sufficiently investigated to allow determination of their potential effects on system performance and to show that these effects will not unacceptably affect system performance."

NWTS Program Office (Feb., 1981) p. 8-9

"Areas with abnormally high geothermal gradients or with evidence of relatively recent volcanic activity are possible candidates for future volcanic events and should be avoided."

Frye et al. (1978) p. 7

Additional references include: Lipschutz, 1980, p. 105.

Natural Site Considerations

GEOPHYSICS

Tectonics

"The site shall be located so that its tectonic environment can be evaluated with a high degree of confidence to identify tectonic elements and their impact on system performance."

NWTS Program Office (Feb., 1981) p. 8

"The site should be relatively stable structurally and geomorphically. Areas where tectonic processes such as faulting, folding, seismic activity or vulcanism may adversely affect the ability of the site to isolate the wastes shall be avoided."

U.S. NRC (Feb., 1981) P. 15

"A special detailed investigation of the geology of the site area and the site vicinity should be conducted to identify tectonic structures that might localize earthquakes in the site area, to establish a basis for determining the age of movement of faults that may be present, to identify geological hazards, such as karstic phenomena or subsidence, that may affect safety, and to determine seismic energy transmission characteristics of the site area."

IAEA (1979) p. 6

Additional references include: Klingsberg and Duguid, 1980, p. 2, 3; NWTS Program Office, Feb., 1981, p. 9.

Other topics noted as important in the context of tectonics include: 1) isoseismal maps 2) intensity at the epicentre 3) intensity at the site 4) aftershock zone 5) origin time 6) focal mechanisms 7) focal locations 8) peak acceleration and 9) magnitude (Barnes, 1979, p. 6 and IAEA, 1979, p. 3, 4, 5).

Natural Site Considerations

SOILS

The properties of the soil must be considered in any evaluation of a low-level radioactive waste disposal site.

It is difficult to use quotations on soils accurately because some authors use an engineering definition of soil (unconsolidated material) and others use a geological or agricultural definition (the weathered layer that supports plant growth). Although this report will not define soil, we emphasize surface soil or the geologic definition because we want to distinguish between soil and host material (rock). The waste will be buried in the "host material" but the surface will be covered with "soil." Therefore, different properties may be more important for soils than for host material (for more information see the section on "Host Material"). The properties of the surface soil may be important in insuring stable conditions after burial and in cases where there is leachate on the surface. Also of considerable importance is the effect of the soils on infiltration.

> "For the purposes of waste management, knowledge of the absorption properties of the soil and of the ground-water contamination is required for assuring the continued safe disposal of radioactive wastes; knowledge of the exact location of the radiosotopes fixed on a given soil column is not considered to be essential."
>
> Pearce et al. (1960) p. 359

> "The site should be chosen so that the hydrogeologic environment of the area surrounding the disposal site will act to prevent or minimize the migration of waste through groundwater pathways. Site characteristics desirable in achieving this include low groundwater flow rates and soil properties which would absorb the waste material, if it were released."
>
> Massachusetts Rept. (1980) p. 19

Additional references include: GAO Rept., 1976, p. 9; Donohue and Associates, 1980, p. 1.

Natural Site Considerations

SOILS

Permeability

"Any site chosen for temporary or permanent disposal should be located on land that has low permeability and is not subject to flooding or high ground water problems."

Illinois Rept. (1980) p. 16

"The following hydrogeologic features are considered favorable for management of contaminants near the land surface.

1. Sufficient permeability of surface soils to allow infiltration and thus prevent overland movement of contaminants.
2. Sufficient clay in the path that contaminants will take so that retention or sorption of contaminants is favorable.
3. A deep water table, which allows for sorption of contaminants on earth materials, slows subsurface movement of contaminants, and facilitates oxidation or other beneficial 'die-away' effects.
4. A great distance between wells and waste sites so that advantages of the above factors can accumulate.
5. A gradient of the water table beneath a waste site away from nearby wells."

LeGrand (1980) p. 17-18

"Both the Maxey Flats and West Valley sites were located in soils that were exclusively impermeable to water. At both sites, the trenches filled with water and overflowed, resulting in small amounts of radioactivity leaving the trenches. To avoid such problems, minimum acceptable requirements for soil permeability should be established."

U.S. DOE (Mar. 13, 1981) p. 26

No additional references.

Natural Site Considerations

SOILS

Infiltration

Infiltration is an important consideration for management of any low-level radioactive waste site.

Although infiltration is directly related to soil permeability, it is also related to topography and drainage. Therefore it is considered a separate category by many authors. Whereas permeability is considered in respect to migration of fluids, infiltration must also be considered in regard to a balance with erosion.

> "The control of infiltration of water into trenches is a major step in the prevention or minimization of contact between water and buried waste. Infiltration that occurs (1) promotes further infiltration by damaging the structural integrity of the trench cover and trench contents and (2) provides a vehicle for migration of the waste."
>
> Jacobs, Epler, and Rose (1980) p. 19

> "(b) The disposal facility shall be designed and operated to enhance and improve the ability of the natural characterisitics of the site to confine the waste after disposal. Such improvements may include measures to direct surface water away from disposal areas, to reduce infiltration of precipitation into disposal cells or to reduce the potential for erosion. Independent and diverse engineering barriers shall be provided, as necessary, to complement natural barriers in avoiding contact of waste with percolating water, in reducing potential releases from the facility and in complying with the performance objectives of Subpart C."
>
> U.S. NRC (Feb., 1981) p. 15-16

> "Selection of a suitable burial site management program must consider a balance between the control of infiltration and erosion."
>
> Jacobs, Epler, and Rose (1980) p. 19

Additional references include: Falconer, 1981, no pages given; Massachusetts Rept., 1980, p. 19.

Natural Site Considerations

TOPOGRAPHY CRITERIA

There are two reasons for considering topography as a criterion for evaluation of a low-level waste disposal site: 1) topography is critical to the vehicular transportation of waste and the operation of machinery and 2) topography is a geomorphic indicator of natural processes such as erosion and flooding.

The first series of quotations emphasize the importance of topography to the transportation of wastes and the operation of the waste site. Ease of movement to (and within) a site will determine the economic success and safety of a site. In general, flat or gentle topography improves transportation safety and facilitates disposal operations.

> "The site shall be located in an area where surface topographic features do not unacceptably affect repository operation."
>
> NWTS Program Office (Feb., 1981) p. 10

> "The topography of a site including the location of streams and other bodies of surface water is an important consideration in determining site suitability for use as a burial ground. A relatively flat level surface is desirable, as this permits maximum utilization of land and simplifies burial operations. However, in the humid parts of the country, areas with flat level surfaces are usually characterized by shallow water tables, and the land area may be subject to flooding."
>
> DeBuchananne (1974) p. 358

> "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."

Panel on Land Burial (1976) p. 68

Topography is also important as a geomorphic indicator of natural processes. Flat topography can indicate flood prone areas (especially in the humid areas of the eastern U.S.), while steep slopes suggest decreased slope stability and increased erosion potential.

> "For solid wastes, the principal requirement is a shallow burial site in a location which is so situated with respect to surface geologic and geomorphic features that the buried materials are safe from exhumation. Examination of the site with respect to local topography and sediments which reveal past erosional history will provide valuable data on which to base a prognosis for future operations."
>
> Galley (1972) p. 123

V.4 Topography

> "Sites should be chosen in areas that have good drainage of surface water from the site and when surface or sub-surface storage is planned, weather elements such as tornados and high winds will cause no disturbance of the site or facility."
>
> Illinois Rept. (1980) p. 17

> "At INEL the burial grounds are located in a natural topographic depression below the level of the channel of the Big Lost River. The burial ground area has been flooded in periods when rapid snowmelt combined with high rates of precipitation (USERDA 77, Ba 76, Ba 79)."
>
> Jacobs, Epler, and Rose (1980) p. 13

> "Topography. The slope of the land should not allow surface runoff to enter the disposal site; the site should not be located in areas of potential landslide, earth creep, or high rates of erosion."
>
> Cartwright et al. (1981) p. 13

> "Terrain characteristics provide clues to the long term stability of a particular location. These characteristics include steepness of slopes, general topographic character, and surface drainage density. Steep slopes and rugged topography with a high density drainage network indicate relatively high erosion rates. As a result, a repository may be breached by incised drainage, land sliding, or soil creep."
>
> TENRAC (1980) p. 61

Additional references include: Barnes, 1979, p. 14; Donohue and Associates, 1980, p. i; IAEA, 1979, p. 2; Jacobs, Epler, and Rose, 1980, p. 38; Steger, 1979, p. 669.

Natural Site Considerations

CLIMATE CRITERIA

Both the climate and regional location of the site are important in assessing the potential success of the site.

Important areas affected by climate include: pathways of nuclide migration; stability of the site; operation of the site; and potential for disasters. The criterion of climate is divided for clarity and completeness into the following sections: precipitation; evapotranspiration; temperature; wind direction and velocity; trends; cycles; and extremes. The first quotations are of a general nature.

> "The local meteorology must be studied to assure that rain-water intrusion or wind erosion will not enhance the migration of waste to an unacceptable level. This study will also characterize local atmospheric dispersion to allow assessment of the off-site environmental impact from airborne releases."
>
> Massachusetts Rept. (1980) p. 19

> "6. The site should be located in areas where climatologic conditions are sufficiently simple to allow reliable performance prediction.
>
> Climatic cycles and trends need to be accurately predicted to determine their effect on near and long term site performance. Climate should also be characterized to determine the recurrence probabilities of any extreme meterological events which could threaten site performance."
>
> Falconer (1981) no pages given

> "Predictive modeling, monitoring, and management of radionuclides dissolved and transported by groundwater can best be done for sites in relatively simple hydrogeologic settings; namely in unfaulted relatively flat-lying strata of intermediate permeability such as silt, siltstone and silty sandstone. In contract, dense fractured or soluble media, and poorly permeable porous media (aquitards) are not suitable for use as burial sites, first because of media heterogeneity and difficulties of sampling, and consequently of predictive modeling, and second, because in humid zones burial trenched in aquitards may overlflow."
>
> Papadopulos and Winograd (1974) p. 1-2

> "The aridity of the climate may be more important than many other aspects because it affects groundwater migration, one of the primary paths to the biosphere.
>
> Remson (1981) personal communiction

Additional references include: GAO Rept., 1976, p. 9; DeBuchananne, 1974, p. 358; Jacobs, Epler, and Rose, 1980, p. 38; Lipschutz, 1980, p. 105; Macbeth et al., 1979, p. 29; Morton, 1968, p. 28; Panel on Land Burial, 1976, p. 68; Papadopulos and Winograd, 1974, p. 6; Steger, 1979, p. 669; U.S. DOE, Oct., 1980, V.3, p. 213.

Natural Site Considerations

CLIMATE CRITERIA

Precipitation

"The annual precipitation at ORNL is the highest of all of the burial sites and the only significant barrier to radionuclide migration is the adsorptive property of the soil (USERDA 76b)."

Jacobs, Epler, and Rose (1980) p. 6

"The major source of groundwater and surfacewater potentially capable of transporting activity from a burial site to a point of release to the environment is precipitation."

DeBuchananne 91974) p. 358

"(b) The disposal facility shall be designed and operated to enhance and improve the ability of the natural characteristics of the site to confine the waste after disposal. Such improvements may include measures to direct surface water away from disposal areas, to reduce infiltration of precipitation into disposal cells or to reduce the potential for erosion. Independent and diverse engineering barriers shall be provided, as necessary, to complement natural barriers in avoiding contact of waste with percolating water, in reducing potential releases from the facility and in complying with the performance objectives of Subpart C."

U.S. NRC (Feb., 1981) p. 15-16

"A model land burial facility for other than high-level wastes consists of 100 acres of land located in a rural sparsely settled area. The site location is near a highway so that there is reasonable access to the site. The site characteristics are such that the ground water is well below the bottom of the deepest trench. The precipitation in the site area is on the order of a few inches per year up to 35-45 inches per year."

U.S. Atomic Energy Commission (1974) p. G-7

"Ideally, precipitation at the potential site should be low; the distance to any aquifers should be long; aquifer flows and utilization should be low; and underlying strata should be neither highly fractured nor contain voids and flow channels."

Macbeth et al. (1979) p. 29

Additional references include: GAO Rept., 1976, p. 43; Donohue and Associates, 1980, p. 10; Jacobs, Epler, and Rose, 1980, p. 5; Morton, 1968, p. 28.

Natural Site Considerations

CLIMATE CRITERIA

Evapotranspiration

"In a paper on the significance of climate in ground disposal of wastes, Richardson emphasized that climate (particularly precipitation, temperature, and evapotranspiration) has an important influence on the movement of water and dissolved radionuclides at shallow depths below ground, and these factors must be defined for each burial project."

Morton (1968) p. 28

Additional references include: GAO Rept., 1976, p. 43.

Temperature

"In a paper on the significance of climate in ground disposal of wastes, Richardson emphasized that climate (particularly precipitation, temperature, and evapotranspiration) has an important influence on the movement of water and dissolved radionuclides at shallow depths below ground, and these factors must be defined for each burial project."

Morton (1968) p. 28

Additional references include: Donohue and Associates, 1980, p. 10.

Wind

Direction

"In the absence of moving groundwater the rates of movement of non-gaseous radionuclides by molecular or ionic diffusion are very small. However, for some gaseous or volatile radionuclides, transport in the vapor phase may be important. Diffusion coefficients for gaseous radionuclides in air are on the order of 0.1 to 0.5 cm^2/sec. Consequently gaseous radionuclides may move appreciably due to molecular diffusion. For example, radon, a noble gas daughter in the uranium decay series, and tritium may be expected to migrate significantly in the vapor phase. Carbon-14, in the form of CO_2 or short chain hydrocarbons may also move in the vapor phase. The magnitude of such transport should be established by field measurements."

Jacobs, Epler, and Rose (1980) p. 23

Additional references include: Donohue and Associates, 1980, p. 10.

Natural Site Considerations

CLIMATE CRITERIA

Wind

Velocity

"Sites should be chosen in areas that have good drainage of surface water from the site and when surface or sub-surface storage is planned, weather elements such as tornados and high winds will cause no disturbance of the site or facility."

Illinois Rept. (1980) p. 17

Additional references include: Donohue and Associates, 1980, p. 10.

Trends

"Climate cycles and trends need be accurately predicted to determine their effect on near and long term site performance. Climate should also be characterized to determine the recurrence probabilities of any extreme meteorological events which could threaten site performance."

Falconer (1981) no pages given

No additional references.

Cycles

"The site shall be located so that the surficial hydrological system, both during anticipated climatic cycles and during extreme natural phenomena, will not cause unacceptable impacts on repository operations or system performance."

NWTS Program Office (Feb., 1981) p. 10

Additional references include: Falconer, 1981, no pages given.

Extremes

A disposal facility should be "preferably located outside of regions of frequent tornado activity or areas prone to floods."

Illinois Rept. (1980) p. 22

"Climate cycles and trends need be accurately predicted to determine their effect on near and long term site performance. Climate should also be characterized to determine the recurrence probabilities of any extreme meteorological events which could threaten site performance."

Falconer (1981) no pages given

Additional references include: NWTS Program Office, Feb., 1981, p. 10; Illinois Rept., 1980, p. 17.

Natural Site Considerations

HYDROLOGY

Hydrology is considered in the literature as one of the most important technical criteria for evaluating potential sites for low-level radioactive waste disposal.

Hydrology is the science which studies the properties, distribution, and circulation of water on the surface of the land, in the soil and underlying rocks, and in the atmosphere. Water is one of the main pathways through which humans are exposed to radionuclides. While low-level radioactive waste is not very hazardous as an external radiation threat, it represents a danger to public health if it is ingested through water or food. Several areas of hydrology are of particular concern in evaluating potential sites for low-level radioactive waste disposal: regional hydrology; site hydrology; surface hydrology; and subsurface hydrology. Each will be presented separately with representative quotations. The quotations given below pertain to hydrology in general.

> "Because movement by water is the most probable means by which radionuclides might escape to the biosphere, the hydrological factors of the waste repository are among the most critical in choosing a site."
>
> Frye et al. (1978) p. 9

> "The most serious technical problems in shallow land burial are related to water management."
>
> Jacobs, Epler, and Rose (1980) p. 3

> "One of the primary concerns in waste storage is water. Hydrologic characteristics of the host formation and the proximity of the host formation to surface drainage and subsurface aquifers are important considerations. The waste material should be adequately insulated away from both surface water and groundwater. Permeability and formation thickness are the contributing factors. A site should be located where natural buffer zones would prevent interaction of waste materials and hydrologic conduits. Potential flood zones should be avoided."
>
> TENRAC (1980) p. 61

> "Water is the principle vehicle for radionuclide transport; thus knowledge of the direction, depth of water table, flow paths, rate of movement, and dispersion of water coupled with the mechanisms and degree of interactions of specific radionuclides with the formation are required to understand radionuclide migration."
>
> Jacobs, Epler, and Rose (1980) p. 8-9

> "The hydrology of the proposed site and surrounding area is also of special importance."
>
> U.S. DOE (March 13, 1981) p. 27

"The selection of future disposal sites, that will be required as the expansion of nuclear energy continues, will be dependent upon detailed knowledge of the hydrology of the proposed area plus a better understanding of several hydrologic factors that are directly related to the migration of waste."

DeBuchananne (1978) p. 11

"In view of the high costs of constructing and operating a successful waste-management facility, and especially in view of the crises to be faced in the event of failure, it is obvious that full geologic and hydrologic investigations must be conducted before the disposal site is acquired."

Galley (1972) p. 123

"The suitability of a site for burial of radioactive wastes depends on the geological and hydrological characteristics of a site and its ability to retain the radioactive material so that there will be no migration of the radioactive material from the burial site."

U.S. Atomic Energy Commission (1974) p. G-5

Some states have included hydrology in their lists of criteria needed for licensing or permitting low-level waste disposal sites; often this inclusion has been based on prior water management problems at existing sites.

"The criteria are based on: (1) thickness, excavation characteristics, permeability, solubility, and reactivity of the host material with the waste products; (2) hydrologic parameters including depth of water table, seasonal variation in water table level, and rate of liquid movement; (3) nature of erosion; and (4) potential for subsidence."

TENRAC (1980) p. 59

"West Valley and Maxey Flats have been closed temporarily because of water management problems."

Jacobs, Epler, and Rose (1980) p. 4

Water use is especially important. Public water supplies or aquifers used for water supply offer the greatest potential for immediate danger to the public health.

"The hydrology must be such that flow from the disposal site does not lead to areas which provide potential pathways to man, such as fractured bedrock, public waterways, and aquifers used for water supply;"

GAO Rept., (1976) p. 11

The hydrologic system is dynamic and may change over long periods of time due to natural causes or more rapidly due to changes induced by man.

"Major climatic oscillations, with periods on the order of tens of thousands of years, have been a feature of global climate for at least the past million years and may be expected to continue. Therefore, existing paleo-climatological data need to be reviewed to judge the likelihood of the wastes being exposed during a future erosion cycle and/or transported as a result of change in the hydrologic regime."

in Lipschutz (1980) p. 78 by DeBucananne

"The flooding of a large area behind a dam will profoundly modify the hydrologic system. It may take many decades for the area to come into equilibrium with the perturbing force. Further, the added water load on the reservoir floor and the introduction of fluid to greater depths may induce unpredictable seismic disturbances. Several earthquakes in the past have been attributed to this effect."

Frye et al. (1978) p. 15

Additional references include: Barnes, 1979, p. 14, 46; Frye et al., 1978, p. 4, 5; IAEA, 1966, p. 416; Jacobs, Epler, and Smith, 1980, p. 19; Klingsberg and Duguid, 1980, p. 2-3; Lipschutz, 1980, p. 75; Massachusetts Rept., 1980, p. 19; NWTS Program Office, Feb., 1981, p. 7; U.S. AEC, 1974, p. 6-8; U.S. DOE, Mar. 13, 1981, p. 26; U.S. NRC, 1981, p. 10-14.

Natural Site Considerations

HYDROLOGY

Regional Hydrology

The hydrology of the region in which a site might be located should be studied extensively. Two issues are of particular concern: changes to the site from outside influences and the possibility that contaminants from the site could migrate off the site.

"2. Hydrology - A detailed description of the regional and local hydrology must be available to predict ground/surface water interactions and radionuclide transport via the water pathway."

Steger (1979) p. 669

"In addition there is a need to assist the hydrogeologists in their determinations of the flow of water through fractured rock media. Emphasis is thus being given to geophysical methods of determining water flows and regional aquifer characteristics as well as evaluations of the nature of fractures intersected by drill-holes."

Dence and Scott (1980) p. 190

"The only natural vehicle capable of transporting significant quantities of radionuclides away from a burial ground is water, moving under the influence of gravity on and beneath the surface of the ground. Therefore, to evaluate the suitability of a site, it is necessary to determine, in general terms, the amount of water, and its direction and rate of movement at the site; and, of equal importance, the movement of water after it leaves the site."

Morton (1968) p. 28

Additional references include: Barnes, 1979, p. 7, 17.

Natural Site Considerations

HYDROLOGY

Site Hydrology

The relationship between the hydrologic system, the method of burial, and monitoring design is necessary for proper evaluation.

> "Site studies must be conducted to determine the extent that the natural geologic, biologic and hydrologic systems influence the confinement of radionuclides."
>
> Steger (1979) p. 669

> "Site suitability for radioactive materials disposal depends on its ability to retain such materials and prevent the radioactivity from becoming a public hazard. Properly assessing this ability requires that qualified geologists, geochemists, and hydrologists study and define the site's earth science characteristics (geology, geochemistry, hydrology, soil, water chemistry, and climatology). Such studies may require 2 to 5 years of data before interpretations can be made."
>
> GAO Rept. (1976) p. 9

> "The management and disposal of radioactive waste necessitates consideration of geologic and hydrologic processes that can reasonably be expected to supervene during the toxic life of the waste. Each proposed waste site should be studied to assure that the waste products, geologic environment and hydrologic conditions all blend together to facilitate maximum use of geochemical and hydrologic conditions to isolate the waste from the biosphere."
>
> DeBuchananne (1974) p. 361

> "Water and air, however, both as valuable resources to be safeguarded and as transporting agents, usually are the controlling factors in evaluations of proposed facilities for waste burial. Information on these factors must be included in any site evaluation."
>
> Morton (1968) p. 27

Additional references include: GAO Rept., 1976, p. 43; Morton, 1968, p. 28; Steger, 1979, p. 664; Wheeler and Smith, 1979, p. 17.

Natural Site Considerations

HYDROLOGY

Surface Hydrology

Surface water should never come into contact with radioactive waste, nor should it directly affect a disposal site.

However, if a site is poorly drained and water seeps into the host rock and waste, dangerous leachate may be moved via groundwater. Well-drained areas, while preferred for siting, may have other problems: steep grades that complicate disposal options or increase the potential for erosion and possibly site failure.

> "The site shall be located so that the surficial hydrological system, both during anticipated climatic cycles and during extreme natural phenomena, will not cause unacceptable impacts on repository operations or system performance."
>
> NWTS Program Office (Feb., 1981) p. 10

> "The site should be generally devoid of surface water;"
>
> GAO Rept. (1976) p. 11

> "The West Valley and Maxey Flats sites closed in 1975 and 1977, respectively, as a result of operational problems related to water management. Because of poor trench design and site selection, rainwater collected in the trenches and became contaminated with radionuclides. The rainwater had to be collected and processed to protect groundwater and surface-water systems."
>
> EG & G, Idaho, Inc. (1980)

> "Several commenters stated that the final Statement should address the interrelationship between deep and shallow ground-water aquifers and surface water systems and the potential for transport of nuclides between these systems."
>
> U.S. DOE (Oct., 1980) V.3, p 266

> "1. Site Characteristics - Data required include local meteorology, topography, vegetation, surface streams, land and water use, population density and accessibility."
>
> Steger (1979) p. 669

> "One of the primary concerns in waste storage is water. Hydrologic characteristics of the host formation and the proximity of the host formation to surface drainage and subsurface aquifers are important considerations. The waste material should be adequately insulated away from both surface water and groundwater. Permeability and formation thickness are the contributing factors. A site should be located where natural buffer zones would prevent interaction of waste materials and hydrologic conduits. Potential flood zones should be avoided."
>
> TENRAC (1980) p. 61

Knowledge of the distance from a site to surface water systems is important for two reasons: to control contamination that may affect a surface water regime and to predict the dilution and distinction of that contamination.

> "Factors important in locating a shallow land burial facility include distances to ground and surface water systems, meteorology and climatology of the area, degree of remoteness, geologic stability, proximity to the sources of waste, competing uses of the land, and ownership for long-term control."
>
> Macbeth et al. (1979) p. 29

> "Features to be considered include nearby surface water bodies, impoundments, embayments, streams, floodplains, runoff, and drainage. Consideration of such features must include evaluation of their impact on surface and subsurface facilities and onsite access corridors during both the operational phase of the repository and the long-term isolation phase of the disposal system."
>
> NWTS Program Office (Feb., 1981) p. 10

> "The current IEPA guidelines require, in addition to a permeability barrier at the bottom and sides of trenches, a minimum of 500 feet from the nearest water well. To protect surface water, siting on a floodplain is prohibited, surface runoff must be controlled, and the site must be at least 500 feet from a body of surface water."
>
> Cartwright et al. (1981) p. 3

Floodplains and wetlands should also be considered because of their impact on operations and their potential for erosion or infiltration.

> "The site should be generally well drained and devoid of inundation, or frequent ponding or flash flooding such as arrayoes. Floodplains, swamps, bogs and other types of wet or potentially wet terrain should be avoided. No part of the site shall be located in a 100-year floodplain, regulatory floodway, coastal high hazard area, or wetland as defined by the Environmental Protection Agency in 40 CFR 250.43-1."
>
> U.S. NRC (Feb., 1981) p. 13

> "The land surface should be devoid of surface water, except during snowmelt runoff and exceptional periods of rain fall. In other words the sites should not be located in flood plains, swamps, bogs, or other types of very wet (or potentially very wet) terrain."
>
> Papadopulos and Winograd (1974) p. 6

> "The topography of a site including the location of streams and other bodies of surfacewater is an important consideration in determining site suitability for use as a burial ground. A relatively flat level surface is desirable, as this permits maximum utilization of land and simplifies burial operations. However, in the humid parts of the country, areas with flat level surfaces are usually characterized by shallow water tables, and the land area may be subject to flooding."
>
> DeBuchananne (1974) p. 358

To avoid ponding and infiltration, good drainage is often sought.

"Sites should be chosen in areas that have good drainage of surface water from the site and when surface or sub-surface storage is planned, weather elements such as tornados and high winds will cause no disturbance of the site or facility."

Illinois Rept. (1980) p. 17

In locating sites in well-drained areas, the potential for erosion must not be too high.

"(b) The disposal facility shall be designed and operated to enhance and improve the ability of the natural characteristics of the site to confine the waste after disposal. Such improvements may include measures to direct surface water away from disposal areas, to reduce infiltration of precipitation into disposal cells or to reduce the potential for erosion. Independent and diverse engineering barriers shall be provided, as necessary, to complement natural barriers in avoiding contact of waste with percolating water, in reducing potential releases from the facility and in complying with the performance objectives of Subpart C."

U.S. NRC (Feb., 1981) p. 15-16

"Terrain characteristics provide clues to the long term stability of a particular location. These characteristics include steepness of slopes, general topographic character, and surface drainage density. Steep slopes and rugged topography with a high density drainage network indicate relatively high erosion rates. As a result, a repository may be breached by incised drainage, land sliding, or soil creep."

TENRAC (1980) p. 61

"Topography. The slope of the land should not allow surface runoff to enter the disposal site; the site should not be located in areas of potential landslide, earth creep, or high rates of erosion."

Cartwright et al. (1981) p. 13

Implied in the above quotations and other references is the need for detailed descriptions and quantification of hydrologic properties. The following subdivisions of surface hydrology criteria were noted--but not frequently--in the literature. Because of the few references mentioning them, we are providing only a list of these topics: rates and volume of runoff and stream flow; size of drainage basin; flood frequency and potential; drainage pattern; and inventory and long-range plans for engineered structures (for example, dams) affecting the surface water.

Additional references include: Cartwright et al., 1981, p. 3, 5, 9; DeBuchananne, 1974, p. 357, 358, 360; Donohue and Associates, 1980, p. 1; Morton, 1968, p. 3, 4; Papadopulos and Winograd, 1974, p. 5, 22; TENRAC, 1980, p. 43.

Natural Site Considerations

HYDROLOGY

Subsurface Hydrology

Within the major division of hydrology, the criterion of subsurface hydrology is considered as most important by the authors.

The aspects of subsurface hydrology that are presented here include: depth to water; seasonal variations in water table; importance of aquifer; size of aquifer; transmissivity; diffusion coefficient; storage coefficient; hydraulic conductivity and permeability; dispersion and dispersivity coefficients; distribution coefficients; aquifer boundary conditions; recharge areas; discharge areas; location of aquifers, and groundwater flow or gradient.

The following section of general quotations, while lengthy, illustrates the importance given to the criteria of subsurface hydrology by many different authors.

> "The only natural vehicle capable of transporting significant quantitites of radionuclides away from a burial ground is water, moving under the influence of gravity on and beneath the surface of the ground. Therefore, to evaluate the suitability of a site, it is necessary to determine, in general terms, the amount of water, and its direction and rate of movement at the site; and, of equal importance, the movement of water after it leaves the site."
>
> Morton (1968) p. 28

> "Once waste material is buried or released beneath the soil, only water is capable of transporting it in significant quantities away from a burial site or beneath the surface of the ground. For this reason, to evaluate the suitability of the site for disposal it is necessary to determine the amount, direction, and rate of water movement through a disposal site."
>
> DeBuchananne (1974) p. 357

> "The principal means of subsurface migration from any of these sites is assumed to be flowing groundwater. Assessing the extent of or potential for migration at any burial site requires:
>
> (1) definition of the groundwater flow system;
> (2) determination of controlling geochemical factors; and
> (3) determination of leach rates and other source term factors."
>
> Robertson (1980) p. 256

> "The basic problem of ground disposal is the avoidance of contamination of underground water which could finally lead to an unacceptable contamination of drinking water supplies and food chain products."
>
> OECD (1972) p. 160

"Natural waste confinement capability is the most important consideration in selecting sites for burial of solid low-level radioactive waste. Because water is the primary agent for transport of radionuclides from the burial site, more attention should be given to the local hydrogeological system than to any other aspect of the burial site."

Steger (1979) p. 669

"Ideally, a radioactive waste repository should occur in an area with little or no circulating groundwater. However, the occurrence of groundwater should not necessarily remove an area from consideration as a potential site if the collective capabilities of all other hydrogeolgical parameters are judged to be acceptable barriers to waste migration."

Barnes (1979) p. 6-7

"The site shall be located so that the present and probable future geohydrological regime will minimize contact between the ground water and wastes and will prevent radionuclide migration or transport from the repository to the accessible environment in unacceptable amounts."

NWTS Program Office (Feb., 1981) p. 6-7

"A model land burial facility for other than high-level wastes consists of 100 acres of land located in a rural sparsely settled area. The site location is near a highway so that there is reasonable access to the site. The site characteristics are such that the ground water is well below the bottom of the deepest trench. The precipitation in the site area is on the order of a few inches per year up to 35-45 inches per year."

U.S. Atomic Energy Commission (1974) p. G-7

"Aquifers. The site should be isolated from all aquifers that may be used or developed as a source of water."

Cartwright et al. (1981) p. 13

"The site should be chosen so that the hydrogeologic environment of the area surrounding the disposal site will act to prevent or minimize the migration of waste through groundwater pathways. Site characteristics desirable in achieving this include low groundwater flow rates and soil properties which would adsorb the waste material, if it were released."

Massachusetts Rept. (1980) p. 19

"The aridity of the climate may be more important than many other aspects because it affects groundwater migration, one of the primary paths to the biosphere."

Remson (1981) personal communication

"The major vehicle for transport of radionuclides in the ground is the convective movement of groundwater. When water is the transporting vehicle, one must have knowledge of the direction, flow path, rate of movement, and dispersion as well as the mechanism and degree of interactions of specific radionuclides with the formation in order to predict radionuclide migration."

Jacobs, Epler, and Rose (1980) p. 23

"One of the primary concerns in waste storage is water. Hydrologic characteristics of the host formation and the proximity of the host formation to surface drainage and subsurface aquifers are important considerations. The waste material should be adequately insulated away from both surface water and groundwater. Permeability and formation thickness are the contributing factors. A site should be located where natural buffer zones would prevent interaction of waste materials and hydrologic conduits. Potential flood zones should be avoided."

TENRAC (1980) p. 61

"Any site chosen for temporary or permanent disposal should be located on land that has low permeability and is not subject to flooding or high ground water problems."

Illinois Rept. (1980) p. 16

Many other authors consider groundwater important to land use, radionuclide migration, and characteristics of the geologic environment and host material.

"Determining the release rate of unattenuated or poorly attentuated contaminants from fine-grained geolgic materials to surface water or ground water (aquifers) is a necessary step in evaluating a waste disposal site."

Cartwright et al. (1981) p. 9

"The specific hydrological parameters are the dispersivity and the ground water flow rates, which are largely determined by factors such as porosity, permeability, fractures, and hydraulic heads and gradients in the geological environment."

Frye et al. (1978) p. 10

"Groundwater flow should be minimal in the formation and hydraulic conditions both in and above the formation including at the surface should be such as to reduce the possiblity of nuclide migration and possible concentration in the event of leakage."

Gibbs (1980) p. 488

"The soil provides good ion exchange characteristics to minimize percolation of radioactivity which may be leached from the solid waste to the groundwater. There is no nearby use of groundwater or well water downstream from the site. The site and its vicinity have the characteristically slow water movement through the soil in a direction in which there is little or no land use."

U.S. Atomic Energy Commission (1974) p. G-7

"Several commenters stated that the final Statement should address the interrelationship between deep and shallow ground-water aquifers and surface water systems and the potential for transport of nuclides between these systems."

U.S. DOE (Oct., 1980) V. 3. p. 266

"The site should be chosen so that the hydrogeologic environment of the area surrounding the disposal site will act to prevent or minimize the migration of waste through groundwater pathways. Site characteristics desirable in achieving this include low groundwater flow rates and soil properties which would adsorb the waste material, if it were released."

Massachusetts Rept. (1980) p. 19

"The evaluation of the geohydrological regime will include characterization of ground-water residence times, travel times, recharge rates, potentiometric surfaces, and path lengths and orientations. These factors must be assessed to show that path lengths are long enough and transport times are slow enough under present and probable future conditions to constitute effective barriers to radionuclide transport."

NWTS Program Office (Feb., 1981) p. 7

"The parameters which can effect repository safety are rate of access and composition of groundwater, stability of the waste container, stability of the waste form, rock - water - waste interactions, and dilution and dispersion as the waste moves away from the repository site."

Bird (1980) p. 199

"The anticipated conditions should include not only the native hydrogeological characteristics of the site,, but also the changes in parameters that may occur from operation of the facility or from nearby construction."

Jacobs, Epler, and Rose (1980) p. 21

"It is important to be able to estimate as closely as possible: (1) the probable leaching of radionuclides from the wastes: (2) the ability of the soil materials to sorb the radioactive constituents and prevent their movement in surface or groundwater; and (3) the expected pattern of dispersion which might lead to exposures of people and potential radiation hazards."

Morton (1968) p. 3-4

"The geological record of previous hydrological conditions, or the paleo hydrogeological record, should be such that predictions can be made that are favorable for long-term hydrological isolation of the repository site in a perturbed geologic environment."

Frye et al. (1978) p. 10

"Predictive modeling, monitoring, and management of radionuclides dissolved and transported by groundwater can best be done for sites in relatively simple hydro-geologic settings; namely in unfaulted relatively flat-lying strata of intermediate permeability such as silt, siltstone and silty sandstone. In contrast, dense fractured or soluble media, and poorly permeable porous media (aquitards) are not suitable for use as burial sites, first because of media heterogeneity and difficulties of sampling, and consequently of predictive modeling, and second, because in humid zones burial trenched in aquitards may overflow."

Papadopulos and Winograd (1974) p. 1-2

"The site should be located in areas where hydrogeologic conditions are sufficiently simple to allow reliable performance prediction."

Falconer (1981) no pages given

"The hydrogeologic data available at most sites is insufficient to permit the design of an adequate monitoring program (US ERDA 76b, Pru 79, USNRC 76, CG 076, USNRC 76, Pa 74)."

Jacobs, Epler, and Rose (1980) p. 16

"The hydrogeologic conditions must be simple enough for reliable residence time predictions to be made;"

GAO Rept. (1976) p. 11

Additional references include: Barnes, 1979, p. 6, 67; Cartwright et al., 1981, p. 5; DeBuchananne, 1978, p. 12, 13, 357, 358; Dence and Scott, 1980, p. 190; Donohue and Associates, 1980, p. 1, 12, 13; Falconer, 1981, no pages given; Hawley and Gallaher, 1981, p. 561; Klingsberg and Duguid, 1980, p. 66; LeGrand, 1980, p. 28; Lipschutz, 1980, p. 105; EG & G, Idaho, Inc., 1980, no pages given; Macbeth et al., 1979, p. 29; Morton, 1968, p. 28; NWTS Program Office, Feb., 1981, p. 6, 7; OECD, 1972, p. 160; Papadopulos and Winograd, 1974, p. 5; Relyea, J.F., D. Rai, and R.J. Serne, 1979, abstract; Tennessee Rept., Nov., 1980, p. 34; TENRAC, 1980, p. 43, 61.

Natural Site Considerations

HYDROLOGY

Subsurface Hydrology

Depth to Water Table

There are two different opinions about the water table and its affect on low-level radioactive waste disposal: 1) disposal should not occur in the water table portion of any host material; and 2) disposal can occur in the water table portion of any host material, if the hydraulic conductivity and flow rates are low enough to preclude migration of nuclides beyond the site, before their half-lives render them harmless.

Most reports (especially the earlier ones) support the former opinion; however, since sites where the waste can remain above the water table for the duration of the hazardous period are difficult to find, recent publications consider flow rates as the critical limiting factor in siting.

To date, most low-level radioactive waste disposal sites have been located where the water table is important. For this reason and also because of potential significance to waste migration and disposal operations, the criterion of "depth to water table" is discussed extensively in the literature. Although the potentiometric surface of confined systems may have some similarities to the water table, the potential for operational problems and migration of radionuclides are very different. Few authors mention the potentiometric surface, but it should be included in any study or description of subsurface hydrology.

> "The key parameters are: 1. distance to a water supply, 2. depth to water table, 3. hydraulic gradient, and 4. permeability sorption, as indicated by the geologic setting."
>
> LeGrand (1980) p. ii

> "It is very important to determine the maximum elevation and fluctuations of the water table; the direction, slope and velocity of ground water movement; and the places where contaminated ground water might emerge at the surface or where water might enter aquifers containing useful or potentially useful supplies of ground water."
>
> Morton (1968) p. 29

> "Criteria used by Cherry for intermediate-term sites include:
>
> 1. burial site devoid of surface water except snowmelt and rainfall
> 2. burial trenches sufficiently above fractured bedrock to prevent migration of radionuclides through the bedrock
> 3. predicted rate of waste solvents movement provides decades of delay time before radionuclides can reach undesirable areas

4. water table, naturally or artificially, below bottom of burial trenches
5. site hydrologically suitable to monitoring and to waste containment by groundwater flow manipulation by pumping."

DeBuchananne (1974) p. 357

"The site should have sufficent depth to water table to permit all burial operations to occur above the water table,, or an an alternative the site should be suitable for producing an adequate water-table depth by flow system manipulation."

Papadopolus and Winograd (1971) p. 7

"Depth to water table, including perched water tables, if present"

GAO Rept. (1976) p. 43

"It is therefore clear that burial grounds should be chosen only on the basis of extensive geological, hydrogeological and geochemical investigations. Contact between the radioactive materials and percolating groundwater must be prevented. Arid areas are best suited in this connection. Where such areas are not available, the water table should be well below the bottom of the trenches or wells. Leaching can be prevented if the geological structure is impermeable. However, if leaching should occur, the ion exchange capacity of the geological materials should be adequate to restrict the migration of radionuclides."

OECO (1972) p. 160

"(ii) For sites located in predominately course grained materials, the following criteria should be met:

(A) low unsaturated hydraulic conductivity.
(B) low groundwater resource value and inadequate yields for groundwater use in the unconfined and underlying confined aquifers.
(C) sufficient depth to the water table such that the groundwater intrusion, perennial or otherwise, into the waste will not occur.
(D) an area which does not provide significant recharge to the unconfined or underlying confined aquifers.
(E) an absence of discharge areas such as perennial streams, seeps, springs, and wetlands.
(F) sufficient thickness and lateral extent to permit burial of the waste entirely within the unit and to promote retardation, low groundwater flux, and long groundwater travel time to the water table."

U.S. NRC (Feb., 1981) p. 14

"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 scenary, unique flora or fauna, or high recreational potential."

Panel on Land Burial (1976) p. 68

Additional references include: DeBuchananne, 1974, p. 357, 358; Donohue and Associates, 1980, p. 12, 13; Hawley and Gallaher, 1981, p. 561; IAEA, 1979, p. 28, 29; Jacobs, Epler, and Rose, 1980, p. 8, 9; LeGrand, 1980, p. 17, 18; TENRAC, 1980, p. 59.

Natural Site Considerations

HYROLOGY

Subsurface Hydrology

Seasonal Variations in Water Table

Areas with large variations in water table elevation generally should be avoided for siting.

It is difficult to manage or monitor waste sites with large changes in hydraulic head. In addition, the continued wetting and drying of host material may adversely affect the site.

> "Large water table fluctuations should be unlikely."
>
> GAO Rept. (1976) p. 11

> "The criteria are based on: (1) thickness, excavation characteristics, permeability, solubility, and reactivity of the host material with the waste products; (2) hydrologic parameters including depth of water table, seasonal variation in water table level, and rate of liquid movement; (3) nature of erosion; and (4) potential for subsidence."
>
> TENRAC (1980) p. 59

> "Although a proposed site may at the present time be 'dry' and seem free of the effects of groundwater, it undoubtedly is, or at some time during period of concern (up to one million years) will be, in fact, located within an active groundwater flow system."
>
> in (Lipschutz, 1980) p. 77 (APS, 1977)

> "It is very important to determine the maximum elevation and fluctuations of the water table; the direction, slope and velocity of ground water movement; and the places where contaminated ground water might emerge at the surface or where water might enter aquifers containing useful or potentially useful supplies of ground water."
>
> Morton (1968) p. 29

> "The site should:
>
> 1. be geomorphically and seismically stable;
> 2. be such that adequate burial space can be created at a significant depth below the level of active water-table fluctuation in a zone where the rate of hydraulic flow of groundwater is negligible in comparison to rates of molecular diffusion."
>
> Cherry et al. (1979) p. 1024-1025

Additional references include: GAO Rept. 1976, p. 43; Donohue and Associates, 1980, p. 12, 13.

Natural Site Considerations

HYDROLOGY

Subsurface Hydrology

Importance of Aquifer

Waste disposal near important or significant aquifers should be evaluated closely in regard to the potential for contamination or degradation of the aquifer. Aquifers that are very important because of the quantity, quality, or usefulness of the water may need added protection and concern.

The importance of an aquifer is related to several issues: size; type and amount of water use; potential uses (for example, human or animal consumption, irrigation); quality of water; and ease of water retrieval.

> "The possibility of contaminating a really significant body of groundwater by disposal operations needs to be considered."
>
> DeBuchananne (1974) p. 360

> "(ii) For sites located in predominately course grained materials, the following criteria should be met:
>
> (A) low unsaturated hydraulic conductivity.
> (B) low groundwater resource value and inadequate yields for groundwater use in the unconfined and underlying confined aquifers.
> (C) sufficient depth to the water table such that the groundwater intrusion, perennial or otherwise, into the waste will not occur.
> (D) an area which does not provide significant recharge to the unconfined or underlying confined aquifers.
> (E) an absence of discharge areas such as perennial streams, seeps, springs, and wetlands.
> (F) sufficient thickness and lateral extent to permit burial of the waste entirely within the unit and to promote retardation, low groundwater flux, and long groundwater travel time to the water table."
>
> U.S. NRC (Feb., 1981) p. 14

Additional references include: Macbeth et al., 1979, no pages given; U.S. AEC, 1974, p. 6, 7.

Natural Site Considerations

HYROLOGY

Subsurface Hydrology

Size of Aquifer

"Aquifer Sensitivity. The term "Aquifer Sensitivity" is used to indicate the likelihood of, and degree to which ground water resources may be contaminated at a particular site. It also concerns the aquifer's areal extent and importance, or potential importance, as a ground water source. Any sensitivity study must indicate whether or not the aquifer is the only significant one available."

LeGrand (1980) p. 28

"(ii) For sites located in predominately course grained materials, the following criteria should be met:

(A) low saturated hydraulic conductivity.
(B) low groundwater resource value and inadequate yields for groundwater use in the unconfined and underlying confined aquifers.
(C) sufficient depth to the water table such that the groundwater intrusion, perennial or otherwise, into the waste will not occur.
(D) an area which does not provide significant recharge to the unconfined or underlying confined aquifers.
(E) an absence of discharge areas such as perennial streams, seeps, springs, and wetlands.
(F) sufficient thickness and lateral extent to permit burial of the waste entirely within the unit and to promote retardation, low groundwater flux, and long groundwater travel time to the water table."

U.S. NRC (Feb., 1981) p. 13-14

Additional references include: Barnes, 1979, p. 7.

Natural Site Considerations

HYDROLOGY

Subsurface Hydrology

Transmissivity

"Pumping, bailing, or slug tests to determine transmissivity and storage coefficients."

GAO Rept. (1976) p. 43

Additional references include: DeBuchananne, 1974, p. 358..

Diffusion Coefficient

"Diffusion can be an important migration mechanism for the low Kd radionuclides. Its potential contribution to migration should be examined for each radionuclide.:

Ames and Rai (1978) p. 2-15

"The site should:

1. be geomorphically and seismically stable;
2. be such that adequate burial space can be created at a significant depth below the level of active water-table fluctuation in a zone where the rate of hydraulic flow of groundwater is negligible in comparison to rates of molecular diffusion;
3. be such that the burial space can be located in a position within the regional groundwater flow system that, in the event that radionuclide leakage occurs, would prevent contamination of aquifers used for water supply and which would tend to prevent migration of radionuclides into the biosphere."

Cherry et al. (1979) p. 1024-1025

No additional references.

Storage Coefficient

"Pumping, bailing, or slug tests to determine transmissivity and storage coefficients."

GAO Rept. (1976) p. 43

Additional references include: Barnes, 1979, p. 7; DeBuchananne, 1974, p. 358; Papadopulos and Winograd, 1974, p. 17 and 18.

Natural Site Considerations

HYDROLOGY

Subsurface Hydrology

Hydraulic Conductivity and Permeability

Areas with low hydraulic conductivity and permeability are preferred for siting low-level radioactive waste sites.

Hydraulic conductivity and permeability will be significant in determining the distance that contaminants may migrate over time. Permeability is a property of the aquifer material and hydraulic conductivity is dependent on the aquifer material and the properties of the liquid. Note that both field and laboratory measurements are suggested.

> "In migration of radionuclides, hydraulic conductivity is of primary importance."
>
> Ames and Rai (1978) p. 2.19

> "(ii) For sites located in predominately course grained materials, the following criteria should be met:
>
> (A) low saturated hydraulic conductivity.
> (B) low groundwater resource value and inadequate yields for groundwater use in the unconfined and underlying confined aquifers.
> (C) sufficient depth to the water table such that the groundwater intrusion, perennial or otherwise, into the waste will not occur.
> (D) an area which does not provide significant recharge to the unconfined or underlying confined aquifers.
> (E) an absence of discharge areas such as perennial streams, seeps, springs, and wetlands.
> (F) sufficient thickness and lateral extent to permit burial of the waste entirely within the unit and to promote retardation, low groundwater flux, and long groundwater travel time to the water table."
>
> U.S. NRC (Feb., 1981) p. 14

> "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 should be measured at different water contents and suctions."
>
> GAO Rept. (1976) p. 43

> "As another example, field measurements of hydraulic conductivity and dispersivity at a storage site excavated in a thick aquitard, say a 60-foot (18 m) thick glacial till, is impractical, as might be the attempt to measure the three-dimensional distribution of heads. In such a medium, perhaps only a long-term monitoring may permit determination of velocity, flow direction, and dispersion."
>
> Papadopulos and Winograd (1974) p. 19

"The specific hydrological parameters are the dispersivity and the ground water flow rates, which are largely determined by factors such as porosity, permeability, fractures, and hydraulic heads and gradients in the geological environment."

Frye et al. (1978) p. 10

"In certain applications, such as the underground storage of radioactive wastes, accuracy in the determination of the hydraulic properties is of greatest importance."

Witherspoon et al. (1979) p. 3

Additional references include: Klingsberg and Duguid, 1980, p. 27; OECD, 1972, p. 160; Papadopulos and Winograd, 1974, p. 1, 2.

Natural Site Considerations

HYDROLOGY

Subsurface Hydrology

Dispersion and Dispersivity Coefficients

"The specific hydrological parameters are the dispersivity and the ground water flow rates, which are largely determined by factors such as porosity, permeability, fractures, and hydraulic heads and gradients in the geological environment."

Frye et al. (1978) p. 10

"Field measurements of dispersivity coefficients."

GAO Rept. (1976) p. 43

"Water is the principle vehicle for radionuclide transport; thus knowledge of the direction, depth or water table, flow paths, rate of movement, and dispersion of water coupled with the mechanisms and degree of interactions of specific radionuclides with the formation are required to understand radionuclide migration."

Jacobs, Epler, and Rose (1980) p. 8-9

"It is important to be able to estimate as closely as possible: (1) the probable leaching of radionuclides from the wastes; (2) the ability of the soil materials to sorb the radioactive constituents and prevent their movement in surface or groundwater; and (3) the expected pattern of dispersion which might lead to exposures of people and potential radiation hazards."

Morton (1968) p. 3-4

Additional references include: Jacobs, Epler, and Rose, 1980, p. 23; Klingsberg and Duguid, 1980, p. 27.

While there is agreement in the literature on the importance of dispersivity, discussion continues on how to use or determine dispersivity. The discussion centers around the transition from numbers in the laboratory to numbers in the field.

"As another example, field measurements of hydraulic conductivity and dispersivity at a storage site excavated in a thick aquitard, say a 60-foot (18 m) thick glacial till, is impractical, as might be the attempt to measure the three-dimensional distribution of heads. In such a medium, perhaps only a long-term monitoring may permit determination of velocity, flow direction, and dispersion."

Papadopulos and Winograd (1974) p. 19

"There is considerable controversy in the literature at present regarding the extension of the dispersion concept to a field scale."

Ames and Rai (1978) p. 2.23

No additional references.

Subsurface Hydrology

Distribution Coefficients

"One of the most useful concepts for dealing with radionuclide migration and retention processes on geologic materials is that of the distribution coefficent of Kd."

Ames and Rai (1978) p. 2.27

"4. Sorption and Ion Exchange - the distribution coefficient and the partial ion-exchange capacity of each soil and rock type must be determined for the appropriate radionuclides.

Steger (1979) p. 670

"The importance of an accurately determined Kd value cannot be overemphasized when it is used in calculating the velocity of radionuclide movement in geologic materials."

Ames and Rai (1978) p. 2.3

No additional references.
(See also "Sorption")

Natural Site Considerations

HYDROLOGY

Subsurface Hydrology

Aquifer Boundary Conditions

> "Thus, accurate prediction of the migration of radionuclides from a repository requires detailed knowledge of: the physical chemistry of the waste/rock interactions; transient repository temperatures; the three-dimensional distribution of the aquifer porosity, permeability, dispersivity, and hydraulic gradient; water sources and sinks, and aquifer boundary conditions; sorptive characteristics along the transport pathways; and water chemistry and radiochemistry. This type of geohydrologic and geochemical information is not fully available even for the best understood aquifers, and would require considerable effort to obtain at a repository site becuase (sic) of the need to minimize disruption of the repository area by drilling."
>
> Klingsberg and Duguid (1980) p. 27

No additional references.

Natural Site Considerations

HYDROLOGY

Subsurface Hydrology

Recharge Areas

It is important to identify recharge areas because they represent areas where surface contamination can enter the groundwater flow system. Most authors agree that recharge areas should be avoided because of the potential for groundwater contamination.

> "Definition of recharge and discharge areas are unconfined and shallowest confined aquifers."
>
> GAO Rept. (1976) p. 43

> "It is very important to determine the maximum elevation and fluctuations of the water table; the direction, slope and velocity of ground water movement; and the places where contaminated ground water might emerge at the surface or where water might enter aquifers containing useful or potentially useful supplies of ground water."
>
> Morton (1968) p. 29

> "Thus, accurate prediction of the migration of radionuclides from a repository requires detailed knowledge of: the physical chemistry of the waste/rock interactions; transient repository temperatures; the three-dimensional distribution of the aquifer porosity, permeability, dispersivity, and hydraulic gradient; water sources and sinks, and aquifer boundary conditions; sorptive characteristics along the transport pathways; and water chemistry and radiochemistry. This type of geohydrologic and geochemical information is not fully available even for the best understood aquifers, and would require considerable effort to obtain at a repository site because of the need to minimize disruption of the repository area by drilling."
>
> Klingsberg and Duguid (1980) p. 27

"(ii) For sites located in predominately course grained materials, the following criteria should be met:

- (A) low unsaturated hydraulic conductivity.
- (B) low groundwater resource value and inadequate yields for groundwater use in the unconfined and underlying confined aquifers.
- (C) sufficient depth to the water table such that the groundwater intrusion, perennial or otherwise, into the waste will not occur.
- (D) an area which does not provide significant recharge to the unconfined or underlying confined aquifers.

(E) an absence of discharge areas such as perennial streams, seeps, springs, and wetlands.

(F) sufficient thickness and lateral extent to permit burial of the waste entirely within the unit and to promote retardation, low groundwater flux, and long groundwater travel time to the water table."

U.S. NRC (Feb., 1981) p. 14

Additional references include: Barnes, 1979, p. 7.

Natural Site Considerations

HYDROLOGY

Subsurface Hydrology

Discharge Areas

Discharge areas are lakes, wetlands, streams, springs, and seeps where groundwater exists or discharges to the surface. A disposal site should not be located in an area where groundwater discharges to surface drainage (for example, streams), or to a water supply source (for example, a lake).

Some researchers consider discharge areas consisting of contained wetlands as favorable for disposal sites; the surface water in these areas is easy to monitor and there is little potential for groundwater contamination because the groundwater flow is up instead of down. This opinion conflicts with the concern of ecologists for protection of wetlands and may necessitate compromises.

> "Definition of recharge and discharge areas for unconfined and shallowest confined aquifers."
>
> GAO Rept. (9176) p. 43

> "It is very important to determine the maximum elevation and fluctuations of the water table; the direction, slope and velocity of ground water movement; and the places where contaminated ground water might emerge at the surface or where water might enter aquifers containing useful or potentially useful supplies of ground water."
>
> Morton (1968) p. 29

> "Thus, accurate prediction of the migration of radionuclides from a repository requires detailed knowledge of: the physical chemistry of the waste/rock interactions; transient repository temperatures; the three-dimensional distribution of the aquifer porosity, permeability, dispersivity, and hydraulic gradient; water sources and sinks, and aquifer boundary conditions; sorptive characteristics along the transport pathways; and water chemistry and radiochemistry. This type of geohydrologic and geochemical information is not fully available even for the best understood aquifers, and would require considerable effort to obtain at a repository site because of the need to minimize disruption of the repository area by drilling."
>
> Klingsberg and Duguid (1980) p. 27

"(ii) For sites located in predominately course grained materials, the following criteria should be met:

(A) low unsaturated hydraulic conductivity.

(B) low groundwater resource value and inadequate yields for groundwater use in the unconfined and underlying confined aquifers.

(C) sufficient depth to the water table such that the groundwater intrusion, perennial or otherwise, into the waste will not occur.

(D) an area which does not provide significant recharge to the unconfined or underlying confined aquifers.

(E) an absence of discharge areas such as perennial streams, seeps, springs, and wetlands.

(F) sufficient thickness and lateral extent to permit burial of the waste entirely within the unit and to promote retardation, low groundwater flux, and long groundwater travel time to the water table."

U.S. NRC (Feb., 1981) p. 14

Additional references include: Barnes, 1979, p. 7.

Natural Site Considerations

HYDROLOGY

Subsurface Hydrology

Location of Aquifers

The location of aquifers is important because they represent potential pathways for movement of radionuclides. The distance both vertically and horizontally from the waste to nearby aquifers usually should be maximized.

> "Suggested geologic and hydrologic criteria for shallow burial of hazardous wastes in New Mexico include: (1) rock type and permeability;...(2) absence of known aquifers below or adjacent to site and minimum depths to the water-table exceeding 100-200 feet (31 to 62 m); (3) surface stability in terms of water and wind erosion, with minimum land-surface ages in the 10,000 to 100,000-year range; the site should also be stable in terms of seismic and solution subsidence processes; (4) absence of known mineral and geothermal resources whose development could be affected by disposal operations."
>
> Hawley and Gallaher (1981) p. 561

> "Factors important in locating a shallow land burial facility include distances to ground and surface water systems, meteorology and climatology of the area, degree of remoteness, geologic stability, proximity to the sources of waste, competing uses of the land, and ownership for long-term control."
>
> Macbeth et al. (1979) p. 29

> "Ideally, precipitation at the potential site should be low; the distance to any aquifers should be long; aquifer flows and utilization should be low; and underlying strata should be neither highly fractured nor contain voids and flow channels."
>
> Macbeth et al. (1979)

Additional references include: Barnes, 1979, p. 7.

Natural Site Considerations

HYDROLOGY

Subsurface Hydrology

Groundwater Flow or Gradient

Groundwater flows or gradients are necessary in determining the velocity and direction of groundwater movement, which in turn control the velocity (distance over time) and direction that contaminants will travel.

> "2. Mechanisms of groundwater flow into and radionuclide transport out of the repository must be identified. A suitable geologic site should be essentially free of the circulating groundwater that would constitute the primary transport mechanism for radionuclide migration into the biosphere."
>
> Lipschutz (1980) p. 77

"The key parameters are: 1. distance to a water supply, 2. depth to water table, 3. hydraulic gradient, and 4. permeability sorption, as indicated by the geologic setting."

LeGrand (1980) p. ii

"It is very important to determine the maximum elevation and fluctuations of the water table; the direction, slope and velocity of ground water movement; and the places where contaminated ground water might emerge at the surface or where water might enter aquifers containing useful or potentially useful supplies of ground water."

Morton (1968) p. 29

"Thus, accurate prediction of the migration of radionuclides from a repository requires detailed knowledge of: the physical chemistry of the waste/rock interactions; transient repository temperatures; the three-dimensional distribution of the aquifer porosity, permeability, dispersivity, and hydraulic gradient; water sources and sinks, and aquifer boundary conditions; sorptive characteristics along the transport pathways; and water chemistry and radiochemistry. This type of geohydrologic and geochemical information is not fully available even for the best understood aquifers, and would require considerable effort to obtain at a repository site because of the need to minimize disruption of the repository area by drilling."

Klingsberg and Duguid (1980) p. 27

"Three-dimensional distribution of head in all hydrostratigraphic units to base of shallowest confined aquifer."

GAO Rept. (1976) p. 43

"In addition there is a need to assist the hydrogeologists in their determinations of the flow of water through fractured rock media. Emphasis is thus being given to geophysical methods of determining water flows and regional aquifer characteristics as well as evaluations of the nature of fractures intersected by drillholes."

Dence and Scott (1980) p. 190

Additional references include: Barnes, 1979, p. vi, vii, 5, 7, 14; LeGrand, 1980, p. 17, 18; Lipschutz, 1980, p. 105, 106.

Natural Site Considerations

HYDROLOGY

Subsurface Hydrology

Groundwater Flow or Gradient

direction of flow

"Once waste material is buried or released beneath the soil, only water is capable of transporting it in significant quantities away from a burial site or beneath the surface of the ground. For this reason, to evaluate the suitability of the site for disposal it is necessary to determine the amount, direction, and rate of water movement through a disposal site."

DeBuchananne (1974) p. 357

"It is very important to determine the maximum elevation fluctuations of the water table; the direction, slope and velocity of ground water movement; and the places where contaminated ground water might emerge at the surface or where water might enter aquifers containing useful or potentially useful supplies of ground water."

Morton (1968) p. 29

"Landfills designed to meet performance standards should take into account six factors: (1) the type of waste to be disposed; (2) the site hydrogeology that governs the direction and rate of contaminant travel; (3) the attenuation of contaminants by geochemical interactions with the geologic materials; (4) the release rate of unattenuated pollutants to surface or ground water; (5) character of the receiving waters; and (6) construction problems which may be encountered."

Cartwright et al. (1981) p. 5

"The soil provides good ion exchange characteristics to minimize percolation of radioactivity which may be leached from the solid waste to the groundwater. There is no nearby use of groundwater or well water downstream from the site. The site and its vicinity have the characteristically slow water movement through the soil in a direction in which there is little or no land use."

U.S. Atomic Energy Commission (1974) p. G-7

"The major vehicle for transport of radionuclides in the ground is the convective movement of groundwater. When water is the transporting vehicle, one must have knowledge of the direction, flow path, rate of movement, and dispersion as well as the mechanism and degree of interactions of specific radionuclides with the formation in order to predict radionuclide migration."

Jacobs, Epler, and Rose (1980) p. 23

"As another example, field measurements of hydraulic conductivity and dispersivity at a storage site excavated in a thick aquitard, say 60-foot (18 m) thick glacial till, is impractical, as might be the attempt to measure the three-dimensional distribution of heads. In such a medium, perhaps only a long-term monitoring may permit determination of velocity, flow direction, and dispersion."

Papadopulos and Winograd (1974) p. 19

"The site should be chosen so that the hydrogeologic environment of the area surrounding the disposal site will act to prevent or minimize the migration of waste through groundwater pathways. Site characteristics desirable in achieving this include low groundwater flow rates and soil properties which would adsorb the waste material, if it were released."

Massachusetts Rept. (1980) p. 19

"At the landfill site, the elevation of the potentiometric surface of the dolomite aquifer is approximately 670 feet above mean sea level datum, or about 40 to 50 feet below the surface (USGS Hydrologic Atlas HA 432, and available well records). Groundwater movement is to the east towards discharge points along Lake Michigan. The water table fluctuates directly with the seasonal distribution of precipitation, and perched groundwater is present during part of the year."

Donohue and Associates (1980) p. 12-13

Additional references include: Barnes, 1979, p. 7, 56; DeBuchananne, 1974, p. 357, 358; Jacobs, Epler, and Rose, 1980, p. 5, 8, 9; Klingsberg and Duguid, 1980, p. 27, 66; Massachusetts Rept., 1980, p. 19; Morton, 1968, p. 28; Panel on Hanford Wastes, 1978, p. 4.

Natural Site Considerations

HYDROLOGY

Subsurface Hydrology

Groundwater Flow or Gradient

rate of flow

"The rate of flow and the quantity of water which could contact the waste, as well as the rate of movement and transport pathways of radionuclides to man, must be defined."

Steger (1979) p. 669

"Landfills designed to meet performance standards should take into account six factors: (1) the type of waste to be disposed; (2) the site hydrogeology that governs the direction and rate of contaminant travel; (3) the attenuation of contaminants by geochemical interactions with the geologic materials; (4) the release rate of unattenuated pollutants to surface or ground water; (5) character of the receiving waters; and (6) construction problems which may be encountered."

Cartwright et al. (1981) p. 5

"The site should:

1. be geomorphically and seismically stable;
2. be such that adequate burial space can be created at a significant depth below the level of active water-table fluctuation in a zone where the rate of hydraulic flow of groundwater is negligible in comparison to rates of molecular diffusion;
3. be such that the burial space can be located in a position within the regional groundwater flow system that, in the event that radionuclide leakage occurs, would prevent contamination of aquifers used for water supply and which would tend to prevent migration of radionuclides into the biosphere."

Cherry et al. (1979) p. 1024-1025

"Once waste material is buried or released beneath the soil, only water is capable of transporting it in significant quantities away from a burial site or beneath the surface of the ground. For this reason, to evaluate the suitability of the site for disposal it is necessary to determine the amount, direction, and rate of water movement through a disposal site."

DeBuchananne (1974) p. 357

"The criteria are based on (1) thickness, excavation characteristics, permeability, solubility, and reactivity of the host material with the waste products; (2) hydrologic parameters including depth of water table, seasonal variation in water table level, and rate of liquid movement; (3) nature of erosion; and (4) potential for subsidence."

TENRAC (1980) p. 59

"The only natural vehicle capable of transporting significant quantities of radionuclides away from a burial ground is water, moving under the influence of gravity on and beneath the surface of the ground. Therefore, to evaluate the suitability of a site, it is necessary to determine, in general terms, the amount of water, and its direction and rate of movement at the site; and, of equal importance, the movement of water after it leaves the site."

Morton (1968) p. 28

"The dissolution of the wastes and transport of radionuclides by ground-water is influenced by the following factors: (1) solubility of the waste form and its container at repository geochemical conditions including temperatures and pressures; (2) rate and volume of ground-water flow; (3) the sorptive properties of the host rock at repository temperatures, and of all mineral surfaces along the ground-water flow path; (4) the chemical properties of the ground-water including its pH, oxidation potential, ionic strength, complexing agents present, and chemical changes associated with emplaced wastes."

Klingsberg and Duguid (1980) p. 26

"Water is the principal vehicle for radionuclide transport; thus knowledge of the direction, depth or water table, flow paths, rate of movement, and dispersion of water coupled with the mechanisms and degree of interactions of specific radionuclides with the formation are required to understand radionuclide migration."

Jacobs, Epler, and Rose (1980) p. 8-9

"The site should be chosen so that the hydrogeologic environment of the area surrounding the dispoal site will act to prevent or minimize the migration of waste through groundwater pathways. Site characteristics desirable in achieving this include low groundwater flow rates and soil properties which would adsorb the waste material, if it were released."

Massachusetts Rept. (1980) p. 19

"Ideally, precipitation at the potential site should be low; the distance to any aquifers should be long; aquifer flows and utilization should be low; and underlying strata should be neither highly fractured nor contain voids and flow channels."

Macbeth et al. (1979) p. 29

"The following criteria have been included in most sets of proposed guidelines for identifying sites: 1. Hydrogeologic factors. Physically stable regions should be favored where ground-water flow is slow and flow paths are long."

Klingsberg and Duguid (1980) p. 66

Additional references include: Barnes, 1979, p. 7; Bird, 1980, p. 199; Frye et al., 1978, p. 10; Jacobs, Epler, and Rose, 1980, p. 23; Morton, 1968, p. 29; Papadopulos and Winograd, 1974, p. 19; U.S. NRC, Feb., 1981, p. 13, 14.

Natural Site Considerations

HYDROLOGY

Subsurface Hydrology

Groundwater Flow or Gradient

volume of flow

"The only natural vehicle capable of transporting significant quantities of radionuclides away from a burial ground is water, moving under the influence of gravity on and beneath the surface of the ground. Therefore, to evaluate the suitability of a site, it is necessary to determine, in general terms, the amount of water, and its direction and rate of movement at the site; and, of equal importance, the movement of water after it leaves the site."

Morton (1968) p. 28

"Once waste material is buried or released beneath the soil, only water is capable of transporting it in significant quantities away from a burial site or beneath the surface of the ground. For this reason, to evaluate the suitability of the site for disposal it is necessary to determine the amount, direction, and rate of water movement through a disposal site."

DeBuchananne (1974) p. 357

"The dissolution of the wastes and transport of radionuclides by ground-water is influenced by the following factors: (1) solubility of the waste form and its container at repository geochemical conditions including temperatures and pressures; (2) rate and volume of ground-water flow; (3) the sorptive properties of the host rock at repository temperatures, and of all mineral surfaces along the ground-water flow path; (4) the chemical properties of the ground-water including its pH, oxidation potential, ionic strength, complexing agents present, and chemical changes associated with emplaced wastes."

Klingsberg and Duguid (1980) p. 26

"The rate of flow and the quantity of water which could contact the waste, as well as the rate of movement and transport pathways of radionuclides to man, must be defined."

Steger (1979) p. 669

No additional references.

Natural Site Considerations

HYDROLOGY

Subsurface Hydrology

Groundwater Flow or Gradient

ability to control flow

If contamination occurs or if leachate generation is anticipated, the flow must be manipulated to control or remove the leachate or contamination. The ability to do this will be determined by the hydrogeology of the site. It is connected directly also to the ability to monitor effectively (see sections on "Monitoring" and "Complexity").

"The site should be well suited for effective monitoring and for containment by flow-system manipulation schemes."

Papadopulos and Winograd (1974) p. 7

"Criteria used by Cherry for intermediate-term burial sites include:

1. burial site devoid of surface water except snowmelt and rainfall
2. burial trenches sufficiently above fractured bedrock to prevent migration of radionuclides through the bedrock
3. predicted rate of waste solvents movement provides decades of delay time before radionuclides can reach undesirable areas
4. water table, naturally or artificially, below bottom of burial trenches
5. site hydrologically suitable to monitoring and to waste containment by groundwater flow manipulation by pumping."

DeBuchananne (1974) p. 357

No additional references.

Natural Site Considerations

HYDROLOGY

Subsurface Hydrology

Groundwater Flow or Gradient

predictions of future flow conditions

The previously-mentioned groundwater flow criteria (direction, rate, and volume of flow; ability to control flow) must be determined prior to disposal. Equally important in evaluating a site is the ability to predict what the conditions will be after disposal. These conditions will be determined by natural changes over time or from human activities, including disposal itself.

"A major problem confronting hydrogeologists is to determine the groundwater flow conditions in fractured crystalline or argillaceous rocks prior to mining and to predict what the flow conditions will be long after the repository is closed."

Barnes (1979) p. 36

"The geological record of previous hydrological conditions, or the paleo hydrogeological record, should be such that predictions can be made that are favorable for long-term hydrological isolation of the repository site in a perturbed geologic environment."

Frye et al. (1978) p. 10

No additional references.

Natural Site Considerations

HYDROLOGY

Subsurface Hydrology

Chemistry of the Groundwater

"The chemistry of the natural groundwater also needs to be known to predict sorption properties of the soil or rock with respect to specific dissolved nuclides."

DeBuchananne (1974) p. 359

"The chemical nature of any aquifers around a repository should be briefly discussed, including oxidation-reduction considerations."

U.S. DOE (Oct., 1980) V. 3, p. 250

"If the age can be reliably determined it should be a good indicator of the stability or activity of the hydrogeological regime; this, in turn should provide a means of estimating whether or not the objective of disposal can be met. Knowledge of the water chemistry is important in order to evaluate the potential of the water to dissolve or react with other components of the repository system. If the waste is dissolved it will presumably be transported back to the biosphere unless it is 'fixed' by either the host rock or backfill. If the radionuclides react with the solution to form precipitates their migration rate will be greatly reduced."

Barnes (1979) p. 7

"The choice of the form of the waste, its container, the properties of the specific host rock, the composition of the available water, the ambient temperature and pressure, the nature of any intentionally added materials, and the equilibrium constants of the possible chemical reactions define a complex interacting chemical system that determines the rate at which dissolved species become available for hydrological transport."

Frye et al. (1978) p. 12

"The dissolution of the wastes and transport of radionuclides by ground-water is influenced by the following factors: (1) solubility of the waste form and its container at repository geochemical conditions including temperatures and pressures; (2) rate and volume of ground-water flow; (3) the sorptive properties of the host rock at repository temperatures, and of all mineral surfaces along the ground-water flow path; (4) the chemical properties of the ground-water including its pH, oxidation potential, ionic strength, complexing agents present, and chemical changes associated with emplaced wastes."

Klingsberg and Duguid (1980) p. 26

"Chemical or biological incompatibility between the waste fluids and the natural formation waters can lead to failure of the management program. Undesirable reactions may occur unless the character of the subsurface fluid is studied carefully before operations are commenced and the waste fluids are pretreated so as to neutralize any chemical or biological potentials."

Galley (1972) p. 122

"The site shall be located so that the chemical interactions between radionuclides, rock, groundwater, or engineered components will not unacceptably affect system performance."

NWTS Program Office (Feb., 1981) p. 7

"Chemistry of water in aquifers and confining beds and of leachate from the waste trenches."

GAO Rept. (1976) p. 43

Additional references include: Barnes, 1979, p. xi, 7; Bird, 1980, p. 199; DeBuchananne, 1974, p. 359; GAO Rept. 1976, p. 9; Klingsberg and Duguid, 1980, p. 27; Pearce et al., 1960, p. 359; Robertson, 1980, p. 256; U.S. DOE, Oct., 1980, V. 3, p. 258.

The above references mention the following specific chemical parameters that should be used in the site evaluation: pH, oxidation potential, ionic strength, and complexing agents (especially organics).

Lipschutz and Barnes also mention the need to consider the chemical stability of groundwater; Barnes stresses the importance of determining the age of the water.

"If the age can be reliably determined it should be a good indicator of the stability or activity of the hydrogeological regime; this, in turn should provide a means of estimating whether or not the objective of disposal can be met. Knowledge of the water chemistry is important in order to evaluate the potential of the water to dissolve or react with other components of the repository system. If the waste is dissolved it will presumably be transported back to the biosphere unless it is 'fixed' by either the host rock or backfill. If the radionuclides react with the solution to form precipitates their migration rate will be greatly reduced."

Barnes (1979) p. 7

Natural Site Considerations

FLOODS

"Floodplains. It is generally inadvisable to locate a hazardous waste disposal site on the floodplain of a river or stream."

Cartwright et al. (1981) p. 13

"Areas that are continuously or seasonally flooded, such as marshes, swamps, bogs, and mud flats, or areas of too little slope which may allow precipitation and snowmelt to pond and saturate the waste, should also be excluded from consideration."

Falconer (1981) no pages given

"Any site chosen for temporary or permanent disposal should be located on land that has low permeability and is not subject to flooding or high ground water problems."

Illinois (1980) p. 16

"One of the primary concerns in waste storage is water. Hydrologic characterisistics of the host formation and the proximity of the host formation to surface drainage and subsurface aquifers are important considerations. The waste material should be adequately insulated away from both surface water and groundwater. Permeability and formation thickness (discussed above) are the contributing factors. A site should be located where natural buffer zones would prevent interaction of waste materials and hydrologic conduits. Potential flood zones should be avoided."

TENRAC (1980) p. 61

"The site should be generally well drained and devoid of inundation, or frequent ponding or flash flooding such as arrayoes. Floodplains, swamps, bogs and other types of wet or potentially wet terrain should be avoided. No part of the site shall be located in a 100-year floodplain, regulatory floodway, coastal high hazard area, or wetland as defined by the Enviionmental Protection Agency in 40 CFR 250.43-1."

U.S. NRC (Feb., 1981) p. 13

Additional references include: Papadopulos and Winograd, 1974, p. 6.

The above references show the general concern for flooding by many authors; however, there are several different types of floods and their subsequent effects. Water that is confined or channelized and is flowing at high velocities has the potential to erode and damage the disposal site (see also "Erosion"). Relatively flat areas have little potential for destructive erosion, but are often inundated with water, making operations difficult and increasing infiltration and leachate generation (see also "Surface Water"). Any type of flooding of an operating site could carry radionuclides from the site and contaminate surface waters downstream. Even floods or flooding away from the site may change groundwater flow systems (for example, direction and rates) that might affect the site. These concerns are exemplified in the flooding sections: erosion due to floods; surface water contaminated from floods; ponding and infiltration from floods; and groundwater changes from floods.

FLOODS

Erosion Due to Floods (see also "Erosion")

"Potential mechanisms through which critical radioelements in low-level solid wastes may be released from a burial site and introduced into the hydrosphere, atmosphere or biosphere are: a) transport of dissolved nuclides by water to wells, gaining streams, or springs; b) transport upward to the soil zone by capillary flow followed by concentration of the nuclides in plants; and c) exposure and overland transport by normal erosion processes (water and wind); d) erosion due to floods, or erosion following disruption of landscapes by earthquakes."

Papadopulos and Winograd (1974) p. 5

No additional references.

Surface Water Contamination from Floods (see also "Surface Water")

"The current IEPA guidelines require, in addition to a permeability barrier at the bottom and sides of trenches, a minimum of 500 feet from the nearest waterwell. To protect surface water, siting on a floodplain is prohibited, surface runoff must be controlled, and the site must be at least 500 feet from a body of surface water."

Cartwright et al. (1981) p. 3

"Flooding of a site can remove and transport waste material and/or saturate the waste, increasing leachate formation. To minimize the possibility of flooding, low-level radioactive wastes sites should not be located in flood plains of rivers or streams, coastal areas prone to flooding from hurricanes or storm surges, or regulatory floodways used to divert floodwaters during high river flow, when such locations have a probability for flooding greater than 0.2% per year."

Falconer (1981) no pages given

No additional references.

Natural Site Considerations

FLOODS

Ponding and Infiltration from Floods

"The topography of a site including the location of streams and other bodies of surface water is an important consideration in determining site suitability for use as a burial ground. A relatively flat level surface is desirable, as this permits maximum utilization of land and simplifies burial operations. However, in the humid parts of the country, areas with flat level surfaces are usually characterized by shallow water tables, and the land area may be subject to flooding."

DeBuchananne (1974) p. 358

"At INEL the burial grounds are located in a natural topographic depression below the level of the channel of the Big Lost River. The burial ground area has been flooded in periods when rapid snowmelt combined with high rates of precipitation (USERDA 77, Ba 76, Ba 79)."

Jacobs, Epler, and Rose (1980) p. 5

No additional references.

Groundwater Changes from Floods (see also "Groundwater" and "Dams")

"The flooding of a large area behind a dam will profoundly modify the hydrologic system. It may take many decades for the area to come into equilibrium with the perturbing force. Further, the added water load on the reservoir floor and the introduction of fluid to greater depths may induce unpredictable seismic disturbances. Several earthquakes in the past have been attributed to this effect."

Frye et al. (178) p. 15

No additional references.

Natural Site Considerations

EROSION CRITERIA

"The criteria are based on: (1) thickness, excavation characteristics, permeability, solubility, and reactivity of the host material with the waste products; (2) hydrologic parameters including depth of water table, seasonal variation in water table level, and rate of liquid movement; (3) nature of erosion; and (4) potential for subsidence.

TENRAC (1980) p. 59

"Erosion and weathering should not be at a rate which could greatly alter the land surface over the next few hundred years;"

GAO Rept. (1976) p. 11

"The facility should not be located in an area where surface geologic processes such as erosion, landsliding or weathering could significantly enhance the hydrogeological transport of LLW from the site."

Massachusetts Rept. (1980) p. 19

"Control of trench cap erosion is also needed to minimize the contact between water and the buried waste. Erosion may damage the structural integrity of the trench cap (1) promoting infiltration and (2) exposing waste for subsequent transport by water and air."

Jacobs, Epler, and Rose (1980) p. 21

"The reader is reminded that a complete safety analysis of a low-level radioactive burial site would also have to explicitly consider the following matters: a) introduction of radionuclides to the atmosphere and surface water through long-term erosion and catastrophic erosion due to floods and earthquakes; b) uptake of radionuclides from the soil zone by plants; c) identification of critical nuclides within, and of the critical population group in the vicinity of proposed burial sites; d) long term monitoring of the site to prevent vandalism and blundering by unaware descendents; and e) methods of trench construction and waste emplacement designed to reduce or exclude entry of water into the trenches."

Papadopulos and Winograd (1974) p. 22

Site closure and stabilization

"(6) The potential for erosion of the facility or loss of facility integrity due to such factors as groundwater, surface water, wind subsidence, and frost action is minimized."

U.S. NRC (Feb., 1981) p. 24

"With respect to ultimate disposal, which generally would depend on environmental barriers, proper site selection is important to maintaining protection of the materials over the period of time a radiological hazard exists. In this respect, it is desirable for sites to provide stable isolation over time; thus, the action over time of natural forces, such as erosion, sedimentation, and crystallization ideally should be projected to improve environmental isolation rather than reduce it. For example, wind may be expected to erode the covering of an elevated shallow land burial site, but if the location of such a site were carefully chosen, the action of wind might be expected to increase earth cover with time. All other things being about the same, this latter situation would be more desirable."

U.S. EPA (Feb., 1978) p. 23

Additional references include: Barnes, 1979, p. 14, 30-31; Bishop et al., 1977, p. 7 and 8; Cartwright et al., 1981, p. 13; GAO Rept., 1976, p. 44; DeBuchananne, 1974, p. 357-358; Galley, 1972, p. 123; Hawley and Gallaher, 1981, p. 561; Jacobs, Epler, and Rose, 1980, p. 19; Leopold et al., 1971; Lipschutz, 1980, p. 105; Massachusetts Rept., 1980, p. 19; NWTS Program Office, Feb., 1981, p. 6; Papadopulos and Winograd, 1974, p. 17 and 18; Steger, 1979, p. 669; TENRAC, 1980, p. 43; U.S. AEC, 1974, p. 6-8; U.S. NRC, Feb., 1981, p. 14, 15; .

Natural Site Considerations

EROSION CRITERIA

Types

There are several different types of erosion and each one should be considered separately. The following quotations emphasize the different types of erosion.

Water Erosion

"A less likely, long-term exposure pathway could result from denudation of the cover formation followed by surface erosion of the contaminated zone by wind or water."
Jacobs, Epler, and Rose (1980) p. 44

No additional references.

Wind Erosion

"The local meteorology must be studied to assure that rain-water intrusion or wind erosion will not enhance the migration of waste to an unacceptable level."
Massachusetts Rept. (1980) p. 19

No additional references.

Mass Wasting

"During the required performance period of the site, erosion by wind, water and mass wasting must not 1) uncover the waste, 2) increase surface radiation levels above regulatory limits or 3) shorten radionuclide release pathways."
Falconer (1981) no pages given

Glacial Erosion

"Possible physiographic changes, sea level changes, glacial erosion, or deposition should not change the geological environment to affect any of the above conditions."
Gibbs (1980) p. 488

"Faulting and deformation should be mentioned in addition to erosion as hazards associated with glaciation."
U.S. DOE (Oct., 1980) V.3 p. 214

Additional references include: Barnes, 1979, p. 14, 17, 30, 31.

Catastrophic Erosion

"Potential mechanisms through which critical radioelements in low-level solid wastes may be released from a burial site and introduced into the hydrosphere, atmosphere or biosphere are: a) transport of dissolved nuclides by water to wells, gaining streams, or springs; b) transport upward to the soil zone by capillary flow followed by concentration of the nuclides in plants; and c) exposure and overland transport by normal erosion processes (water and wind), erosion due to floods, or erosion following disruption of landscapes by earthquakes."

Papadopulos and Winograd (1974) p. 5

No additional references.

Natural Site Considerations

EROSION CRITERIA

Rates of Erosion

"Terrain characteristics provide clues to the long term stability of a particular location. These characteristics include steepness of slopes, general topographic character, and surface drainage density. Steep slopes and rugged topography with a high density drainage network indicate relatively high erosion rates. As a result, a repository may be breached by incised drainage, land sliding, or soil creep,"

TENRAC (1980) p. 61

"Major climatic oscillations, with periods on the order of tens of thousands of years, have been a feature of global climate for at least the past million years and may be expected to continue. Therefore, existing paleo-climatological data need to be reviewed to judge the likelihood of the wastes being exposed during a future erosion cycle and/or transported as a result of change in the hydrologic regime."

in (Lipschutz, 1980) p. 78 by G. DeBuchannane

"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."

Panel on Land Burial (1976) p. 68

Additional references include: Barnes, 1979, p. 17.

Depths of Erosion

"As several members of the nuclear waste population (Tc - 99, I - 129, Cs - 135, N - 237, Pu - 242) have half lives in the million year range, we must consider what depth is safe with respect to erosion.

Barnes (1979) p. 56

Additional references include: Barnes, 1979, p. 17.

Two other areas of erosion - volume and extent - were mentioned in Barnes (1979 p. 17). If the waste material is being eroded, it is important to know what percent or amount of waste is being eroded and the magnitude of the problem.

Natural Site Considerations

WEATHERING CRITERIA

The depth and rate of weathering are important in assessing the effects of this criterion on the stability of the site.

Weathering may occur by several different mechanisms: physical, chemical and biological (Barnes, 1979, p. 30 and 31). A site investigation should consider the potential effects of all three types of weathering, and include animals as well as plants when studying the biological mechanisms of weathering.

> "The facility should not be located in an area where surface geologic processes such as erosion, landsliding or weathering could significantly enhance the hydrogeological transport of LLW from the site. The site should not be located near a capable fault such that the migration of waste could increase as a result of seismic activity."
>
> Massachusetts Rept. (1980) p. 19

> "Erosion and weathering should not be at a rate which could greatly alter the land surface over the next few hundred years;"
>
> GAO Rept. (1976) p. 11

> "Areas where surface geologic processes such as mass waiting, erosion, slumping, landsliding, or weathering occur with such frequency and extent so as to significantly affect the ability of the site to isolate the waste or to preclude defensible modeling and prediction of long term impacts shall be avoided."
>
> U.S. NRC (Feb., 1981) p. 15

> "However, there are long-term effects to consider: dispersal of buried material by weathering, reconcentration of specific radionuclides by living organisms, raising of radionuclides to the surface by deep rooted plants, as observed at Chalk River in tree leaves on the site of buried waste from a reactor accident."
>
> IAEA (1966) p. 50

Additional references include: Lipschutz, 1980, p. 105; U.S. NRC, Feb., 1981, p. 24.

Site Impacts to the Environment

These criteria are predominantly in the context of environmental impact on the environment from the disposal of low-level radioactive waste.

> "The site shall be located with due consideration to potential environmental impacts.
>
> The evaluation of such impacts will include assessment of air, water, land, aesthetic, ecological noise, resource, and historical factors appropriate to repository construction, operation, and isolation."
>
> NWTS Program Office (Feb., 1981) p. 11

> "The successful long-term management of nuclear wastes is dependent on satisfying institutional, political, environmental and technical constraints."
>
> U.S. DOE (Mar., 1980) p. 6

> "Siting, developing, and operating the mined geologic disposal system shall be conducted in a manner that preserves the quality of the environment to the extent reasonably achievable and complies with current environmental legislation. The environmental impacts associated with the mined geologic disposal system shall be mitigated to the extent reasonably achievable."
>
> NWTS Program Office (Feb., 1981) p. 5

> "Appendix S decribes the Ecosystem Impact criterion for assessment of the impacts of alternatives. The discussion is limited, however, to preemption of ecologically productive land and does not relate to the short- or long-term effects on the soils, plants, or animals occupying the potential sites, nor of adjacent off-site lands. The criterion should be expanded to consider the radiological effects on plants and animals in addition to humans."
>
> U.S. DOE (Oct., 1980) V.3, p. C.44

Additional references include: Massachusetts Rept., 1980, p. 19; Steger, 1979, p. 669; U.S. DOE, March, 1980, p. 23.

Site Impacts to the Environment

LAND

"The site shall be located with due consideration to potential environmental impacts.

The evaluation of such impacts will include assessment of air, water, land, aesthetic, ecological noise, resource, and historical factors appropriate to repository construction, operation, and isolation."

NWTS Program Office (Feb., 1981) p. 11

Additional references include: Donohue and Associates, 1980; Leopold et al., 1974..

WATER

"Water and air, however, both as valuable resources to be safeguarded and as transporting agents, usually are the controlling factors in evaluations of proposed facilities for waste burial. Information on these factors must be included in any site evaluation."

Morton (1968) p. 27

Additional references include: Donohue and Associates, 1980; Leopold et al., 1971; Lowene, 1980, p. 4; NWTS Program Office, Feb., 1981, p. 11.

NOISE

"The site shall be located with due consideration to potential environmental impacts.

The evaluation of such impacts will include assessment of air, water, land, aesthetic, ecological noise, resource, and historical factors appropriate to repository construction, operation, and isolation."

NWTS Program Office (Feb., 1981) p. 11

Additional references include: Donohue and Associates, 1980.

Site Impacts to the Environment

AIR

"The operator of a site has a program for environmental monitoring. This program includes sampling of air, water, and vegetation to determine migration, if any, of radioactive material from the actual location of burial."

U.S. Atomic Energy Commission (1974) p. G-8

"Water and air, however, both as valuable resources to be safeguarded and as transporting agents, usually are the controlling factors in evaluations of proposed facilities for waste burial. Information on these factors must be included in any site evaluation."

Morton (1968) p. 27

"The reader is reminded that a complete safety analysis of a low-level radioactive burial site would also have to explicitly consider the following matters: a) introduction of radionuclides to the atmosphere and surface water through long-term erosion and catastrophic erosion due to floods and earthquakes; b) uptake of radionuclides from the soil zone by plants; c) identification of critical nuclides within, and of the critical population group in the vicinity of proposed burial sites; d) long-term monitoring of the site to prevent vandalism and blundering by unaware descendents; and e) methods of trench construction and waste emplacement designed to reduce or exclude entry of water into the trenches."

Papadopulos and Winograd (1974) p. 22

"For siting the paper recommends that extensive background monitoring of the air, water and vegetation should be complete prior to the licensing of a facility to determine site suitability and establish a baseline with which later sampling data can be compared. Only with comprehensive baseline data could the management facility be properly watched so that small leaks or small levels of contamination could be recognized before they become large problems."

Lowene (1980) p. 4

Additional references include: Donohue and Associates, 1980; NWTS Program Office, Feb., 1981, p. 11.

Site Impacts to the Environment

ESTHETIC, CULTURAL, NATURAL, HISTORICAL, AGRICULTURAL AND RECREATIONAL VALUES

The site shall be located with due consideration to the potential impacts on the esthetic, cultural, natural, historical, agricultural and recreational values of the area.

"A low-level radioactive waste facility should not be allowed in natural areas not in public trust that have been designated by executive/legislative policy as being of county, state, regional, or national significance due to their recreational, historic, educational, and aesthetic value, importance as a natural resource, and value to local economy.

Lands in public trust dedicated to uses likely to be incompatable with LLW facilities including:

1. Parks (with exceptions)
2. Forest (with exceptions)
3. Wilderness/Scenic Areas
4. Recreational Areas
5. Historic sites on or eligible for the National Register of Historic Places
6. Game lands
7. Other natural areas."

Environmental Resources Management, Inc.
(Sept. 19, 1980) no pages given

"One of the responsibilities of the waste siting council would include:

(4) To deliberate and assess the impact of the proposed facility on the proposed host municipality and make a final determination on the construction permit application, considering at a minimum:

d) The nature of the probable environmental impact, including predictable adverse effects on the natural environment; public health and safety; scenic, cultural, historic and recreational values; and water and air quality and wildlife."

Murphy and Goldsmith (Feb., 1981) p. 13

"A LLW facility should not be located close to historic sites;

Facility operations are typically incompatible with most historic places. However, sensitive planning and coordination with respective agencies may allow for both preservation of the historic attributes of the site as well as operation of the waste management facility."

Environmental Resources Management, Inc.
(Sept. 19, 1980) no pages given

"In general, desirable features for land burial sites of low-level radioactive waste include:

- land not suitable for agriculture and an absence of useful or potentially valuable mineral deposits;
- an absence of any special environmental attractiveness, such as spectacular scenery, unique flora or fauna, or high recreational potential."

Panel on Land Burial (1976) p. 68

"The following considerations are among those necessary for the development of adequate criteria: aesthetic, historic, and recreational concerns, public acceptability."

U.S. EPA (Apr., 1977) p. 2-93

"The evaluation of such impacts will include assessment of air, water, land, aesthetic, ecological noise, resource, and historical factors appropriate to repository construction, operation, and isolation."

NWTS Program Office (Feb., 1981) p. 11

"At a basic mechanical level, an archaeological perspective is important in assessing sites for the disposal of radioactive wastes. The suitability and significance of particular regions is evaluated in terms of the nature and distribution of irreplaceable cultural resources--the material heritage left by our ancestors."

U.S. EPA (Apr., 1977) p. 3-39

"11. THE SITE SHOULD BE SELECTED WITH CONSIDERATION GIVEN TO CURRENT AND PROJECTED LAND USE AND RESOURCE DEVELOPMENT.

The site should not be unique in its economic or aesthetic value for industrial, agricultural or recreational uses. A site located in such an area could interfer (sic) with future land requirements and increase the likelihood of human contact with the waste after institutional control has lapsed. Natural resources, such as fuels, ores, and groundwater, are available in finite quantities. Waste disposal should not prevent the recovery of resources of present or potential economic value."

Falconer (1981) no pages given

Additional references include: Donohue and Associates, 1980, p. 1; Leopold et al., 1971, p. 10.

Site Impacts to the Environment

BIOLOGY

In evaluating sites for location of low-level radioactive waste facilities, the impacts of site construction and operation on resident plant and animal populations should be studied.

Animals and plants are especially susceptible to hazard from synthetic radionuclides. Moreover, the incorporation of radionuclides into plant and animal food chains (through soil, air, and water) could lead to eventual ingestion by man. These potential exposure pathways must be evaluated for the full life cycle of the burial site.

> "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."
>
> Panel on Land Burial (1976) p. 69

> "Site studies must be conducted to determine the extent that the natural geologic, biologic and hydrologic systems influence the confinement of radionuclides."
>
> Steger (1979) p. 669

> "The investigations included in this report are:
>
> 1. The land use and zoning in the area.
> 2. The topography, drainage, and groundwater movement in the area.
> 3. The surficial soils and subsurface materials and bedrock in the area.
> 4. The biological and historical-cultural setting of the area.
> 5. A description of the nature, origin, and volume of the wastes to be disposed of.
> 6. Preliminary engineering plans for proposed site development."
>
> Donohue and Associates (1980) p. 1

> "The Statement is sketchy on environmental surveillance, monitoring, and managing each kind of site. The problems to be encountered in clean-up in the event of decommissioning or serious accident, as well as possible evacuation, require more detailed analysis taking into account comparative environmental effects before and after the event, for each option, with emphasis on behavioral and biological science approaches."
>
> U.S. DOE (Oct., 1980) V.3, p. 421

"The effect of biological magnification that may occur due to the incorporation of materials present in air and water into the plant and animal food chains to man must be evaluated. These assessments must include the full life cycle of the burial site, including the period of active site operation and the potentially much longer period of time following site closure and decommissioning during which long-term surveillance and maintenance must be conducted."

TENRAC (1980) p. 67

"Detailed site characterization factors include:

Characterization of ecology of the site to determine impacts of site operations on plant and animal populations, requirements for revegetation and post closure operation, and determination of long-term effects of plant growth on buried wastes. Identification of endangered plant and animal species."

EG & G, Idaho, Inc. (Aug., 1980) p. 17

"Shell fish beds in estuarine rivers would be highly susceptible to contamination via long-term bioaccumulation of low levels of radionuclides. Siting of facilities in drainage areas for these beds must consider the relative opportunity for dispersion of low concentration of pollutant discharges (leachate and potential episodes of high concentration) and the need to maintain shellfish quality acceptable for human consumption."

Environmental Resources Management, Inc.
(Sept. 19, 1980) no pages given

Areas that contain critical habitat for rare and endangered species should not be considered for a LLW facility site. These critical habitats would include:

"Areas providing sole or significant support to biological populations in: feeding, nesting, breeding, and/or resting for migratory, as well as resident species. Critical habitats could include, but not be limited to: salt marshes, wetlands, bogs, woodlands, and wildlife refuges.

Construction and operation of a facility could alter habitat, irreversibly affecting the survivability of rare and endangered species. Proposed regulations express that a facility can be constructed in such areas if no jeopardy is demonstrated to the U.S. Fish and Wildlife Service."

Environmental Resources Management, Inc.
(Sept. 19, 1980) no pages given

Additional references include: NWTS Program Office, Feb., 1981, p. 5, 11; Panel on Land Burial, 1976, p. 68.

Site Impacts to the Environment

BIOLOGY

Food Chains

"Vegetation, particularly deep rooted plants, growing on the surface of covered burial trenches have accumulated radionuclides and represent a pathway for translocation of radionuclides from the trenches at ORNL (We79), Hanford, (Ad78, Ge77, USERDA 76z). LASL (EGH 77), and SRP (Ho 76, Co 79, DuP 78c, As 76)."

Jacobs, Epler, and Rose (1980) p. 6

"In any study of the releases of radioactive material to the environment, the exposure pathways - i.e., the routes by which the radioactive materials that have been released can cause exposure to man - must be identified."

Straub (1970) p. 14

"The basic problem of ground disposal is the avoidance of contamination of underground water which could finally lead to an unacceptable contamination of drinking water supplies and food chain products."

OECD (1972) p. 160

Additional references include: Dillon, Blantz and Pahwa, 1978, Abstract; Jacobs, Epler, and Rose, 1980, p. 38; Relyea, Rai, and Serne, 1979, Abstract.

Plant Uptake

"Potential mechanisms through which critical radioelements in low-level solid wastes may be released from a burial site and introduced into the hydrosphere, atmosphere or biosphere are: a) transport of dissolved nuclides by water to wells, gaining streams, or springs; b) transport upward to the soil zone by capillary flow followed by concentration of the nuclides in plants; and c) exposure and overland transport by normal erosion processes (water and wind), erosion due to floods, or erosion following disruption of landscapes by earthquakes."

Papadopolus and Winograd (1974) p. 5

"Granted the importance of the total solution concentrations of the element, the nature of the predominant solution species are important since they affect 1) adsorption through their charge; 2) adsorption because of changes in the nature of the species due to alteration if solution properties such as pH, Eh, competing ions and complexing ions; 3) movement through the soil and rock matrix because of their physical size; and 4) plant uptake."

Ames and Rai (1978) p. 2.2

"Plants, and in particular, crops are directly concerned by the risk of pollution from nuclear installations."

OECD (1972) p. 67

Additional references include: Jacobs, Epler, and Rose, 1980, p. 6; Lowene, 1980, p. 4; Papadopulos and Winograd, 1974, p. 22; Steger, 1979, p. 669.

Site Impacts to the Environment

BIOLOGY

Wetlands

"The site should be generally well drained and devoid of inundation, or frequent ponding or flash flooding such as arrayoes. Floodplains, swamps, bogs and other types of wet or potentially wet terrain should be avoided. No part of the site shall be located in a 100-year floodplain, regulatory floodway, coastal high hazard area, or wetland as defined by the Environmental Protection Agency in 40 CFR 250.43-1."

U.S. NRC (Feb., 1981) p. 13

The land surface should be devoid of surface water, except during snowmelt runoff and exceptional period of rain fall. In other words the sites should not be located in (flood plain) swamps, bogs, or other type of very wet (or potentially very wet) terrain."

Papadopulos and Winograd (1974) p. 6

"Areas that are continuously or seasonally flooded, such as marshes, swamps, bogs, and mud flats, or areas of too little slope which may allow precipitation and snowmelt to pond and saturate the waste, should also be excluded from consideration."

Falconer (1981) no pages given

Additional references include: U.S. NRC, Feb., 1981, p. 13-14.

External Hazards

External hazards could affect a site during or after operation; of particular concern are those hazards that might occur after site closure and decommissioning.

External hazards originate outside the site boundaries other than within them (for example, corrosion or container leaks). This criterion is divided into four sections: human intrusions, animal intrusions, plant intrusions and meteorite impact. Volcanoes, earthquakes and floods are considered separately under other criteria headings.

> "The repository should be at a depth sufficient to separate the repository from any surficial process or event that might cause a breach of the repository."
>
> Frye et al. (1978) p. 4

> "However, erosional and vegetative transport vectors, vulnerability to natural events, decommissioning and ease in monitoring the site should also be considered."
>
> Steger (1979) p. 669

Additional references include: Barnes, 1979, p. 14.

External Hazards

HUMAN INTRUSION

The proximity of low-level radioactive waste to the earth's surface leads to concern over possible human intrusion into the waste in the future. The potential for human intrusion should be considered in determining the location and depth of the disposal site.

Human intrusion can occur from normal activities such as plowing, construction, drilling for water or oil, and mineral exploration. It can also occur as a result of vandalism, sabotage, and accidently or purposely during war. Rules proposed recently by the Nuclear Regulatory Commission define performance objectives for protection of individuals from inadvertent intrusion.

> "61.42 Protection of individuals from inadvertent intrusion. Design, operation and closure of the land disposal facility must not result in conditions where any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste after active institutional controls over the disposal site are removed, could receive a dose to the whole body in excess of 500 millirem per year."
>
> U.S. NRC (July 24, 1981) p. 38095

> "...As time proceeds, and the concern over the hazards presented by the site diminishes, the effectiveness of site control, together with the level of information about the site, may well decrease. Historically, the first type of intrusion upon discarded material is the treasure hunter, seeking any possible value in the waste....the second form of intrusion that may be postulated is that of the honest investigator, perhaps the citizen of the year 2177....At some distant time in the future, memory of the site may be completely erased, leading to accidental excavation."
>
> Wheeler and Smith (1979) p. 26-27

> "The proximity of the waste to the earth's surface, and the extent to which man has altered that surface, leads to a concern over possible exhumation of the waste, by man, at some time in the future."
>
> Wheeler and Smith (1979) p. 26

> "The site shall be located to reduce the likelihood that past or future human activities would cause unacceptable impacts on system performance."
>
> NWTS Program Office (Feb., 1981) p. 9

"The reader is reminded that a complete safety analysis of a low-level radioactive burial site would also have to explicitly consider the following matters: a) introduction of radionuclides to the atmosphere and surface water through long-term erosion and catastrophic erosion due to floods and earthquakes; b) uptake of radionuclides from the solid zone by plants; c) identification of critical nuclides within, and of the critical population group in the vicinity of proposed burial sites; d) long-term monitoring of the site to prevent vandalism and blundering by unaware descendents; and e) methods of trench construction and waste emplacement designed to reduce or exclude entry of water into the trenches."

Papadopulos and Winograd (1974) p. 22

"The level of evaluation necessary to access the likelihood of human intrusion will increase with the value of and the proximity of the site to exploitable features or resources such as water, thermal energy, petroleum, or minerals."

NWTS Program Office (Feb., 1981) p. 9

Additional references include: Barnes, 1979, p. 30, 31; Frye et al., 1978, p. 4; Lipschutz, 1980, p. 55, 105, 106; TENRAC, 1980, p. 43.

External Hazards

ANIMAL INTRUSION

"Burrowing animals present a potential mechanism for breaching the barrier imposed by burial. Earth excavated from burrows may be carried directly to the surface, and if removed from sufficient depth, may include contaminated waste materials. The animals constructing the burrows may contact the waste directly, and carry contamination to the surface environment."

Wheeler and Smith (1979) p. 22

"There is potential for small animals to intrude into burial wastes and translocate radaionuclides (GE77)."

Jacobs, Epler, and Rose (1980) p. 6

In addition to providing short-term erosion control, consideration should be given to their ability to remain stable over long periods of time and to provide protection against intrusion be deep-rooted plants and small burrowing animals."

Jacobs, Epler, and Rose (1980) p. 21

"Transport by burrowing animals may well result in measurable (but not necessarily hazardous) concentration at the surface, particularly if such burrowing occurs shortly after the completion of a trench. Further work is needed to establish the long-term significance of this release mechanism."

Wheeler and Smith (1979) p. 24

"However, there are long-term effects to consider: dispersal of buried material by weathering, reconcentration of specific radionuclides by living organisms, raising of radionuclides to the surface by deep rooted plants, as observed at Chalk River in tree leaves on the site of buried waste from a reactor accident."

IAEA (1966) p. 50

Additional references include: Barnes, 1979, p. 30, 31; Lipschutz, 1980, p. 105; TENRAC, 1980, p. 43.

External Hazards

PLANT INTRUSION

"Vegetation, particularly deep rooted plants, growing on the surface of covered burial trenches have accumulated radionuclides and represent a pathway for translocation of radionuclides from the trenches at ORNL (We79), Hanford, (Ad78, Ge77, USERDA 76z), LASL (EGH 77), and SRP (Ho 76, Co 79, DuP 78c, As 76)."

Jacobs, Epler, and Rose (1980) p. 6

"However, there are long-term effects to consider: dispersal of buried material by weathering, reconcentration of specific radionuclides by living organisms, raising of radionuclides to the surface by deep rooted plants, as observed at Chalk River in tree leaves on the site of buried waste from a reactor accident."

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Jacobs, Epler, and Rose (1980) p. 21

Additional references include: Barnes, 1979, p. 30, 31; Lipschutz, 1980, p. 105; TENRAC, 1980, p. 43.

METEORITE IMPACT

The probability of a meteorite impact may be small but the potential would vary with geography. The danger of the hazard would also decrease with lower levels of radioactivity.

"To assess the risk of a geologic repository, methods must account for a spectrum of events that could cause loss of geologic integrity and subsequent adverse consequences. Four type of potential causes of loss of isolation have been identified:

1. Sudden natural events such as meteorite impact
2. Geologic processes such as faulting or ice ages
3. Changes in local geology caused by creating the repository and by introducing thermal and radiation sources
4. Human intrusion."

U.S. EPA (Feb., 1977) p. 2.28-2.29

Additional references include: Barnes, 1979, p. 30, 31; Lipschutz, 1980, p. 105.

External Hazards

GLACIATION

The possibility of another ice age or glacial advance probably is only significant to the disposal of long half-life materials.

This topic is controversial, but should be considered in some of the northern regions of the United States if materials with long half-lives are buried in shallow land burial sites. The melting of an extra heavy snow pack can produce abnormal floods and erosion in areas where they did not occur previously (see "Glacial Erosion" in the "Erosion" section). In addition, a glacial period would make monitoring much more difficult, if not impossible.

> "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."
>
> Panel on Land Burial (1976) p. 67

> "To assess the risk of a geologic repository, methods must account for a spectrum of events that could cause loss of geologic integrity and subsequent adverse consequences. Four types of potential causes of loss of isolation have been identified:
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> 2. Geologic processes such as faulting or ice ages
> 3. Changes in local geology caused by creating the repository and by introducing thermal and radiation sources
> 4. Human intrusion."
>
> EPA (Feb., 1977) p. 2-28

No additional references.

Process Considerations

RISK ANALYSIS

"Information and data evaluations in the areas of health and safety, economics, risk assessments, quality assurance, and EIS's will be developed and reviewed to support the waste management program."

U.S. DOE (Mar., 1980) p. 23

"There was a consensus among the participants that accidents and unplanned releases should be considered in the formulation of criteria. Furthermore, it was felt that traditional risk analysis techniques which are quantitative in nature should be used to the extent feasible, although with full recognition of the fact that quantitative risk analysis is, at best, an imperfect tool."

U.S. EPA (Feb., 1977) p. xiv

"It is extremely difficult to perform a risk analysis of a complex technological system for which little or no operating experience has been accumulated, as is the case with radioactive waste disposal. At best, it is possible to postulate a finite number of events (failures), set upper and lower bounds on their probability of occurrence, determine the consequences, and decide if the risks are acceptable now and will continue to be acceptable in the future. The uncertainties that are associated with such steps may be very large, indeed, large enough in some cases to make predictions meaningless."

Lipschutz (1980) p. 101

Additional references include: Barnes, 1979, p. vi; Lipschutz, 1980, p. 96, 97, 104, 105, 170.

Process Considerations

MONITORING

Monitoring is regarded widely as essential in developing a successful low-level waste operation.

The monitoring design and the ability to monitor efficiently must also be considered when selecting a site (see also "Complexity").

> "An adequate monitoring system is essential to the operation of a hazardous waste disposal site."
>
> Cartwright et al. (1981) p. 11

> "Unless the waste can be monitored for substantial periods following its emplacement, there is no way to confirm the safety of the site."
>
> DeBuchananne (1974) p. 358

> "However carefully waste management may have been planned, the practical success of the program depends on the efficacy of monitoring devices: (a) in measuring onsite and offsite radiation levels over long periods of time, (b) in detecting unexpected radioactive releases, and (c) in alerting management personnel of any abnormalities so that remedial measures can be taken promptly."
>
> Panel on Hanford Waste (1978) p. 73

> "A broad monitoring programme of activity levels in food and water, and of commonly used goods and materials and of general environmental activity levels, is an essential part of the supervision of the effect of radioactive waste disposal on the general public."
>
> IAEA (1966) p. 54

> "A final requirement of any control system is a monitoring programme to demonstrate that the rates of introduction of radioactive material specified as commensurate with the stipulated environmental capacity are being observed."
>
> OECD (1972) p. 124

> "The site should be well suited for effective monitoring and for containment by flow-system manipulation schemes."
>
> Papadopulos and Winograd (1974) p. 7

> "However, erosional and vegetative transport vectors, vulnerability to natural events, decommissioning and ease in monitoring the site should also be considered."
>
> Steger (1979) p. 669

Additional references include: Barnes, 1979, p. ix, 46; DeBuchananne, 1974, p. 357; Falconer, 1981, no pages given; Frye et al., 1978, p. 10; Jacobs, Epler, and Rose, 1980, p. 15, 16, and 37; U.S. NRC, Feb., 1981, p. 13; Papadopulos and Winograd, 1974, p. 1, 2, 6, 19, 22; Steger, 1979, p. 671; U.S. AEC, 1974, p. 6-8; U.S. DOE, Oct., 1980, V. 3, p. 421; U.S. DOE, Mar. 13, 1981, p. 22.

Process Considerations

MODELING

Modeling is most important with respect to groundwater and monitoring, but it may be used in other areas as well (for example, air contamination plumes and dispersion). Because computer modeling is relatively new, much of the data necessary to develop accurate models is not readily available, and few models have been tested in the field. There are few references to modeling. The ability to model is directly connected to the nature of the site (see "Complexity").

> "Predictive modeling, monitoring, and management of radionuclides dissolved and transported by groundwater can best be done for sites in relatively simple hydrogeologic settings; namely in unfaulted relatively flat-lying strata of intermediate permeability such as silt, siltstone and silty sandstone. In contrast, dense fractured or soluble media, and poorly permeable porous media (aquitards) are not suitable for use as burial sites, first because of media heterogeneity and difficulties of sampling, and consequently of predictive modeling, and second, because in humid zones burial trenched in aquitards may overflow."
>
> Papadopulos and Winograd (1974) p. 1-2

> "The site shall be located so that the hydrological regime can be sufficiently characterized to permit modeling to show that present and probable future conditions have no unacceptable impact on repository performance."
>
> NWTS Program Office (Feb., 1981) p. 7

Additional references include: Belyea, J.F., D. Rai, and R.J. Serne, 1978, abstract.

Complexity

This criterion refers to the natural environment of the site and is directly related to the ability to construct, monitor, and model the site efficiently (see also "Modeling" and "Monitoring"). It is especially important with regard to hydrogeology.

> "The site shall not be so complex to preclude characterization, defensible modeling, analysis, and monitoring."
>
> U.S. NRC (Feb., 1981) p. 13

> "The hydrogeologic conditions must be simple enough for reliable residence time predictions to be made;"
>
> GAO Rept. (1976) p. 11

> "The site should be located in areas where hydrogeologic conditions are sufficiently simple to allow reliable performance prediction."
>
> Falconer (1981) no pages given

> "The site shall be located so that the hydrological regime can be sufficiently characterized to permit modeling to show that present and probable future conditions have no unacceptable impact on repository performance."
>
> NWTS Program Office (Feb., 1981) p. 7

> "Predictive modeling, monitoring, and management of radionuclides dissolved and transported by groundwater can best be done for sites in relatively simple hydrogeologic settings; namely in unfaulted relatively flat-lying strata of intermediate permeability such as silt, siltstone and silty sandstone. In contrast, dense fractured or soluble media, and poorly permeable porous media (aquitards) are not suitable for use as burial sites, first because of media heterogeneity and difficulties of sampling, and consequently of predictive modeling, and second, because in humid zones burial trenched in aquitards may overlow."
>
> Papadopulos and Winograd (1974) p. 1 - 2

Additional references

Human Considerations

HUMAN HEALTH AND SAFETY

Protection of human health and safety is the foremost criterion identified in the literature for evaluating sites for location of low-level radioactive waste facilities.

All releases of radiation are potentially harmful and low-level radioactive waste sites must be carefully planned, operated, maintained, and decommissioned so as not to endanger human health. For protection of current and future generations, authors agree that exposures should be as low as reasonably achievable (ALARA), and preferably set in relation to natural background levels. Rules proposed recently by the Nuclear Regulatory Commission define performance objectives for protection of the general population from releases of radioactivity and protection of individuals during operation of the facility.

> "The major concern associated with the management of radioactive waste is the potential health impact that may occur."
>
> Jacobs (1979) p. 230

> "In judging the acceptability for licensing of a proposed facility for waste burial, the primary consideration is radiological health and safety."
>
> Morton (1968) p. 26

> "Any site selection should as the first priority include consideration of the health implications of the site on the population in the immediate vicinity, including the individuals employed on the site. A complete study would have to be undertaken to determine any health impact after a specific site was selected. This study would be made based on the present and potential future population in the region and should include consideration of present and projected future uses of land, water, and natural resources in the region of the site."
>
> Illinois Rept. (1980) p. 16

> "No prescription can be stated for judging an adequate degree of protection for radioactive wastes independent of circumstances. A number of conditions are generally regarded as basic to sound public health practice: a) any allowed exposures to or releases of radioactive materials should be associated with some justifying benefit; b) exposures should be kept as low as is reasonable to achieve in view of technical, economic, and social considerations; and c) inequitable distribution of risks among individuals in a given population should be minimized, and d) certain stated levels of exposures of the general population are not to be exceeded, virtually without regard to circumstances."
>
> U.S. EPA (Feb., 1978) p. 41

> "61.41 Protection of the general population from releases of radioactivity. Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants, or animals must not result in an annual dose exceeding an equivalent of 25 millirems to the whole body, 75 millirems to the thyroid,

and 25 millirems to any other organ of any member of the public. In addition, concentrations of radioactive material in groundwater must not exceed the maximum contaminant levels established in the National Primary Drinking Water Standards (40 CFR Part 141), at the nearest public drinking water supply (a limit of 10 pCi/l above background must be used for uranium and thorium).

61.43 Protection of individuals during operations. Operations at the land disposal facility must be conducted in compliance with the standards for radiation protection set out in Part 20 of this chapter."

U.S. NRC (July 24, 1981) p. 38095

"The only way to set standards that give assurance of avoiding unpleasant and irreversible surprises in the future is to set standards in relation to natural background levels."

Montague (Jan., 1979) p. 21

"The Task Force believes that both hazardous and low-level radioactive wastes have an inherent potential to harm property and people. The risk of such harm may be very low if proper precautions are taken, but the amount and nature of the harm may be very great."

North Carolina Rept. (Jan. 12, 1980) p. 57

"A low-level radioactive waste burial ground can be sited, designed, built, and operated in such a manner that no exposure limit will be exceeded during normal, routine operations during the operational period of the site and the long-term surveillance and maintenance period following site closure and decommissioning. In reality, a low-level radioactive waste burial ground could be operated so that no individual in the general public would be exposed to a dose of 0.025 rem per year previously noted under normal, routine operations or accidents at the site."

TENRAC (1980) p. 68

Most authors agree that a low-level waste facility can be sited, operated and maintained in a way that will not endanger human health and safety. However, because of past waste management problems at low-level sites, continuous and careful monitoring and extensive knowledge collected over time are the only guarantees for both short- and long-term safety.

"Special treatment and disposal techniques are afforded low-level radioactive wastes because the associated radioactivity can present a health risk to biological systems. Since radioactivity is easily detected and measured, and well understood, this risk can be readily quantified.

"It is well documented that average radiation exposures from all human activities are considerably below natural background radiation exposures, and the risk of the two combined is extremely small."

U.S. DOE (Nov., 1980) Sect. 10

"Hydrogeological modeling and operational experience to date indicate no health and safety problems in the near term from operation of shallow land burial facilities, but analyses continue."

Bishop et al. (1979) p. 45

"Because of the natural abundance of radioactive materials, the disposal of sufficiently small quantities of radioactive materials in the ground and via the air would not produce changes that would be considered significant in view of the variations in the existing levels. The highest radiation dose to which any member of the public would be exposed by a properly managed LLW program should not exceed 5 mrem/year.......The potential release of low levels of radioactivity should be weighed against the benefits to society from the activities that produced this radioactivity. Finally, releases should be reviewed for compliance with the ALARA principle which requires that the discharge of pollutants to the environment be kept As Low As Reasonable Achievable and not merely in compliance with pollution regulations."

Massachusetts Rept. (1980) p. 22

"The lax packaging requirements for low-level radwastes, and the 'shallow trench burial is permanent disposal' philosophy are both reasonable only if we know no harm is being done by the radioactive releases that are occurring and that will continue to occur. To know that no harm is being done requires extensive knowledge through time of the effects of current releases. Particularly because radioactivity produces cancer, and because cancer is typically characterized by a delay period of 5 to 50 years between time of effective contact with a carcinogen and time of appearance of the disease, it requires almost omniscience to 'know' that no damage has occurred as a result of a particular radioactive spill or leak."

Montague (Jan., 1979) p. 22

"Short-term safety. Short term safety may turn out to be the most important question of all. How much safety will we require in the transportation, handling, interim storage, and burial operations of the spent fuels and other waste forms? Most attention has been paid to the long-range effects of nuclear waste because frontiers of science are more interesting than such mundane issues as how to get the waste safely off a truck. But these are not only the chief concerns of workers and unions; they are precisely the concerns of greatest importance to people living in the region of the site and will also be the first public test of the competence of the entire operation.

Long-term safety. How safe should the disposal facility be in relation to people living nearby, people who will live there in the future, and the environment?"

Abrams and Primack (Apr., 1980) p. 17

Additional references include: BEIR Rept., 1980, p. 3-5, 7; Clemente et al, 1978, p. 13-14; Cohen, 1979, p. 224; Cunningham Letter, Jan. 26, 1981, p. 438; Gofman, 1972, p. 75, 79; Green, 1972, p. 146; Hebert et al., May, 1978, p. 11-12; Inove and Morisawa, 1974, abstract and p. 62; Jacobs, 1979, p. 231; Lamb, 1979, p. 51; Montague, Jan., 1979; Murphy and Goldsmith, Feb., 1981, p. 13; New Scientist, Nov. 8, 1979, p. 439; North Carolina Rept., Jan. 12, 1980, p. ES-4, 44, 46; Sanders, 1979, p. 521; Straub, 1970, p. 10, 15; Taylor, 1972, p. 174, 176, 177; TENRAC, 1980, p. 15, 68; U.S. DOE, May, 1979, p. 3.6.1, 3.9.1; U.S. DOE, March, 1980, p. 23, 216, 217; U.S. DOE, March 13, 1981, p. 30; U.S. EPA, Feb., 1977, p. 3-3; U.S. EPA, Apr., 1977, p. 2-14, 2-95; U.S. EPA, Feb, 1978, p. 8, 20, 22, 27-28, 49; U.S. NRC, Feb., 1981, p. 11-12; Wincester, July/Aug., 1979, p. 2.

Human Considerations

HUMAN HEALTH AND SAFETY

Environmental Monitoring

To adequately protect human health and the environment, both onsite and offsite environmental monitoring programs should be established.

These programs should have three phases: 1) preoperational, beginning at least one full year prior to site construction; 2) during construction, operation and site closure; and 3) post-closure, or long-term monitoring, until the Nuclear Regulatory Commission terminates the license.

> "61.53 Environmental monitoring. At the time a license application is submitted, the applicant shall have conducted a preoperational monitoring program to provide basic environmental data on the disposal site characteristics. The applicant shall obtain information about the ecology, meteorology, climate, hydrology, geology, and seismology of the disposal site. For those characteristics that are subject to seasonal variation, data must cover at least a twelve month period."
>
> U.S. NRC (July 24, 1981) p. 38096

> "Moreover, an adequate method for monitoring the effectiveness of this State's efforts to manage waste must be established to be doubly certain that harmful substances are not entering the food chain through water, land, or animals and that the ambient air is free of contaminants from the handling, treatment, and disposal of waste. All of these efforts should be part of an on-going evaluation of the waste management system in order to improve upon it as we learn from experience and research."
>
> North Carolina Rept. (Jan. 12, 1980) p. 4

> "A burial site, typically, is operational over a period of 10-20 years. At the end of that time, all surface structures will be removed, and the location and contents of trenches marked with durable monuments. The environmental surveillance program established when the site was first opened will be continued, at a reduced intensity, to monitor the long-term performance of the site. Site control will likely be maintained through some form of fencing. A 'perpetual care' fund, established during site operations, will provide a source of revenue for this monitoring program, and any routine maintenance of the site. The expected time-duration of such maintenance (sic) and site control is not well defined, but may be thought of as 'as long as necessary.'"
>
> Wheeler and Smith (1979) p. 17

> "During the operational phase of a waste facility, offsite monitoring of environmental radiation may be required in order to:
>
> a. extend knowledge of baselines of radiation in the general environment near the facility

b. verify that any effects produced by releases from the site by any pathways are and may be expected to remain within acceptable levels
c. provide information in the event of unanticipated releases which will be useful in assessing the extent of environmental contamination and will allow for timely consideration of remedies.

The nature and extent of offsite environmental monitoring during operation of a waste facility would depend on the form and potential hazard of the waste material, the character of the operations performed upon them, the types of containment barriers used, and the mechanisms by which these barriers might be breached. However, all waste facilities should be designed in such a manner that monitoring for more than 100 years would not be required as a basic element of environmental protection."

U.S. EPA (Feb., 1978) p. 43-44

"Environmental Surveillance: a solution to this situation would be the orderly construction of monitoring wells as the site is filled. Following the closure of a trench, a well could be drilled at each end and along one side as established by the site criteria (for example, one well for each 200 linear feet of trench)."

Blackburn and Ed (1979) p. 839

"Measures that should be taken to make the location (of a low-level radioactive disposal site) more acceptable to citizens: On-going monitoring of plant, wildlife, and human health."

North Carolina Rept., (Jan. 12, 1980) p. 56

"With respect to host localities, state governments need to develop a facility siting process to develop guidelines and policy for facility operations which: - are monitored on a regular basis for adherence to Federal and state regulation, to protect human health and safety and the environment."

Murphy and Goldsmith (Feb., 1981) p. 4-5

Additional references include: U.S. EPA, Apr., 1977, p. 2-16; U.S. EPA, Feb., 1978, p. 43-44

Human Considerations

HUMAN HEALTH AND SAFETY

Long Term Care

A long-term care program should be established to protect future generations from radiation hazards associated with a low-level radioactive waste disposal site.

The criterion "long-term care" includes the procedures needed to maintain and verify the capability of a site to contain radionuclides. The three aspects of long-term care are administrative control, environmental surveillance, and site maintenance.

> "Long-term care begins at the completion of the site stabilization activites and continues until it is determined that the buried waste no longer poses a radiological hazard. Included in long-term care are all the procedures required to maintain and verify site capability to contain the radionuclides in the immediate vicinity of the burial trenches. The three aspects of long-term care are administrative control, environmental surveillance, and site maintenance. Administrative control includes: (1) control of site access; (2) coordination of surveillance and maintenance activities; (3) control and use of property development; and (4) record keeping. The aspects of environmental surveillance are: (1) collection of environmental samples; (2) analysis of environmental samples; and (3) records and maintenance. Site maintenance involves: (1) erosion control; (2) trench cap repair; (3) water infiltration control; and (4) vegetation management."
>
> TENRAC (1980) p. 44-46

> "The successful long-term management of nuclear wastes is dependent on satisfying institutional, political, environmental and technical constraints."
>
> U.S. DOE (Mar., 1980) p. 6

> "Monitoring and maintaining disposal sites will be required for many centuries because of the long-lived, highly toxic radionuclides disposed of at the sites. Therefore, it is important that long-term-care requirements are identified and adequately funded before terminating and decommissioning the sites."
>
> GAO Rept. (1976) p. 34

> "....long-term guarantee that a community will not be left to bear our underestimated expenses would be a very desirable kind of innovation."
>
> Subcommittee on Rural Development (Kasperson Testimony) (Aug. 26, 1980) p. 16

> "There is a need for the development of uniform criteria in the area of bonding and perpetual care of burial sites. National guidance would be beneficial in this area. I recommend that any perpetual care program be based on the biological hazards associated with the waste, and not on some arbitrary unit such as cubic feet or pounds of waste."
>
> Hardin (Apr., 1977) p. 2-34

"With respect to host localities, state governments need to develop a facility siting process which: - develops an extended care plan for the site following site closure."

Murphy and Goldsmith (Feb., 1981) p. 4-5

"What can be done to address and resolve these rad waste siting problems?

- develop stable, long-term, guaranteed arrangements for communities which are asked to make similar long-term commitments to the national interest."

Subcommittee on Rural Development (Peelle Testimony) (Aug. 26, 1980) p. 7

"A means of disposal may satisfy the environmental and public health protection criteria, but the possibility may remain that, after the period during which institutional controls can be relied on, an accidental or intentional disturbance of the disposed materials could present a hazardous situation to an individual or a population. Where this possibility exists, it may be determined that such disturbances may be prevented by the use of passive means of communicating the nature of the hazard to future people."

U.S. EPA (Feb., 1978) p. 46

Additional references include: TENRAC, 1980, p. 44-46; U.S. EPA, Feb., 1978, p. 16-17.

Human Considerations

DEMOGRAPHIC CRITERIA

Population Size, Density, Distribution

Population is a critical criterion in evaluating sites for low-level radioactive waste facilities.

Studies of current and projected population size, density, and distribution should be given a high priority when considering locations for sites. Most authors favor remote areas with low population density for siting. In these areas, the potential for human exposure and the likelihood of intrusion into the site are reduced. Other authors point out, however, that rural areas are often the least prepared to act as hosts and are most vulnerable to adverse socioeconomic impacts.

"Any site selection should as the first priority include consideration of the health implications of the site on the population in the immediate vicinity, including the individuals employed on the site."

Illinois Rept. (1980) p. 16

"A model land burial facility for other than high-level wastes consists of 100 acres of land located in a rural sparsely settled area."

U.S. Atomic Energy Commission (Apr., 1974) p. 6-7

"Demographic Impacts

As a project attracts new workers and their families to the area around the construction site, either for employment on the project or in response to secondary economic growth, changes will occur in the size, density, composition, and location of the population in that area.

Population Size. The actual amount of population growth experienced by the area and by communities surrounding a nuclear waste repository would depend on a number of factors specific to that area, particularly, on the availability of currently unemployed, skilled workers and on the ease with which workers could commute from other surrounding areas.

Population Density. Density is fully accounted for given information on population size and population location within a bounded geographical area. However, density can have direct and important impacts on public services (especially transportation facilities), political actions and trends, and on the rate and nature of social interaction."

Cluett et al. (Sept., 1979) p. 13-15

"The noise levels, truck traffic and other features of facility operations are such that it is more appropriate to locate facilities in low population density areas, where buffer zones are typically greater, than in congested areas.

LLW 'waste disposal areas should be located at remote sites so as to reduce potential population exposures and the likelihood of human intrusions to the maximum extent reasonably achievable.'

Not allowed if there is more than one dwelling unit within 0.5 miles of site boundary."

Environmental Resources Management, Inc. (Sept. 19, 1980) no pages given

"Since remoteness from population centers is a prime site selection consideration for safety, this network of facilities will be located chiefly in rural America where small communities are least prepared to act as hosts and most vulnerable to potential adverse impacts."

Subcommittee on Rural Development (Kasperson Testimony) (Aug. 26, 1980) p. 8

"Identification of potential transportation routes from principal waste generators to the site, and estimate of demographic distributions along the routes. Identification of potential impacts from increased traffic along the transportation routes."

EG & G, Idaho, Inc. (Aug., 1980) p. 16

"The minimum distance a site can be located from a population cluster must be determined by considering the size of the population and the effects of accidental and chronic radiation releases during operations and post-closure. In addition a site located close to population centers could interfere with expansion, as well as increase the likelihood of human intrusion into waste after institutional control has been removed."

Falconer (1981) no pages given

Additional references include: Barnes, 1979, p. 14; Klingsberg and Duguid, 1980, p. 67; Panel on Land Burial, 1976, p. 68; Subcommittee on Rural Development (Leahy Testimony), Aug. 26, 1980, p. 2; Subcommittee on Rural Development (Murdock Testimony), Aug. 26, 1980, p. 11.

DEMOGRAPHIC CRITERIA

Anticipated Demographic Patterns

The evaluation of sites for low-level radioactive waste facilities should consider projected population patterns.

"The site should be selected with consideration given to current and projected population distributions."

Falconer (1981) no pages given

"For an adequately sized site, the facility should be sited in a relatively low population area and must be evaluated with respect to the present and future character and activities of the population in this area."

Massachusetts Rept. (1980) p. 19

"(4) Population impacts of the facility should be the first socioeconomic impact assessment.

Population is typically the 'prime mover' in socioeconomic phenomena. Accordingly, standard accepted demographic methods should be used to project population changes which would be associated with the facility."

Clemente et al. (1978) p. 37

"Identification of population centers located near the site; projections of long-term population growth and land requirements."

EG & G, Idaho, Inc. (Aug. 1980) p. 16

"(2) Potential land use, population growth and resource use. The site shall be evaluated with respect to the present and potential future character and activities of the human population of the region. Such evaluation, should include consideration of present and projected future uses of land, water, and natural resources. Areas with high population density or having economically significant natural resources which, if mined, would result in failure to meet the performance objectives of Subpart C should be avoided."

U.S. NRC (Feb., 1981) p. 13

No additional references.

Human Considerations

DEMOGRAPHIC CRITERIA

Immigrants and their Effect on Local Populations

The socioeconomic impacts of constructing and operating a low-level radioactive waste facility depend in large measure on the number of workers who move into the area.

"Socioeconomic effects associated with the construction and operation of radioactive waste management facilities depend largely on the number of persons who move into the surrounding area. Accordingly, the size of the population influx was forecasted and estimates of their needs for local social services were determined. These social services include medical care, school, police and fire protection, and utilities."

U.S. DOE (May, 1979) V. 1 p. 3.7.1

". . . the size and density of the local population around the site, the availability of workers with necessary skills, and the region-specific employment multiplier will determine the magnitude of required immigration to the site. Operations workers are likely to be highly skilled (and thus hard to find locally) and apt to stay longer; therefore, more operations workers than short-term construction workers are likely to immigrate to the site."

Cluett et al. (Sept., 1979) p. 7

"Community Structure. As a general rule, newcomers to a community often take at least two years before they begin to participate actively in neighborhood activities, local voluntary associations, and community events. In the case of construction workers, this situation is compounded by the fact that they do not intend to remain in the community indefinitely, with the result that very few of them ever join or participate in any neighborhood or community organizations. The construction workers typically remain quite isolated socially, interacting only with other construction workers and never becoming assimilated into the local community.

This situation can weaken the cohesion of a community, create numerous problems with which community agencies must deal, and generate serious cleavages within the community."

Cluett et al. (Sept., 1979) p. 23-24

Additional references include: Cluett et al., Sept., 1979, p. 6.

SOCIAL CRITERIA

Social criteria include all aspects of the public's involvement in the siting of a low-level radioactive waste site. The authors surveyed agree on the following points: 1) the need for public information programs to increase public understanding of the need for the site and its associated risks; 2) the impacts of the site on the local community and the resultant effect on quality of life be considered from the early stages of site planning; 3) that local citizens should be involved from the beginning in the site planning process so that any adverse impact can be mitigated; 4) that individual mitigation plans be developed for each host locality to compensate residents for any negative impacts and to provide incentives for support of the facility. The category "Social Criteria" is divided in this report into eight sections: public education and opinion; public involvement and acceptance; risk assessment and perception; ethical considerations; impact mitigation; incentives and benefits; compensation and liabilities; and change in local community.

Public Education and Opinion

Many authors strongly recommend establishing intensive public information programs to inform the public about all aspects of low-level waste management.

The authors feel that siting activities require an atmosphere of trust in which the public can believe that issues of health, safety, socioeconomic impacts, and compensation will be justly resolved. They also suggest public meetings, citizen panels to include the public in site evaluation and decision-making, and sufficient funding for independent impact evaluations.

> "Siting activities for low-level radioactive waste facilities require an environment of trust in which members of the public can believe that the issues of facility safety, impact and compensation have been addressed and resolved to all reasonable satisfaction."
>
> Murphy and Goldsmith (Feb., 1981) p. 3

> "In particular, it is recommended that an education program be instituted to give everyone the opportunity to understand the L-LW problem and the proper management of L-LW and, hence, to support constructively, the implementation of this necessary program."
>
> Massachusetts Rept. (1980) p. 1

> "Today the challenge for scientists is twofold: there is the need to put into perspective within the community the limits to scientific knowledge while at the same time to interpret this knowledge in its proper perspective to the public. Only then will the public be able to use this information in confrontation with government and industry in order to forego the compromises that the difficult nuclear waste decisions will entail."
>
> Zinberg (Jan., 1979) p. 39

"No radioactive waste management program will ever prove acceptable or achieve success without public support. We recommend that the evolving program include an intensive public information program intended to inform the public about all aspects of the waste management program, including publicly financed dissemination of views that may run contrary to the views and findings of the program managers. We further recommend that the program include the public and the states in the decisionmaking and site suitability review process. Citizens panels, public meetings with waste authority managers and scientists, annual reports to the public and Congress on the progress of the program, and adequate funding--to be made available by a direct tax on nuclear-generated electricity--for independent environmental, social, economic, and technical evaluations of waste management programs and facilities are all elements necessary to the ultimate success of the program. We believe that a waste management program that maximizes public education and involvement can and will minimize public objections to the goals of the program, thus greatly enhancing the program's chances of success."

Lipschutz (1980) p. 173-174

"The degree to which incentives and benefits are utilized to facilitate local acceptance of a site, will depend in part on the success of public education programs. Such programs can minimize the overall need for such incentives or benefits by increasing public awareness regarding the actual low risk associated with such sites. This is especially true given the general public's lack of understanding about the nature of low-level radioactivity."

National Governors' Association (Aug., 1980) p. 18

"The public's grasp, or misunderstanding, of safety problems and the intensity of its concern over them have arisen in large part as a result of the role played by the news media. The involvement and momentum of a multitude of vocal public interest groups on safety-related issues have also made a significant contribution to the public's increased awareness and concern regarding risks."

Capstick (Oct., 1979) p. 17

"In the six year period between 1973 and 1978 there was a substantial increase in the amount of information on the topic of radioactive waste available to the public through a variety of popular and special interest press soucres. This increase in information coincides with documented public concern with the problem of radioactive wastes and as such lends support to the proposition that the media contributes to the setting of the public agenda in policy issues."

Bronfman, Bronfman and Regens (Oct., 1979) p. 6

"Public acceptance of radioactive waste risks depends on a clear understanding of what trade-offs are involved in the use of nuclear power. The public's new view of technology as fallible is not necessarily cynical, but it is realistic. To achieve public acceptance, the benefits and risks of nuclear power must be presented in an equally realistic manner."

Rathje (Apr., 1977) p. 3-44

"Acceptance by special interest groups, public officials, and individual citizens is crucial to the site's establishment. Public perceptions can affect the project in many ways, possibly preventing it from being completed. It is not necessary or even feasible that everyone actively support the process, but their belief in the need for the site and the legitimacy of the process is required. They must understand the decisionmaking process, have their concerns and ideas considered in the decision, and feel that the entire process results in the best course of action."

EG & G, Idaho, Inc. (Aug., 1980) p. 2

"The experience gained in public relations areas has shown that the mere detection of trace radioactivity moving from a burial site can be perceived by the public as a cause for alarm, even though the levels may be far below those considered potentially harmful to human health or to the environment. Even poorly informed public opinion in the area of nuclear waste management appears to weigh heavily in the decision-making process. It is therefore all the more essential that future low-level waste disposal facilities in at least the eastern half of the United States be located and engineered in such a manner as to virtually guarantee no measurable waste migration into the surrounding soil for the period of interest, e.g., 100 to 150 years."

Illinois Rept. (1980) p. 11

"A single state agency should be charged with design of the education program, coordination of information and implementation of the plan. Although a consortium of users might provide educational services, the public is more likely to trust a state agency with fewer specific stakes in the outcome. Funds for the program, however, might be provided partially or wholly by a consortium of users. Responsibility for this program demands more than public relations skills; the coordinator of the effort must be included in technical and policy discussions to understand the issues and goals of the LLW management program."

Massachusetts Rept. (1980) p. 24

Additional references include: Abrams and Primack, Apr., 1980, p. 16, 39-40; Barnes, 1979, p. vi-vii, xii, 3; Bronfman, Bronfman and Regens, Oct., 1979, p. 8, 21, 23, 34, 36, 46; Capstick, Oct., 1979, p. 203; Clemente et al., 1978, p. 37-38; Cluett et al., Sept., 1979, p. 109; Green, 1972, p. 145; Hebert et al., May, 1978, p. 14, 23; Klingsberg and Duguid, 1980, p. 67; Lipschutz, 1980, p. 173, 174; Montague, Jan., 1979, p. 6-7; Murphy Correspondence, Nov., 26, 1980, no pages given; Murphy and Goldsmith, Feb., 1981, p. ii, 2, 5, 8-9, 10, 11; National Governors' Association, Aug. 1, 1980, p. 28; Nealy and Radford, 1978, p. 2; North Carolina Report, Jan. 12, 1980, p. ES-2, ES-3, 46, 51, 54-56, 57-58; Subcommittee on Rural Development (Murdock Testimony), Aug. 26, 1980, p. 11; Subcommittee on Rural Development (Wilkenson Testimony), Aug. 26, 1980, p. 22-23; U.S. DOE, Mar., 1980, p. 215; U.S. DOE, Mar. 13, 1981, p. 26-27; U.S. EPA, Apr., 1977, p. 2-93; Wetmore, 1980, no pages given; Zinberg, Jan., 1979, p. 35.

SOCIAL CRITERIA

Public Involvement and Acceptance

The authors surveyed agree that public involvement with policy and siting decisions should occur early in the siting process on both the state and local level.

Several federal agencies have held public policy hearings to date, but critics claim they were scheduled either too early or too late to effect decisions. Both the quantity and the quality of public participation is important, for every important technical and social view point should be aired and discussed.

> "To achieve an acceptable social and technical consensus on the best course of action, there must be regional, state, and local government and citizen participation in the review of alternatives for radioactive waste disposal. Until there is thorough consultation with the varied concerned segments of local and state governments, universities, and citizens' groups about the goals and criteria of waste management, the Federal program will continue to be embroiled in controversy."
>
> Lash (Feb., 1977) p. 3-17

> "Public Involvement in Low-Level Waste Management. A successful low-level waste management program must involve the public (i.e., citizens and citizen groups, local government, industry, academia, etc.) in planning and implementation of major policies. The state is the proper level of government to facilitate public involvement, and the federal government (through the Department of Energy) is prepared to assist states in this area."
>
> Tennessee Rept. (Nov., 1980) p. 10

> "Ensure maximum public participation in policy decisionmaking and waste facility siting in order to achieve a societal consensus on the acceptability of the program. No radioactive waste management program will ever prove acceptable or achieve success without public support. ...We believe that a waste management program that maximizes public education and involvement can and will minimize public objections to the goals of the program, thus greatly enhancing the program's chances of success."
>
> Lipschutz (1980) p. 173-174

> "Meaningful citizen involvement and participation are critical to developing an effective waste management system in North Carolina. Mechanisms should be developed to provide ample opportunity for citizen involvement in ongoing policy development and decisions concerning proposed facilities."
>
> North Carolina Rept. (Jan. 12, 1980) p. 53

"As a final comment, the development of a program of LLW disposal will have to include the public, allowing it to play an integral role in the planning and implementation. To be effective in this regard, the public must be informed about the benefits from the use of radioactive materials, the need for proper disposal, the safety of proper disposal and the consequences of having no proper disposal available. In addition, the public should understand that the location of geologically suitable sites is not a matter of individual choice, but of geological evolution, that at least one site must be chosen, and that support for the necessary zoning changes will be needed. In short, the role of the public should be constructive and supportive in finding an acceptable solution for LLW disposal."

Massachusetts Rept., (1980) p. 6

"Public participation in decision making serves two basic functions: first, it adds to the legitimacy and public acceptance of government decisions; and, secondly, what the public contributes - an outside perspective, unusual kinds of expertise, a longer-range view than most elected officials can afford, and on occasion basic moral demands - may actually lead to a better decision."

Abrams and Primack (Apr., 1980) p. 14

"Numerous interrelated and complex issues involving technical, legal, political, economic, moral and/or psychological concerns are relevant to the management of commercial nuclear waste. Two of the issues--the need for candor and for public involvement in the decision-making process--are perceived at this time as very important by segments of the public, and seemingly transcend the other issues, which are more specifically related to nuclear waste management."

Hebert et al. (May, 1978) p. 23

"Citizen Involvement. The management of nuclear wastes has traditionally been treated as a purely technical problem that did not concern the general public. That view has shifted in recent years, however, so that in 1976 a task group of the Nuclear Regulatory Commission concerned with nuclear waste management stated that: 'Full and effective public participation must be provided at all stages in the decision making and implementation process.'"

Cluett et al. (Sept., 1979) p. 113

"Public workshops and hearings sponsored by the Environmental Protection Administration (EPA), the Department of Energy (DOE), and the Nuclear Regulatory Commission (NRC) as well as NRC licensing experience indicate that these agencies permit public participation either too early, when plans are extremely vague, or too late, when the public is presented with a *fait accompli*, and also that the agencies have not thought through which of their decisions are the ones on which public participation is essential or most feasible. The resulting confusion of issues makes most current public participation attempts frustrating and nonproductive."

Abrams and Primack (Apr., 1980) p. 15

"The credible resolution of locally-held citizen concerns will determine successful facility siting and licensing. This resolution should occur publicly, for the most part, for while the process may move somewhat slowly, it will have far greater potential for success than a process largely concealed from the public."

Murphy and Goldsmith (Feb., 1981) p. ii

"In particularly important and far-reaching decisions it seems to me one needs to achieve two things: (a) sufficient public participation, and participation of sufficiently high quality, in the decision-making process to give strong assurance that no important technical or social viewpoint has been omitted or overlooked or ignored; and (b) one needs to achieve sufficient public participation, and participation of sufficiently high quality, that no citizen feels that his or her viewpoint has been omitted, overlooked, or ignored. I stress the quality of public participation because it is so important and so frequently neglected by managers."

Montague (Jan., 1979) p. 3

Additional references include: Barnes, 1979, p. 4, 14; Cluett et al., Sept., 1979, p. 105-112; EG and G, 1980, no pages given; Klingsberg and Duguid, 1980, p. 67; Lipschutz, 1980, p. 170-171, 173-174; Murphy and Goldsmith, Feb., 1981, p. 2, 7, 11-12, 17, 20-21; Montague, Jan., 1979, p. 5; National Governors' Association, Aug., 1980, p. 13, 14, 18-27; North Carolina Rept., Jan. 12, 1980, p. 22, 44-45, 50, 53; Perkins, Apr., 1977, p. 3022; Subcommittee on Rural Development (Peele Testimony), Aug. 26, 1980, p. 5-7; Tennessee Rept., Nov., 1980, p. 42; U.S. DOE, Mar., 1980, p. 44-45, 215; Wetmore, 1980, p. 182.

Human Considerations

SOCIAL CRITERIA

Risk Assessment and Perception

The authors unanimously agree that the assessment of risk to humans and the environment from radioactivity is a key factor in deciding where to locate a low-level radioactive waste facility. They stess that the public perception of risk, which could have a critical negative impact on any siting decision, is equally important.

Many authors feel that the public lacks a true understanding of radioactivity and its associated risks; they suggest public information programs that address this subject throughly and in depth.

> "Radioactive wastes represent a risk of potential exposure to people which varies considerably with time. The risks are dependent to a large extent on whether the wastes are controlled, the type of controls that could be adopted, and how long the controls would last. In a practical sense, risk considerations and control considerations are necessarily interrelated because each influences the other. Therefore the risks due to the presence of radioactive wastes in the human environment need to be assessed without controls and at different levels of control. The risk assessed at a particular level of control is especially important to the consideration of whether a risk is acceptable, which is discussed further in a later section."
>
> U.S. EPA (Feb., 1978) p. 14

> "No prescription can be stated for judging an adequate degree of protection for radioactive wastes independent of circumstances. A number of conditions are generally regarded as basic to sound public health practice: a) any allowed exposures to or releases of radioactive materials should be associated with some justifying benefit; b) exposures should be kept as low as is reasonable to achieve in view of technical, economic, and social considerations; and c) inequitable distribution of risks among individuals in a given population should be minimized, and d) certain stated levels of exposures of the general population are not to be exceeded, virtually without regard to circumstances."
>
> U.S. EPA (Feb., 1978) p. 41

> "The experience gained in public relations areas has shown that the mere detection of trace radioactivity moving from a burial site can be perceived by the public as a cause for alarm, even though the levels may be far below those considered potentially harmful to human health or to the environment. Even poorly informed public opinion in the area of nuclear waste management appears to weigh heavily in the decision-making process. It is therefore all the more essential that future low-level waste disposal facilities in at least the eastern half of the United States be located and engineered in such a manner as to virtually guarantee no measurable waste migration into the surrounding soil for the period of interest, e.g., 100 to 150 years."
>
> Illinois Rept. (1980) p. 11

"....the key consideration in deciding whether and how to store or dispose of radioactive wastes should be based primarily on an assessment of the risk for a wide range of relevant factors, especially the level of potential exposure, the time involved, and levels of control. Because of the long term implications of many of the waste materials and the ethical responsibility to minimize intergenerational risk transference, it is concluded that as a limiting case the risks imposed on future generations be no greater than those the producing generation is willing to accept, as expressed in the public health protection standards and policies it adopts.

Risk determinations rest on a number of key factors, especially the total amount of waste material in a location, its persistence due to form and concentration, the potential to enter the biosphere and produce adverse health effects on individuals and populations, the effectiveness of various controls imposed, and the inherent uncertainty of many of the parameters."

U.S. EPA (Feb., 1978) p. 20

"An overriding issue of concern with regard to criteria development for low-level and intermediate-level waste is the basic radiation protection objective in the disposal of these wastes. Should disposal be based on the premise of 'as low as feasible' or 'as low as practicable,' or should the objectives be tailored to fit each specific type of waste? Since the range of waste types includes high-activity, long-lived materials (transuranics), low-activity, long-lived materials (uranium mill tailings and phosphate wastes), and high-activity, short-lived materials (cobalt-60, strontium-90), it is apparent that the underlying factor is the associated risk, and that a determination should be possible through risk analysis (cost-benefit, risk-cost, etc.)."

U.S. EPA (Apr., 1977) p. 2-15

Essentially, the purpose of risk assessment or analysis is to identify all the hazards and then quantify the risk involved in any proposed action or inaction. Because risk estimates are essentially probability estimates, it is important that such estimates and figures not be considered as absolute, but rather as illustrative or benchmark for cooperative purposes. Also, because hazards to society are based on different sources of data and on varying models employing different considerations, care must be exercised in drawing valid direct comparisons between various risks."

Capstick (Oct., 1979) p. 9

"In the field of radiation protection we make two fundamental assumptions that permit us to compare the detrimental costs (risks) of radiation doses with the expenditures required to avoid radiation doses:

1. Every increment of radiation dose represents the same cost (risk) regardless of when, where, how, and to whom delivered. This is simply another way of stating the linear nonthreshold model for the biological effects of radiation.

2. <u>The cost of a detrimental health effect is the same regardless of its cause</u>.

The total expenditure we (as individuals or as a society) are willing to make to prevent and/or cure a particular injury or illness, divided by the total radiation dose that would cause the same injury or illness, is the cost per unit radiation dose. The radiation dose required to produce specific illnesses have been expressed statistically as 'risk.'

Many analyses have been made to determine the cost per unit dose, and values ranging from $10 to $1,000 per man-rem have been proposed. Until the data base and methodology for such analyses are improved, most prudent analysts will continue to use the highest cost value, i.e., $1,000/man-rem."

Schiager (Apr., 1977) p. 2-46

".....unlike most nuclear power reactors, the (nuclear waste) facilities will involve only limited benefits for the host communities. <u>What they will have are risks which, while judged small by most technical experts are still not well understood and are particularly feared by the public</u>.

The acquiescence of communities for uncertain risks with few compensating benefits will require a high degree of trust and confidence at a time when the very absence of these ingredients has plagued the orderly development of nuclear power in the United States."

Subcommittee on Rural Development (Kasperson Testimony)
(Aug. 26, 1980) p. 8

"<u>There is a dramatic lack of understanding about the nature of radioactivity</u> among the public, elected decisionmakers and the communications media. Radioactive waste materials, and for that matter other hazardous and toxic materials, are in great measure the publicly unexamined byproducts associated with the benefits of life in a technological society. That <u>they represent a risk is increasingly believed by the public</u>.

Murphy and Goldsmith (Feb., 1981) p. 17

"Many students of the nuclear power conflict have asserted that perceived risk is a major factor creating opposition to the technology. The data provide evidence that <u>a substantial amount of the information available to a variety of segments of the public is composed of discussions of real or perceived risk related to the existence of radioactive waste and the methods for disposing of it</u>."

Bronfman, Bronfman and Regens (Oct., 1979) p. 23

"It is apparent that <u>public concerns about the safety of nuclear waste repositories, regardless of the extent to which these concerns are based on an accurate understanding of the risks involved, will be</u>

a critical impact of any proposed waste management policy. In addition, giving the public more information about radioactive wastes may not eliminate critical risk assessments, since research has found that increased knowledge can actually heighten people's concerns about potential risks (Kasperson, et al., 1976)."

Cluett et al. (Sept., 1979) p. 109

Additional references include: Barnes, 1979, p. vi, 21-22; Capstick, Oct., 1979, p. 2-3, 5, 6, 11-12, 13-17, 19-21; Clemente et al., 1978, p. 13-14; Cohen, 1979, p. 225-226; Hebert et al., May, 1978, p. 23; Massachusetts Rept., 1980, p. 3, 13, 22; Murphy and Goldsmith, Feb., 1981, p. ii, 3, 8-9; Nealey and Radford, 1978, p. 6; Rochlin, Feb., 1977, p. 3-31; Subcommittee on Rural Development (Kasperson Testimony), Aug. 26, 1980, p. 10; Subcommittee on Rural Development (Peelle Testimony), Aug. 26, 1980, p. 4-6; Tennessee Rept., Nov., 1980, p. 42; U.S. EPA, Apr., 1977, p. 2-96; U.S. EPA, Feb., 1978, p. 14-15, 17-18, 20; Zinberg, Jan., 1979, p. 38.

SOCIAL CRITERIA

Ethical Considerations

Closely related to perceptions of risk are the ethical considerations associated with radioactive waste disposal.

The responsibility for long-term maintenance of waste facilities will fall on future generations who have no voice in siting decisions. The authors stress that we have no assurances that the institutions we establish to protect human health and safety will be able to do so in the future. One author states that we have two obligations to future generations: 1) to provide the fullest possible information as to future risks and costs and 2) we must act so as to minimize irreparable harm.

> "The objective of waste management is to ensure that we do not pass on to future generations any risk we would not be willing to assume ourselves."
>
> U.S. EPA (Apr., 1977) p. 2-95

> "The only principles that can be used for bringing the future into our decisions are moral and ethical ones, and these are difficult to apply...The first is to provide the fullest information possible as to future risks and costs. That the future may not be able to act upon this information does not remove our obligation to supply it. A minimum ethical principle for exporting risks is to do so openly. The second principle is to act so as to minimize irreparable harm."
>
> Rochlin (Feb., 1977) p. 3-30

> "There are at least two major factors that make the intergenerational aspect of the radioactive waste disposal issue problematic from an ethical point of view. First, intergenerational effects imply impacts on persons who, since they are not yet born, are unable to assess their willingness to undergo the risk and are unable to appraise how the risks might be mitigated and/or traded off against benefits for themselves or others...
>
> "A second feature that makes the problem of nuclear waste disposal an important moral problem is the knowledge of this generation that radioactive materials can impose risks on people yet to be born."
>
> Hebert et al. (May, 1978) p. 29

> "The degree of risk that the producing generation passes on to the future represents an important legacy of radioactive wastes. This transference involves a moral judgment of responsibility including the length of time for which responsibility extends into the future. An ethical basis for decisions regarding risk transference is needed not only for philosophical reasons, but also for the practical purpose of implementing evaluation techniques such as cost-effectiveness and risk-cost analyses. Unfortunately, society has not established clear approaches for dealing with the imposition of such risks far into the future.

Once it is accepted that the waste producing society is responsible to provide environmental protection and limitation of risk for future populations, it still remains to be decided how far into the future responsibility should extend. The implications of such a decision are not purely philosophical, however. One of the bases upon which alternate waste storage and disposal systems would be compared, and with respect to which judgments of acceptability of technology will be made, is their associated risks. The farther into the future the responsibility extends the greater will be the number of people to be protected, and it may be supposed, the greater the justification for additional measures of control."

U.S. EPA (Feb., 1978) p. 17-18

"Another related element of shifting public perception involves public concern over the displacement of known and uncertain impacts of our present technological systems upon future generations. . . Public concern is not limited to the risk of cancer from possible exposure of radiation, i.e., to the ability of our technology to isolate radioactive waste. It also relates to the issue of our placing responsibility for maintenance of waste isolation facilities upon future generations, i.e., the question of the perceived integrity and ability of our institutions to remain viable and insure the safe isolation of wastes to protect future generations."

Capstick (Oct., 1979) p. 20-21

Additional references include: Montague, Jan., 1979; U.S. EPA, Feb., 1978, p. 20-21.

Human Considerations

SOCIAL CRITERIA

Impact Mitigation

In selecting sites for low-level waste facilities, consideration must be given to the social and economic impact on communities and the region hosting the site.

Several authors suggest that the facility should be located so that adverse impacts from construction and operation of the facility can be mitigated. Mitigation can take various forms (see sections following on "Incentives and Benefits" and "Compensation and Liabilities"). To be effective, the authors stress that a mitigation plan should be tailored to each host locality.

> "The site shall be selected giving due consideration to social and economic impacts on communities and regions affected by the repository.
>
> (1) The site shall be located so that adverse social and/or economic impacts resulting from repository construction and operation can be accomodated by migration or compensation strategies.
>
> Social and economic impacts include both positive and negative effects on individuals, communities, and institutions, such as: the influx of new workers into a town, the effect of population growth on housing markets and community services, the fiscal burden on the local government, and impacts on governmental processes, and changes in land use patterns. Some impacts may remain for which compensation or migration may be necessary."
>
> NWTS Program Office (Feb., 1981) p. 11

> "It is also essential to keep in mind that there is, perhaps, no ideal general mitigation strategy, but rather that strategies must be tailored to the local area's needs and preferences if they are to be successful and acceptable.
>
> A specific mitigation plan must involve the following features: 1) early involvement of local residents and local decisionmakers 2) local area planning and other technical assistance be provided 3) developed comprehensive information base on impacts and the processes associated with the site of a repository 4) as a nation, to simply recognize that such a process will require long-term financial and other commitments 5) our Nation must begin to think of repositories in a broader perspective (to insure that our undesirable national projects be shared around geographically, not concentrated in one place)."
>
> Subcommittee on Rural Development (Murdock Testimony) (Aug. 26, 1980) p. 11 - 12

> "The responsibilities of the waste siting council should include:
>
> 7. To consider the concerns and objections submitted by the public, making an effort to provide that the concerns and objections are mitigated by establishing additional stipulations specifically applicable to the facility and operation at that site. The council

also shall to the fullest extent practicable integrate by stipulation the provisions of the local ordinances, permits or requirements."

Murphy and Goldsmith (Feb., 1981) p. 14

"What can be done to address and resolve these rad waste siting problems?

- policy and programs that might include efforts to distinguish mitigable effects from unmitigable, and to reduce the number and scope of the unmitigables;
- aggressive mitigation of all mitigable effects in a prompt, adequate, and complete manner."

Subcommittee on Rural Development (Peelle Testimony) (Aug. 26, 1980) p. 6-7

Example of private industry paying for the cost of mitigating social economic impact on broad scale - the most notable example is:

"... in the State of Wyoming. Wyoming's siting laws require, often as a condition of siting, a great deal of mitigation. This mitigation can include such things as building a designated number of housing units, it can include front end financing for local school systems in which the private developer, in fact, builds or provides the money to build an elementary school system, for example. It includes, in most cases in that siting requirement, long-term monitoring and adjustment of mitigation payments, if necessary, over time. That is, the company is required to keep track of what the impacts actually are, and if they exceed those that were projected, they are required to come up with additional funds to mitigate those additional impacts."

Subcommittee on Rural Development (Murdock Testimony) (Aug. 26, 1980) p. 16

"Perhaps some sort of contingency fund or trust fund needs to be set aside to allow response to future impacts which are as yet unknown and unexpected. Otherwise we can only resort to after-the-fact, patch-up mechanisms as are being considered now in the proposed superfund for toxic waste management. In this latter case, chemical manufacturers would be asked to provide money to repair past mistakes and compensate those who have been affected."

Subcommittee on Rural Development (Peelle Testimony) (Aug. 26, 1980) p. 14

"Several commenters stated that if a repository is sited in a particular state, the Federal government should:

- Give states or communities impact funds.
- Consider mitigating the effects of increased monitoring, escorting, and emergency planning responsibilities of the states."

U.S. DOE (Oct., 1980) V.3. p. 15

No additional references.

SOCIAL CRITERIA

Incentives and Benefits

Some authors stress that the concept of incentives and benefits is vital to mitigating the impacts of a low-level radioactive waste site. For a site to be socially acceptable, the incentives and benefits available to the host area must outweigh the perceived risks and costs of the project.

An incentive is anything that assists a community in accepting and supporting a low-level radioactive waste facility. A benefit is a compensation or commitment for a specific need that arises as a result of the facility. Some authors feel that insufficient attention has been given to date to this important criterion.

> "Expeditious development of regional low-level nuclear waste facilities will likely depend on the quality and quantity of incentives and benefits available to state and local units of government. The concept of incentives recognizes the need to encourage and motivate the states and local communities to accept location of a low-level nuclear waste disposal facility. For example, the availability of funds to be used at the discretion of site states and site communities, would act as a positive inducement toward locating a site. On the other hand, the concept of benefits acknowledges the need to provide some type of rightful compensation or commitment for specific needs of or effects on a state and community as a result of their acceptance of such a regional facility. For instance, such benefits could include financial commitments to the site state and community for substantial Perpetual Care and Decommissioning Funds to be provided by waste generators, agreed to as a condition of their licensing.
>
> Successful efforts to encourage public acceptance of a site must provide incentives and benefits to those affected by the presence of a regional site. Accordingly two distinct parties need to be benefited: (1) the local community hosting the waste facility; and (2) the site state. These two parties should receive some kind of incentive and benefit to be provided by the federal government and the generating states within the region. Various state and federal legislative action should be encouraged to achieve that purpose."
>
> National Governors' Association (Aug., 1980) p. 17-18

> "Facility Siting Incentives. The use of incentives to help a locality offset the real and perceived negative aspects of accepting a treatment or disposal facility may be essential for facility siting. An incentive is anything which assists a community in accepting and supporting a low-level waste management facility. Possibilities are: impact management--such as utility improvements, planning assistance to local governments, etc.; compensation--that is, payment for impacts which cannot be mitigated; and, premium payments--a grant or other 'bonus' monies not specifically related to any aspect of the facility. Communities may be given the opportunity to suggest modifications to a proposed facility. This may be considered an incentive as it can

enhance the acceptability of the project. Some individuals working on the energy facility siting problem have suggested that if an attractive and reasonable incentives package is put together, qualified communities may actually 'bid' for such a facility."

Tennessee Rept. (Nov., 1980) p. 10

"I think the incentives to host areas - the incentives to local areas to be hosts and to participate in the process - must outweigh the perceived costs and risks.

There has been remarkably little attention, really, devoted to this area of how do you develop and what are the options we have in providing incentives. Incentives should be distinguished from mitigation of impacts caused by repository construction or from compensation for injury or damage caused by repository operation. ...Incentives may need to be increased futhermore to balance out costs and uncertainties or malfunctions in any other part of the siting and mitigation process. Incentives, finally, need to be substantial in order to overcome such perceived disbenefits.

The key to producing some willing host areas or, in fact, any willing host areas, I think, lies in having real monetary and other incentives. I doubt personally that very much progress is going to be made in resolving the dilemmas until someone pays attention to the incentive matter. The attention, concern and help of the Congress is needed to address and resolve these difficult institution-building tasks."

Subcommittee on Rural Development (Peelle Testimony)
(Aug. 26, 1980) p. 6 - 7

"The specific types of potential benefits which might be designed in a low level nuclear waste repository proposal could include funds for:

(a) highway/safety improvements and new access roads;
(b) fire and police protection and training;
(c) protection of water supply and waste water treatment facilities;
(d) recreation facilities and programs;
(e) hospitals and health care; and
(f) general government management."

Murphy and Goldsmith (Feb., 1981) p. 19

Additional references include: National Governors' Association, Aug., 1980, p. 13, 18-27; Murphy and Goldsmith, Feb., 1981, p. ii, 14, 21, 22; Subcommittee on Rural Development (Peelle Testimony), Aug. 26, 1980, p. 4-6; Subcommittee on Rural Development (Kasperson Testimony), Aug. 26, 1980, p. 8, 9, 15.

Human Considerations

SOCIAL CRITERIA

Compensation and Liabilities

The concept of compensation for the risks involved in hosting a low-level radioactive waste disposal site should be adequately addressed prior to siting.

Compensation may take the form of benefits for specific local needs or creation of new projects to create jobs. The public must also be assured that adequate liability coverage is carried for the life of the site and after its closure. Under federal law, the facility operator must assume primary responsibility for liability during site life and for 30 years after closure. After that period, the state (having title to the land) must assume liability. Some states are considering imposing the doctrine of strict liability on low-level radioactive waste sites for increased public protection.

> "...unavoidable risks should be accompanied by compensating benefits: Not all risks can be avoided, of course, in reactors or in waste facility locations. For those risks which are unavoidable, there should be compensating benefits. Such a principle is recognized in the 1980 Presidential statement on nuclear waste management wherein the designated beneficiaries of commercial and defense wastes, respectively, are the utility consumers in the Nation, as a whole. The statement calls for these groups to internalize the burden of cost. The costs should be social risk defined, however, to include avoidance in management."
>
> Subcommittee on Rural Development (Kasperson Testimony) (Aug. 26, 1980) p. 9

> "Potential benefits should shape project design. It is critical -- and this cannot be overemphasized -- that this expanded understanding of compensating benefits be linked to the design of the project itself. In the general case, it will mean using the understanding of the generic needs of state/local governments in the typical case (e.g., to raise revenues to support necessary services, lower taxes, or to ensure adequate job opportunities) so as to better design the program. In particular cases, it might mean identifying state and local public 'agenda' items (e.g., agricultural preservation, economic development) and designing the project -- and its financing, and its operation -- to address these priorities. Customized land acquisition and management, for example, might be the result in one case, in order to promote 'presentation.' The development of a proximate or inclusive large industrial site might be the result somewhere else. (Note: This contrasts significantly with the way in which proposed waste facilities are frequently presented by government, as though their design will be totally based on externally-determined 'technical' considerations.)"
>
> Murphy and Goldsmith (Feb., 1981) p. 17

"It is necessary for the public to be assured that adequate liability coverage is carried for a hazardous or low-level radioactive facility during both the life of the site and after its closure.

"Under Federal law, the facility operator must assume primary responsiblity for liability during site life and for 30 years after closure. This is accomplished by the operator providing adequate liability insurance during this period. The Task Force feels that the issue of whether the state should provide back up liability insurance during this period also must be considered. One reason for this is the possibility that the insurance coverage is inadequate to cover damages.

"The question of post closure liability is even more critical. The operator's liability extends 30 years after closure. Injuries from these facilities may occur after the 30 year period has ended. Since the operator's responsibility has ended and the state has title to the land, the state must be in a position to assume liability."

North Carolina Rept. (Jan. 12, 1980) p. 51

"Strict liability is a legal doctrine which imposes liability without fault on a person or company whose activity has caused damage to another person. ...Strict liability has already been imposed by North Carolina courts on activities that are considered ultrahazardous or abnormally dangerous in character, such as blasting or keeping dangerous animals. There is the possibility that courts would find activities associated with hazardous or low-level radioactive waste to be ultrahazardous and thus judicially impose the doctrine. The Task Force feels, however that imposing the doctrine by statute would enhance public acceptance of the waste management system and show that there is concern that people who have been harmed will have the greatest possible chance of recovering damages."

North Carolina Rept. (Jan. 12, 1980) p. 57-58

Additional references include: North Carolina Rept., Jan. 12, 1980, p. 51, 54-57.

SOCIAL CRITERIA

Change in Local Community

Many authors point out that the construction and operation of a low-level radioactive waste facility can cause major changes in the life of a local community (increased revenues, expanded services, new jobs and residents).

Impacts must be carefully managed (limiting the negative and optimizing the positive) so that the quality of life in the vicinity of the site will not be diminished. Early involvement of local citizens in the site planning process should aid in this endeavor.

> "While public expenses associated with a low level repository might not be extremely large, they could represent a significant addition to the budget of a small community. Depending on the size of the investment, it should be understood that the impacts of the investments could raise the population's levels of expectation. People could likely demand improved services. The style of local government could change, depending on the scale of the facilities, their location relative to existing labor, and the degree to which employment is 'targeted' for local residents. It is of critical importance that there be sound management of repository impacts, limiting negative consequences and optimizing benefits, so as to improve and not diminish the quality of life in the general vicinity of a LLW repository. Many communities are skeptical of significant new development, with good reason, and only thoughtful planning and execution by local and state actors will assuage residents' fears."
>
> Murphy and Goldsmith (Feb., 1981) p. 20

> "The broad heading of community services includes all services provided for citizens in most communities, by both public and private organizations. Such services include education and training, medical and dental services, hospitals, mental health clinics, law enforcement and judicial services, traffic control and mass transit systems, information and counseling services; programs for children and youth, social assistance and welfare services, recreational activities, and libraries and other cultural activities. The growth in demand for all such services is generally directly proportional to the size of the immigrating population.
>
> Consequently, communities located near a large construction project must be prepared to expand rapidly their capabilities for providing all kinds of services to both old and new residents."
>
> Cluett et al. (Sept., 1979) p. 24-25

> "Rapid demographic and economic growth can create a wide variety of changes and problems for the affected communities."
>
> Cluett et al. (Sept., 1979) p. 21

No additional references.

Human Considerations

LEGAL INSTITUTIONAL CRITERIA

In the literature, the legal and institutional aspects of siting a low-level radioactive waste facility are considered to be equal in importance to technical concerns.

The effectiveness of the institutions responsible for licensing, overseeing, maintaining and monitoring sites will determine in large measure the ultimate success of these facilities. The resolution of institutional issues could affect the public's support of the whole waste management system.

> "Effective implementation of a safe radioactive waste disposal system depends upon the competence and persistance of the implementing institutions. Failure in the planning and implementation process could render ineffective even the most promising disposal technology, and the public response to such failure could severely limit the freedom to implement similar systems at a later date."
>
> Lipschutz (1980) p. 157

> "The March 1979 IRG report to the President states the following:
>
> ...the resolution of institutional issues, required to permit the orderly development and effective implementation of a nuclear waste management program is equally important as the resolution of outstanding technical issues and problems and would add that the resolution of institutional issues may well be more difficult than finding solutions to remaining technical problems."
>
> U.S. DOE (Mar., 1980) p. 45

> "The biggest problem, I believe, in the entire rad waste repository siting business is the institutional gap, or the absence of appropriate institutions.....
>
> Who can guarantee that needed protective and accountability arrangements will survive shifting government priorities and budget cuts for a generation or more? How do we arrange these structures that I claim we need to protect those bearing special risks in the national interest? How do we avoid the Indian treaty analogy when making commitments to local areas?
>
> Perhaps contractual arrangements will provide the institutional certainty that is needed to enable resolution of this dilema."
>
> Subcommittee on Rural Development (Peelle Testimony)
> (Aug. 26, 1980) p. 5 - 6

In this report, the criterion "LEGAL - INSTITUTIONAL ISSUES" is divided into the following sections: Institutional Control; Federal Authority; State Authority; Local Authority; Land Ownership; Legislation; Regulations; and Public Policy Formation; Political Issues and Regionalization; and Decision-Making Process.

LEGAL INSTITUTIONAL CRITERIA

Institutional Control

Institutional control of low-level wastes is used primarily to protect human health and includes the acquisition, treatment, preparation and storage of these wastes.

The ability to maintain institutional control during critical periods may be necessary for a successful site. Institutional control is intended only for short-term protection (100 years) and not long-term security. The Nuclear Regulatory Commission has recently published requirements for a 100-year period of active institutional controls and has asked for financial assurances that these activities will be fulfilled.

> "Control of radioactive wastes can be provided by institutional forms of management or by disposal. Institutional management is used primarily to control exposure to present populations and includes the acquisition, treatment, preparation, and storage of radioactive wastes. The disposal of radioactive wastes, on the other hand, presumes no such dependence on formal institutional mechanisms to maintain isolation of the wastes from the biosphere. Rather, disposal is achieved by placing the wastes in an acceptable location with no intent of recovery. In general, institutional management of radioactive wastes is a short term process; disposal is a long term action."
>
> U.S. EPA (Feb., 1978) p. 22-23

> "Institutional Control. The land owner or custodial agency shall carry out an active institutional control program to physically control access to the disposal site following transfer of control of the disposal site from the disposal site operator. The active control program must also include, but not be limited to, carrying out an environmental monitoring program at the disposal site, periodic suveillance, (sic) minor custodial care, and other requirements as determrmined (sic) by the Commission and administration of funds to cover the costs for these activities. The period of active controls will be determined by the Commission, but active controls may not be relied upon for more than 100 years following transfer of control of the disposal site to the owner."
>
> U.S. NRC (July 24, 1981) p. 38090

> "Institutions are to be used for error correction and detection, and are not relied upon to provide a secure barrier."
>
> Rochlin (Feb., 1977) p. 3-31

"The principal criterion for measuring the adequacy of institutional arrangements is:

1 - performance
2 - accountability
3 - stability or durability
4 - adaptability
5 - economic efficiency"

Hebert et al. (May, 1978) p. 66

Additional references include: Capstick, Oct., 1979, p. 11-12, 22; Clemente et al., 1978, p. 10; Hebert et al., May, 1978, p. 62; Illinois Rept., 1980, p. 21-22; Lipschutz, 1980, p. 158; Murphy and Goldsmith, Feb., 1981, p. i, ii, 8, 12, 13; North Carolina Rept., Jan. 12, 1980, p. ES-4, 57-58; Subcommittee on Rural Development (Peelle Testimony), Aug. 26, 1980, p. 4; TENRAC, 1980, p. 4, 15; U.S. DOE, Oct., 1980, V. 3, p. 15; U.S. DOE March 13, 1981, p. 30-31; U.S. EPA, Feb., 1977, p. 3-3, 3-8; U.S. EPA, Feb., 1978, p. 25, 28-29; Wetmore, 1980, p. 182.

LEGAL INSTITUTIONAL CRITERIA

Federal Authority

In the United States, the Nuclear Regulatory Commission, the Environmental Protection Agency, the Geological Survey, and the Departments of Energy and Transportation are responsible for technology and criteria development, licensing and regulation of all low-level radioactive waste facilities. Such facilities must by law be sited on land owned by the federal or state government.

"Department of Energy (DOE)

The primary objective of the DOE low-level waste management program is to develop the technology to provide for disposal of low-level radioactive wastes in a manner that protects the public health and safety. The Department of Energy has not been assigned regulatory authority over commercial low-level waste activities.

Nuclear Regulatory Commission

The responsibilities of the Nuclear Regulatory Commission include establishing performance and licensing criteria for low-level waste disposal facilities, licensing the facilities, and regulating operation. In agreement states, this role has been delegated to the states.

Department of Transportation

The Department of Transportation regulates transportation of low-level radioactive wastes. Transportation routing and regulatory requirements must be taken into account in waste management needs assessment.

Environmental Protection Agency

The Environmental Protection Agency is responsible for developing general standards and criteria for low-level waste disposal. This development process is now underway, and will consider potential health effects and impacts of treatment and disposal methods.

U.S. Geological Survey

As part of the U.S. Department of the Interior, the U.S. Geological Survey's role in low-level waste management is to advise and assist other agencies and the states. Serving as 'earth science consultants,' they can provide an objective assessment of geologic and hydrologic aspects of suggested areas. The Department of the Interior may also be involved in authorizing the use of certain federal land for siting purposes."

U.S. DOE (Nov., 1980) no pages given

"Near-surface radioactive waste disposal facilities shall only be sited on land owned by the Federal or State goverment."
U.S. NRC (Feb., 1981) p. 28

The role of the federal government in siting and compensating host localities is discussed by several authors.

"Where a facility is proposed to be sited on Federal land or land to be transferred to the Federal government, the application shall include a certification by the applicable Federal land manager that the use of the site for the purpose of land disposal of radioactive wastes is authorized under Federal law, and has been approved for such use or will be so approved before completion of the Commission's review of the license application if such application meets all other Commission requirements for licensure. The certification shall indicate that the Federal government will assume ownership if the land is to be transferred and if the application meets all Commission requirements for licensure. The certification shall also show that the federal land manager has consulted with the State in which the proposed site is located according to applicable Federal law."
U.S. NRC (Feb., 1981) p. 35

"Successful efforts to encourage public acceptance of a site must provide incentives and benefits to those affected by the presence of a regional site. Accordingly, two distinct parties need to be benefited: (1) the local community hosting the waste facility; and (2) the site state. These two parties should receive some kind of incentive and benefit to be provided by the federal government and the generating states within the region. Various state and federal legislative action should be encouraged to achieve that purpose."
National Governors' Association (Aug., 1980) p. 18

"The Federal government has a significant interest in the regionalization of low-level waste disposal, whether in Non-Agreement or Agreement States, as this should lead to an optimal number of sites. Federal agencies should cooperate fully with representatives of state and local government in the management of low-level wastes."
Murphy and Goldsmith (Feb., 1981) p. 7

"I feel it is a questionable approach for the Federal Government to be assuming the prime responsibility for impacts. I believe that the Federal role here might be to create a market for those externalities by requiring local developers, utilities, or whoever, to negotiate with local communities and set up programs, perhaps under State aegis, as in Wyoming, that attempt to deal with the problems as they are at the local level. ....But the Federal role might be to set up the market by requiring mitigation be done within a certain framework."
Subcommittee on Rural Development (Aug. 26, 1980) p. 18

Additional references include: Abrams and Primack, Apr., 1980, p. 15, 16; Clemente et al., 1978, p. 10; Falconer, 1981, no pages given; National Governors' Association, Aug., 1980, p. 18; Perkins, Apr., 1977, p. 3-24; Subcommittee on Rural Development (Davis Testimony), Aug. 26, 1980, p. 34, 44; Subcommittee on Rural Development (Leahy Testimony), Aug. 26, 1980, p. 17.

LEGAL INSTITUTIONAL CRITERIA

State Authority

Most authors feel that the state is the proper level of government to facilitate public involvement in the siting process and that the federal government should assist states in this endeavor.

Through the "Low-Level Radioactive Waste Policy Act (Public Law 96-573)," states were given responsibility for disposing of their own low-level wastes (see also "Legislation").

> "There are a number of reasons states should provide leadership in low-level radioactive waste management. Hospitals and colleges, and utilities to some degree, are closely associated with the responsibilities and activities of state government. Furthermore, the beneficiaries of the services of these organizations are largely the citizens of that state.
>
> Effective waste management will ultimately require new waste treatment and disposal facilities. The siting of such a facility is best addressed as a state and local matter. This may be a preferable and more successful approach than a solution instituted by the federal government."
>
> Tennessee Rept. (Nov., 1980) p. 5-6

> "Planning and implementation of state policy on low-level waste management will involve the executive and legislative branches of state government, local officials, and many segments of the general public."
>
> Tennessee Rept. (Nov., 1980) p. 6

> "Public Involvement in Low-Level Waste Management. A successful low-level waste management program must involve the public (i.e., citizens and citizen groups, local government, industry, academia, etc.) in planning and implementation of major policies. The state is the proper level of government to facilitate public involvement, and the federal government (through the Department of Energy) is prepared to assist states in this area."
>
> Tennessee Rept. (Nov., 1980) p. 10

> "State and local review by citizens and policymakers is an essential part of the overall siting process. Local acceptance of the siting process requires information on the need for the site, participation in development activities, opportunities for access to the decisionmaking, and opportunities to review documents such as permit and license applications. State and local officials also participate in decisions on site ownership and operation."
>
> EG & G, Idaho, Inc. (1981) Sheet 7

Some authors feel that the state must have the final authority on siting.

"Recent experiences in North Carolina and other states document the very real possibility that resistance and exclusion by localities may be pervasive enough to prevent the needed waste management facilities from being developed. Many other states are convinced of the seriousness of this problem and have either proposed or adopted laws which guarantee that the state has final siting authority for these types of facilities. This policy has been endorsed by the National Governors' Association.

The Task Force gave a great deal of consideration to this issue and recommends that every effort be made to find suitable sites in receptive communities. It is in the best interest of the citizens of the State to ensure that sites are available for these facilities. If this approach is not successful, however, the state must be in a position to make a final decision on a site location."

North Carolina Rept. (Jan. 12, 1980) p. 44-45

"...as a minimum, the burial site and the buffer zone need to be owned by the State, but more desirable, that the entire site be State property. This would also protect the State in case of premature closing; for example, before the entire perpetual care fund had been fully established."

Blackburn and Ed (1979) p. 839

There are various mechanisms that states can develop to facilitate the siting process. Authors feel that the enactment of siting legislation will be important for the success of regional siting efforts.

"The Massachusetts Hazardous Waste Facility Siting Act specifies a siting process that encourages communities to want facilities rather than forcing facilities upon them, and the legislation takes seriously the lesson learned through other siting conflicts that no power is great enough to make communities accept facilities they strongly oppose. Thus while most other states are strengthening state control over local decisions, Massachusetts has adopted an approach focusing on the prevention of opposition, thereby removing the need for strong state control."

Wetmore (1980) p. 184

"Within the regional context, it is important that states demonstrate to other compact states their good faith, to provide an incentive for regional facility siting activities. Enactment of siting legislation will assure other states within the region that each state is approaching regional siting efforts with the intention of meeting its responsibilities. Siting efforts coordinated among states will help in answering requirements of Federal regulations and the local concern of 'why my town?'"

Murphy and Goldsmith (Feb., 1981) p. ii

"...it is necessary to create three entities within a state to establish an environment for a participatory low-level siting process. They should be temporary in duration and should be dissolved or become dormant upon completion of their siting responsibilities, being reactivated only when a second regional site is being assessed sometime in the future. The three are:

- a local municipal review committee authorized by state legislation;
- a waste siting council;
- a waste management planning committee."

Murphy and Goldsmith (Feb., 1981) p. 8

"With respect to host localities, state governments need to develop a facility siting process which:

- has adequate planning resources;
- provides for public understanding of low-level radioactive waste issues;
- provides for a program designed to ensure adequate understanding by local officials of the technical issues associated with siting and later operation of a waste facility;
- assesses the technical adequacy of potential sites;
- assesses the hazards of operating a burial facility and the response capability required to protect the town's citizens;
- balances the reasonable concerns of the locality with the state and national needs;
- ensures adequate and safe transportation of waste materials;
- develop an extended care plan for the site."

Murphy and Goldsmith (Feb., 1981) p. 4-5

Additional references include: Blackburn and Ed, 1979, p. 839; Falconer, 1981, no pages given; Illinois Rept., 1980, p. 21-22, 24; Lipschutz, 1980, p. 173, 174; EG & G, Idaho, Inc., 1980, no pages given; Massachusetts Rept., 1980, p. 24; Murphy and Goldsmith, Feb., 1981, p. i, 3, 4-5, 6, 7, 10; National Governors' Association, Aug., 1980, p. 17-18; North Carolina Rept., Jan. 12, 1980, p. ES-2, 34, 56; Subcommittee on Rural Development (Cunningham Testimony), Aug. 26, 1980, p. 31; Subcommittee on Rural Development (Davis Testimony), Aug. 26, 1980, p. 34; Subcommittee on Rural Development (Kasperson Testimony), Aug. 26, 1980, p. 10; Tennessee Rept., Nov., 1980, p. ii-iii; U.S. NRC, Feb., 1981, p. 28, 34-35.

Human Considerations

LEGAL INSTITUTIONAL CRITERIA

Local Authority

Many authors feel that local acceptance is crucial to the successful siting of any low-level radioactive waste facility.

Local authority can play a large role in achieving this success by involving citizens in both advisory and decision-making capacities. Local authority should be permitted to establish fees or taxes, depending on the social and economic impacts sustained by the locality. As described in the two subsections following, local governments traditionally exercise zoning and land use planning powers and coordinate emergency preparedness planning.

> "Local government is, however, where people believe that they have the greatest influence over decisions which can have significant impacts on their lives. They are able to hold their officials accountable for more than a term of office - for a lifetime, at the Kiwanis barbeque, at the local filling station or on Main Street. The support of local officials is essential to the siting of waste facilities. Their confidence that such facilities can be operated safely and their ability to transmit their confidence to their fellow citizens are necessary for a community to consider hosting such a facility. While their fellow citizens' adamant opposition to a policy can typically halt it, their majority support, if nurtured and shaped in response to broadly held perceptions, can endow it with legitimacy."
>
> Murphy and Goldsmith (Feb., 1981) p. 11

> "To promote local citizen involvement in facility siting decisions, the Task Force recommends the establishment of local siting advisory committees in localities in which facilities are proposed. These committees would serve as a forum for exchange of information and opinions between state regulatory agencies and the involved locality. This should provide state agencies with a means for understanding and addressing local concerns. This approach should help to avoid misinformation and distrust by subjecting the decision-making process to an open forum.
>
> The formation of such advisory committees should not be made a legal requirement but should be optional according to the preference of the local governing body. Nevertheless, widely based local participation is vital and the Task Force strongly recommends that committees be formed, organized, and operated along the following lines."
>
> North Carolina Rept. (Jan. 12, 1980) p. 54-56

> "Local communities become involved in the evaluation and management of socioeconomic impacts associated with constructing and operating large industrial facilities within their jurisdictions. Clearly, the construction and operation of a waste management facility would involve substantial social and economic impacts on the small communities that might serve as host sites."
>
> Hebert et al. (May, 1978) p. 103

"7. Local governments should be given the authority to establish a fee, surcharge, or tax based on actual costs and lost revenues associated with a waste management facility."

North Carolina Rept. (Jan. 12, 1980) p. ES-3

"State and local review by citizens and policymakers is an essential part of the overall siting process. Local acceptance of the siting process requires information on the need for the site, participation in development activities, opportunities for access to the decisionmaking, and opportunities to review documents such as permit and license applications. State and local officials also participate in decisions on site ownership and operation."

EG & G, Idaho, Inc. (1981) Sheet 7

"It is also essential to keep in mind that there is, perhaps, no ideal general mitigation strategy, but rather that strategies must be tailored to the local area's needs and preferences if they are to be successful and acceptable.

A specific mitigation plan must involve the following features: 1) early involvement of local residents and local decisionmakers 2) local area planning and other technical assistance be provided 3) developed comprehensive information base on impacts and the processes associated with the site of repository 4) as a nation, to simply recognize that such a process will require long-term financial and other commitments 5) our Nation must begin to think of repositories in a broader perspective (to insure that our undesirable national projects be shared around geographically, not concentrated in one place)."

Subcommittee on Rural Development (Murdock Testimony)
(Aug. 26, 1980) p. 11 - 12

"This site approval process can help to ensure program credibility by its incorporation of local representation on the state body (a waste siting council) designed to approve a site."

Murphy and Goldsmith (Feb., 1981) p. 12

Additional references include: Lipschutz, 1980, p. 173, 174; Murphy and Goldsmith, Feb., 1981, p. 2; Subcommittee on Rural Development (Kasperson Testimony), Aug. 26, 1980, p. 10, 19; Tennessee Rept. Nov., 1980, p. 6.

Human Considerations

LEGAL INSTITUTIONAL CRITERIA

Local Authority

Zoning and Land Use Authority

Local governments traditionally exercise zoning and land-use planning powers that may affect the siting of a low-level radioactive waste site.

> "Local governments have traditionally exercised zoning and land use planning powers to regulate activities that occur within their jurisdictions. Although zoning and land use planning controls may not directly impinge upon federal repositories, it is clear that in a number of instances, localities may utilize such powers to hinder implementation of plans to the point where implementation may no longer be feasible."
>
> Hebert et al. (May, 1978) p. 103

> "The State waste siting council also shall to the fullest extent practicable integrate by stipulation the provisions of the local ordinances, permits or requirements."
>
> Murphy and Goldsmith (Feb., 1981) p. 14

> "In addition, localities should be authorized to recoup any real property tax revenues that are permanently lost because of state ownership of land on which facilities are located or the lowering of property values on adjacent land. The former will be particularly applicable to burial facilities because of the recommendation that the State acquire title to any land on which hazardous or low-level radioactive wastes are buried."
>
> North Carolina Rept. (Jan. 12, 1980) p. 46

> "Responsibilities of the waste siting council would include assessment of:
>
> The impact on the proposed host municipality in terms of health, safety, cost and consistency with local planning and existing development. The council shall consider local ordinances, permits or other requirements and their potential relationship to the proposed facility."
>
> Murphy and Goldsmith (Feb., 1981) p. 13

No additional references.

Human Considerations

LEGAL INSTITUTIONAL CRITERIA

Local Authority

Emergency Preparedness Planning

Emergency preparedness planning will be critically needed in localities where low-level radioactive waste sites are located.

"Local communities are also involved in emergency preparedness planning, either for transportation accidents or for industrial accidents at waste management complexes. The local police force or fire department is often called to the scene first in any accident situation. As such, local governments have a distinct continuing concern about emergency preparedness actions."

Hebert et al. (May, 1978) p. 103

"The formulation of criteria should take into account the probability of accidents. It was suggested that remedial measures for an accident should be preplanned."

U.S. EPA (Apr., 1977) p. 2-95

"Large shipments (i.e. greater than 75 cubic feet) should be required to notify the appropriate agency of the primary route 72 hours before hand. Contingency plans should be available in the event of transporation accidents."

TENRAC (1980) p. 6

"With respect to host localities, state governments need to develop a facility siting process which:

- includes emergency response procedures and preparedness plans prepared with Federal guidance."

Murphy and Goldsmith (Feb., 1981) p. 4-5

No additional references

Human Considerations

LEGAL INSTITUTIONAL CRITERIA

Land Ownership

The criterion of land ownership is important because it implies responsibility for long-term care of the site.

Current regulations require that the state or federal government must own the site; if the state owns the site, it should have the option of turning it over to the federal government for long-term care.

> "Responsibility for long-term care is related to the issue of site ownership. Current state regulations, and existing and draft NRC regulations, require that either the federal government or the state must own the disposal site. Ownership implies responsibility for post-operation care. It has also been proposed that if the state owns the site, it should have the option to maintain ownership and care, or turn ownership over to the federal government for long-term care."
>
> Tennessee Rept. (Nov., 1980) p. 11

> "Regulations require commercial disposal sites to be on land owned by the Federal or a State government. When the operations at a commercial site are completed, the facility decommissioned, and the license terminated, the State government will assume responsibility for long-term care of the site."
>
> GAO (1976) p. 34

> "The site shall be located on land for which the federal government can obtain ownership, control access, and obtain all surface and subsurface activities at the site will not cause unacceptable impact on system performance."
>
> National Waste Terminal Storage Program Office (Feb., 1981) p. 10

> "Near-surface radioactive waste disposal facilities shall only be sited on land owned by the Federal or State government."
>
> U.S. NRC (Feb., 1981) p. 28

> "...as a minimum, the burial site and the buffer zone need to be owned by the State, but more desirable, that the entire site be State property. This would also protect the State in case of premature closing; for example, before the entire perpetual care fund had been fully established."
>
> Blackburn and Ed (1979) p. 839

Additional references include: Macbeth et al., 1979, p. 29; U.S. NRC, Feb., 1981, p. 35.

Human Considerations

LEGAL INSTITUTIONAL CRITERIA

Legislation

Essentially all activities in the nuclear industries are controlled by federal laws and regulations.

Major Laws

1. Public Law 83-703, 'Atomic Energy Act of 1954.' This is the basic law that controls the Department of Defense and Department of Energy nuclear activities.
2. Public Law 93-438, 'Energy Reorganization Act of 1974.' This law established the Nuclear Regulatory Commission with powers to promulgate regulations for nondefense nuclear activities.
3. Public Law 95-95, 'Clean Air Act Amendments of 1977.' Under Section 110 of this law, which is the revised Section 112 of Public Law 91-604, 'Clean Air Amendments of 1970,' the Environmental Protection Agency is proposing the addition of radionuclides to the list of hazardous air pollutants.
4. Public Law 93-523, 'Safe Drinking Water Act.' This law requires the Environmental Protection Agency to establish maximum permissible concentrations of nuclides that sources or potential sources of drinking water may contain.
5. Public Law 94-580, 'Resource Conservation and Recovery Act.' Proposed regulatory Section 3001 for this law defines radioactive waste as a hazardous waste, and that waste not covered by the Atomic Energy Act of 1954 is subject to all of the requirements of Subsection 'C' of this law.
6. Public Law 92-532, 'Marine Protection, Research, and Sanctuaries Act of 1972.' This law prohibits the ocean disposal of radioactive waste without a permit.
7. Public Law 91-190, 'National Environmental Policy Act of 1969.' This is a general law that has the objective of protecting the environment from man-made contamination.
8. Public Law 96-573, 'Low-level Radioactive Waste Policy Act.' This act assigns to the states responsibility for providing disposal of low-level radioactive waste generated within their boundaries except for waste generated as a result of defense activities."

U.S. DOE (Nov., 1980) Sect. 9

"THE SITE SHOULD NOT BE LOCATED WITHIN AREAS THAT ARE PROTECTED FROM SUCH USE BY FEDERAL, STATE, OR LOCAL LAWS AND REGULATIONS.

Federal laws which preclude, by intent, the selection of low level waste disposal sites within the boundaries of areas protected under them include:

Wilderness act of 1964
Wild and Scenic Rivers Act of 1968
Endangered Species Act of 1969

National Wildlife Refuge Act of 1966
National Parks
National Historic Preservation Act of 1966
Archeological and Historical Preservation Act of 1974 (sic)
Heritage Conservation and Recreation Service"

Falconer (1981) no pages given

"To date, federal legislation has taken a negative approach in attempting to force state action on the disposal issue. The Task Force prefers the carrot to the stick and believes that sanctions should be a last resort, only instituted if constructive programs fail to accomplish state action."

National Governors' Association (Aug., 1980) p. 18

"In 1963, Illinois, recognizing the need to provide for the responsible disposal of LLW, passed the Radioactive Wastes Act which directed the Illinois Department of Public Health to provide for State ownership of an LLW site, and to operate the site directly or by subcontract."

Illinois Rept. (1980) p. 4-5

The following is a summary of proposed amendments to the Radiation Protection Act, the statute which establishes North Carolina's low-level radioactive waste regulatory program.

a. The Radiation Protection Commission should be given clear authority to establish fees or charges for radioactive waste disposal, long term or perpetual care costs and associated training, inspection, and enforcement costs.

b. The Radiation Protection Commission should be authorized to impose civil penalties for violations of the Radiation Protection Act and regulations pursuant to it. The procedures and dollar amounts should be the same as those for hazardous wastes."

North Carolina Rept. (Jan. 12, 1980) p. 34

"Through a system of private insurance and Government indemnity, the Price-Anderson Act is designed to assure that the public is protected in the event of a nuclear accident connected with a facility operated under a contract with a license issued by the Government.

Under the Price-Anderson Act, the DOE and NRC are authorized to enter into indemnity agreements with contractors and licensees operating nuclear facilities."

U.S. DOE (Mar., 1980) p. 216-217

Additional references include: Falconer, 1981, no pages given; Lipschutz, 1980, p. 159; Subcommittee on Rural Development (Kasperson Testimony), Aug. 26, 1980, p. 19.

Human Considerations

LEGAL INSTITUTIONAL CRITERIA

Regulations

Specific enforcement regulations may be critical to a successful evaluation of low-level radioactive waste disposal sites.

The major federal regulations pertaining to siting of low-level waste facilities include:

1. Licensing of Radioactive Waste Disposal Sites (Prepared by Nuclear Regulatory Commission)
2. Environmental Impact Statements for Radioactive Waste Disposal Sites (Prepared by Nuclear Regulatory Commission)
3. Packaging of Radioactive Waste Material (Prepared by Nuclear Regulatory Commission and Department of Transportation)
4. Transport of Radioactive Materials (Prepared by Nuclear Regulatory Commission and Department of Energy)
5. Manifests, Records, and Incident Reporting Requirements (Prepared by Nuclear Regulatory Commission and Department of Transportation)
6. Radioactive Waste Disposal (Prepared by Nuclear Regulatory Commission)

U.S. DOE (Nov., 1980) Sect. 9

"Currently effective laws and regulations give the Texas Department of Health adequate authority and standards to license and regulate interim storage and volume reduction practices such as incineration and compaction. The present provisions of the Texas Regulations for Control of Radiation parallel Federal Regulations and standards for the protection of public health and safety. The limits on radiation exposures and concentrations of radioactive materials in air and water effluents were conservatively set to protect public health and safety. Neither interium storage nor volume reduction operations present problems or hazards that are unique to waste operations and, therefore, the licensing and regulation processes need not be changed to adequately address these operations."

TENRAC (1980) p. 69

No additional references.

LEGAL INSTITUTIONAL CRITERIA

Public Policy Formation

Many authors state that meaningful citizen involvement and participation in siting are dependent on the development of a concensus public policy for disposal of low-level radioactive wastes.

The authors suggest that this policy must be formulated from the local view on up, incorporating the concerns, fears, and needs of the local population.

> "In this report, the Task Force has attempted to first define the pivotal issues related to the national waste disposal problem and then recommend pragmatic and innovative solutions. The Task Force has concluded that the remaining issues are not technical, but matters of public policy and political decisionmaking. The consequences of inaction in developing additional sites were dramatically revealed last year with the temporary closure of two of the three national disposal facilities."
>
> National Governors' Association (Aug. 1, 1980) p. 28

> "The balance between social benefits and goals and public and individual safety related to these goals is difficult to strike. Further, this balance depends not only upon individual perceptions but is constantly shifting by virtue of legislative, court and regulatory decisions. This striving for dynamic balance is essentially an attempt to arrive at a concensus public policy, at a time when the widespread phenomenon of single issue politics is proof of the difficulty of achieving consensus and compromise."
>
> Capstick (Oct., 1979) p. 22

> "A significant issue is whether the possibility of exposure to radiation from waste can be justified at all, in view of the universal understanding that waste itself is a material which is not being used for any beneficial purpose. This issue is somewhat different, however, if one is trying to reach conclusions about existing wastes as opposed to wastes which have not yet been produced. ...The only policy issue for existing waste, therefore, is whether at any given level of control the expenditures or other costs to gain additional control are justified by the degree of risk reduction that would result."
>
> U.S. EPA (Feb., 1978) p. 15

> "For the process to occur successfully, state and Federal decision-makers will have to succeed in viewing the world as town citizens and officials see it, from the bottom up. What is the local knowledge base regarding the social benefits associated with the waste, what are the concerns and fears, what is required in the way of knowledge to make a thoughtful social decision, what particular benefits should accrue to the town for helping to make a broader social benefit available to society?"
>
> Murphy and Goldsmith (Feb., 1981) p. 2

"Meaningful citizen involvement and participation are critical to developing an effective waste management system in North Carolina. Mechanisms should be developed to provide ample opportunity for citizen involvement in ongoing policy development and decisions concerning proposed facilities."

North Carolina Rept. (Jan. 12, 1980) p. 53

"Public information is only one of a number of democratic practices, however, which makes policy making complicated. Committed to public involvement, the Federal government chooses to work with the States or a public utility like TVA to implement radioactive waste policies. This commitment also introduces new actors, raises new issues and generally confounds the resolution of the problem.

Lest one forget the obvious, expanding the audience to a debate, redefining the policy problem, introducing new actors, or shifting decision arenas can be beneficial steps in the evolution of a major policy. Certainly in radioactive waste this would appear to be the case. In the past 20 years, there has been considerable controversy between some members of the scientific community and Federal bureaucrats over the direction of radioactive waste research and the form of radioactive waste management policies. These controversies have revolved around a variety of technical issues. As controversies and decisions however, came increasingly under public scrutiny, new issues emerged reflecting broader social concerns. These new issues and the expanded audience to the policy discussions have frequently frustrated the decision-maker and made resolution of policy decisions more difficult. They have, at the same time, resulted in new efforts by scientists and bureaucrats to rethink the original technical problems, and have contributed to redefining the scope of the radioactive waste policy problem to include all forms of radioactive waste, as well as a variety of nontechnical concerns. They have resulted in new policies which, in the opinion of the authors, more accurately reflect the realities of the nuclear industry."

Bronfman, Bronfman and Regens (Oct., 1979) p. 46

Additional references include: Capstick, Oct., 1979, p. 2-3.

Political Issues and Regionalization

The siting process for low-level radioactive waste facilities will be largely a political one entailing a mixture of state legislative and executive actions. For legitimacy and public acceptance in siting, the authors state that the decision-making process must involve the public, state, and local governments.

> "Similar to the determination of regions, the siting process will be largely a political one. It will inevitably entail a mixture of state legislative and executive actions."
>
> National Governors' Association (Aug., 1980) p. 13

> "The successful long-term management of nuclear wastes is dependent on satisfying institutional, political, environmental and technical constraints."
>
> U.S. DOE (Mar., 1980) p. 6

> "...the radioactive waste problem is not one simply amenable to technical fixes. A solution will require careful consideration of not only technical, but also societal and political requirements.
>
> "Nuclear waste management activities are likely to cause a set of social and political impacts that are unique to these kinds of facilities and that are potentially as significant as the standard social impacts discussed in earlier chapters. These special impacts arise primarily from the radioactive danger and the long life span of nuclear wastes, the possible use of such wastes for terrorist or military purposes, and the prospect of governmental controls that may have to be imposed to protect public safety and security. These special impacts are not limited to the immediate, surrounding areas or communities, but can affect the encompassing state, region, or indeed the entire country, and may endure for even longer than the lifetime of the facility."
>
> Cluett et al. (Sept., 1979) p. 104

> "Waste generation rates and transportation consideration should be taken into account in the formation of regions for new disposal sites. But in the final analysis region-formation is a political question which will be influenced by considerations such as historic and geographic ties among the states and the track record they have established for cooperation in other areas of mutual concern."
>
> National Governors' Association (Aug., 1980) p. 9

The concept of regionalization is endorsed by many authors. It offers advantages in economics of scale, reduced risk in transport, and a national balance of regional waste management facilities.

The disadvantages noted by other authors include the complexity of legal considerations in developing regional compacts and the requirement that the U.S. Congress approve of all compact agreements.

> "The most fundamental fact is that we do not need 50 separate state sites. Instead, there is a need for an optimum of 6 to 8 well-regulated and economically viable regional sites. The difficult problem is how to rapidly develop a process to first define the most appropriate multi-state regions. Unlike high level waste, which is primarily a federal state responsibility. In that respect, a regional solution, where disposal sites would be determined by groups of states negotiating cooperatively, is the Task Force's preferred approach. Regionalization, as precribed by states, is mandated by such considerations as costs, risk in transport, regional balance, and geologic or hydrologic circumstances which may render some states unsuitable for such sites."
>
> National Governors' Association (Aug., 1980) p. 5

> "In summary, it is expected that at least 148,000 cubic meters of low-level waste will be generated annually by the year 1990, significantly exceeding the capacity of the existing three commercial disposal sites. The regional distribution of this waste indicates a need for a system of five or six disposal sites geographically distributed."
>
> U.S. DOE (Mar. 13, 1981) p. 13

> "Regional management of low-level waste offers several important advantages. Economies of scale exist when managing a larger waste stream, and savings would pass on to the citizens of the states. Risks from transportation can be reduced if all states ship waste to a regional site which is nearby; long distance inter-regional transportation is minimized. A national balance of regional waste management facilities and related activies also can enhance public and political acceptability. Furthermore, regional waste management offers a framework under which member states may also cooperate on similar or related issues."
>
> Tennessee Rept. (Nov., 1980) p. 42

> "There may well be advantages for regional participation in which several states share costs, facilities and sites. However advantageous, the legal considerations are complex and Congressional action will be required for the states to enter into contracts that protect each others rights. Because resolution of the legal problems and enactment of Congressional legislation will take a few years, immediate action by Massachusetts to solve its own problem is the best course to follow. Should regional legislation be enacted, Massachusetts can enter into appropriate regional agreements in an advantageous and strong bargaining position."
>
> Massachusetts Rept. (1980) p. 5

"A regional low-level radioactive waste facility siting program should result in several concurrent siting efforts within several states of a region. This is important, to reassure individual communities that they are not the only object of site investigation activity and to provide redundant sites in the event of an unforeseen problem occurring with an otherwise acceptable site. Any of the states is potentially the actual host state and each will approach the siting process as if it were in fact the host state, seeking to ensure a process broadly perceived as legitimate."

Murphy and Goldsmith (Feb., 1981) p. 3

"Waste generation rates and transportation considerations should be taken into account in the formation of regions for new disposal sites. But in the final analysis region-formation is a political question which will be influenced by considerations such as historic and geographic ties among the states and the track record they have established for cooperation in other areas of mutual concern."

National Governors' Association (Aug., 1980) p. 9

Additional references include: Hebert et al., May, 1978, p. 6-23; Illinois Rept., 1980, p. 21-22; Murphy and Goldsmith, Feb., 1981, p. ii; National Governors' Assn., Aug. 1, 1980, p. 28; North Carolina Rept., Jan. 12, 1980, p. 13; Subcommittee on Rural Development (Kasperson Testimony), Aug. 26, 1980, p. 8; U.S. DOE, Mar. 13, 1981, p. 2, 12-13, 31; Utroska, 1981, p. 7.

Human Considerations

LEGAL-INSTITUTIONAL CRITERIA

Decision-making Process

All authors agree that the decision-making process for siting of radioactive waste facilities must involve the public, state and local governments.

In the siting of low-level radioactive waste facilities, the most critical decisions will be made by the citizens who inhabit the potential host communities. Their decisions will primarily be social ones, involving risks, negative impacts, social benefits, and other quality of life issues. The decision-making process can be improved by increasing both the quantity and quality of public participation.

> "There was a clear consensus among Workshop participants that the public, and state and local governments, should be involved in the decision-making process on radioactive waste criteria and other such future regulation and criteria-forming efforts."
>
> U.S. EPA (Feb., 1977) p. xv

> "...there is a great need, and opportunity, to improve our decision-making process. Nuclear power, and energy policy in general, are social issues that cannot be decided by bureaucrats and technocrats alone. The public has demonstrated a growing interest in the future of nuclear power. Citizens and legislators must work with the scientists and bureaucrats who have traditionally determined our nuclear policy in order to establish a comprehensive set of objective criteria for judging the acceptability of various options. I hope that NRC and ERDA will follow and, indeed, improve on the example being set by EPA at this Workshop."
>
> Lash (Feb., 1977) p. 3-17

> "Low level waste repository siting is clearly a quality of life issue, for a sound decision-making process can contribute significantly to how people feel about their ability to control important impacts on their lives. What makes it such a positive challenge is the possibility of a body of citizens dealing responsibly with the issue in all its social breadth. No one can take away from the necessity of their doing that, but sensitive state and Federal decision-makers can contribute significantly to a thoughtful decision-making climate, and it should be foremost on their agenda. . . .The most critical decisions that will be made in the siting of low level waste repositories will be those of the citizens who inhabit potential host communities for such facilities. Their decisions have to be the most informed and thoughtful that are debated and made in the repository siting process. They are not primarily technical decisions, although technical perspectives will inform them. They are not primarily economic decisions, although economic factors will contribute to them; nor are they primarily institutional although adequacy and responsibility will be demanded. They are social decisions, where questions of value are paramount and

where an informed populace can assess social benefits and place a value on the wise management of their negative side effects."

Murphy and Goldsmith (Feb., 1981) p. 2

"Public participation in decision making serves two basic functions: first, it adds to the legitimacy and public acceptance of government decisions; and, secondly, what the public contributes - an outside perspective, unusual kinds of expertise, a longer-range view than most elected officials can afford, and on occasion basic moral demands - may actually lead to a better decision."

Abrams and Primack (Apr., 1980) p. 14

"In particularly important and far-reaching decisions it seems to me one needs to achieve two things: (a) sufficient public participation, and participation of sufficiently high quality, in the decision-making process to give strong assurance that no important technical or social viewpoint has been omitted or overlooked or ignored; and (b) one needs to achieve sufficient public participation, and participation of sufficiently high quality that no citizen feels that his or her viewpoint has been omitted, overlooked or ignored. I stress the quality of public participation because it is so important and so frequently neglected by managers."

Montague (Jan., 1979) p. 3

"Much of the groundwork in developing a methodology for siting a LLW facility has been completed by the New England Regional Commission (NERCOM, 1979) for the purpose of disposing hazardous wastes. This study points out the importance of allowing the maximum number of parties to participate in the decision-making process with the underlying assumption that 'some final siting decision has to be made.,' Massachusetts now has siting legislation for hazardous waste (COM, 1980) that defines the decision-making process quite clearly with respect to community participation and the procedures to overcome a potential impasse. Many parts of this law apply to the siting considerations of LLW disposal."

Massachusetts Rept. (1980) p. 18

Additional references include: Green, 1972, p. 145; Hebert et al., May 1978, p. 10; Lash, Feb., 1977, p. 3-17; Montague, Jan., 1979, p. 9; Murphy and Goldsmith, Feb., 1981, p. 10; U.S. EPA, Feb., 1977, p. 3-43; Weinberg, 1972, p. 34; Wetmore, 1980, p. 182.

ECONOMIC CRITERIA

Cost to Plan, Construct, Operate, Maintain and Decommission and Close a Site

The costs of planning, constructing, operating, maintaining, and closing a low-level radioactive waste disposal site are important criteria in evaluating sites.

Rules proposed recently by the Nuclear Regulatory Commission require financial assurances for the construction and operational phases of the facility, in addition to the closure and post-closure phases. A legal binding arrangement must exist between the site operator and the site owner to ensure financial responsibility for the 100-year period following site closure.

"Site capital costs include initial expenditures for land, equipment, buildings, site environmental monitoring system, and site security.

1. Land--To determine land cost, it is assumed that waste is buried at 325,000 ft^3 per acre, at a price of $2000 per acre.
2. Buildings--Buildings used for administrative functions and storage vary in size depending on the volume of waste to be received at the site. Nonvariable building costs (security, medical facilities, etc.) remain the same for any site.
3. Equipment--Equipment required for office use and site instrumentation is nonvariable at $400,000 per site. Cost of heavy equipment used for waste handling depends on the volume of waste to be accepted. In this case, either the multi-state site or the State A site would require the same amount of heavy equipment.
4. Environmental Monitoring--Costs for establishing a site environmental monitoring program will vary greatly depending on geologic and hydrologic features of specific sites.
5. Security--The three primary cost components are fencing, perimeter road construction, and automatic perimeter monitors.

Other costs include: licensing, operating, disposal fees, site disposal cost, transportation."

U.S. DOE (Nov., 1980) Sect. 7

"Life cycle costs are the summation of expenditures from the conception to the termination of the project. By definition, they are subdivided into 'first' costs, 'operating and maintenance' costs, and 'disposal' costs.

The 'first' costs are the total investment required to get the project ready for operation. In the case of LLW burial ground, this includes the cost of siting (environmental assessment, land purchase, engineering fees, legal fees, etc.), ground work, training personnel, and other similar activities prior to operation.

Operating and maintenance costs are recurring costs that are necessary to operate and maintain a project during its useful life. Operating costs usually consist of labor, overhead, electricity, insurance premiums, other charges, and indirect materials.

Maintenance costs may or may not be recurring or may be incurred on an annual basis. Annual maintenance costs include preventative maintenance and minor repairs. As a best estimate, it is assumed that the operation and maintenance costs are proportional to burial activity.

Disposal costs in the context of a LLW burial ground are the costs of site stabilization and long-term care. These costs are incurred when burial activity ceases at the facility and continues until it is determined that the buried LLW poses no radiological threat to the public.

Fixed costs are those costs that do not vary as to the quantity of output (e.g., amount of waste buried) changes. In general, they include administrative salaries, taxes, insurance, rent, depreciation of equipment, amortization of first costs, and similar costs that are invariant with activity. Variable costs vary in relation to the quantity of output. Direct labor and direct materials, the labor and materials directly involved in the burial activity, are variable costs. Direct material in this case is the land used per unit buried. The summation of the fixed and variable costs is the total cost of operation."

TENRAC (1980) p. 33-34

"Subpart E requires that the applicant be financially qualified to conduct all licensed activities during the construction and operational phases of the land disposal facility.

Section 61.62 of the Part 61 requires the applicant to provide an acceptable form of financial surety to ensure that funds are available to perform closure and stabilization and observation until the license is transferred to the custodial agency for institutional control or terminated.

Section 61.63 requires the applicant to provide evidence to the Commission that a legally binding arangement, such as a lease, exists between the applicant and the party holding title to the disposal site. Such a binding arrangement would delineate financial responsibility for the active institutional control period. which is not expected to exceed 100 years."

U.S. NRC (July 24, 1981) p. 38085-38086

"Development of a new, licensed disposal site would require a substantial amount of capital investment, probably between six and twelve million dollars depending on size."

Tennessee Rept. (Nov., 1980) p. 33

Some authors feel that the generators of waste should pay all costs directly and indirectly associated with the treatment and disposal of the wastes they produce.

"The Task Force strongly supports the principle that the generators of waste should pay all costs directly and indirectly associated with treatment and disposal of their waste. In keeping with this principle, the Task Force recommends that localities be given the statutory authority to establish appropriate fees or taxes on waste handled by treatment or disposal facilities located within their jurisdiction. Such fees or taxes should be compensatory in nature, and should therefore be limited by statute to an amount or rate that is reasonably related to the direct and indirect costs incurred by the locality as a result of the facility operation. Permissible costs should include expenses associated with local health and environmental monitoring, fire and other emergency protection, and measures to ensure safe traffic patterns and transportation."

North Carolina Rept. (Jan. 12, 1980) p. 46

A public opinion study has shown that the public places a higher priority on the safety of a disposal facility than on its cost.

"In some ways, the cost of a waste management system is not an issue. There seemed to be widespread agreement at the Public Policy Conference that we must be willing and able to pay for an adequate waste disposal system. Rochlin suggested that the cost factor for different waste management strategies should be considered last, after all of the other criteria have been considered. A study by Maynard, Nealy, Hebert, and Lindell indicated that public values regarding short-term risks, long-term risks, and accident detection and recovery are perceived to be more important by the public than cost in a waste management strategy."

Hebert et al. (May, 1978) p. 22

Current disposal costs are increasing rapidly because of fuel costs and the long distances required to transport wastes to available disposal sites. With the creation of state or regional sites, disposal costs could be reduced significantly.

"It is important to consider the economic impact of the development of local or regional disposal sites. The cost of the disposal of LLW is currently absorbed as part of normal operations involving radioactive material. This cost is increasing rapidly primarily because of the spiraling costs of fuel and the long distances required for transportation and because of unreasonably escalating burial fees. Thus, the cost of disposal would be significantly reduced with shorter shipping distances, and the savings could be applied to the establishment of local or regional disposal facilities. In addition to maintaining manageable disposal costs, funds and fees and the accompanying creation of jobs would accrue to the host community as important economic benefits."

Massachusetts Rept. (1980) p. 3-4

The location of a low-level radioactive waste facility could provide both direct and indirect benefits to the local community.

"By its nature, such a project is likely to involve substantial purchases in the immediate vicinity, most particularly for land (i.e., the site itself and surrounding areas) and for excavation and earthmoving equipment, with a resultant flow of money into the local economy.

The potential economic development benefits extend beyond the direct investments....They also include the indirect benefits which could result from decisions, e.g. by radiopharmaceutical firms, research organizations, utilities and other LLW generators to locate new facilities, which do or do not in themselves generate waste, in a host community.

Murphy and Goldsmith (Feb., 1981) p. 21

"Low-volume generators of LLW usually contract with a middle-man or 'broker,' who collects the packaged waste from several such generators, warehousing as necessary until full trailer-loads are accumulated. A significant factor in the recent cost escalation in this entire process is associated with the distant locations for burial."

Massachusetts Rept. (1980) p. 13

"Regional management of low-level waste offers several important advantages. Economies of scale exist when managing a larger waste stream, and savings would pass on to the citizens of the states."

Tennessee Rept. (Nov., 1980) p. 42

Additional references include: Clemente et al., 1978, p. 36-37; EG and G, 1979, p. 1; Massachusetts Rept., 1980, p. 13-14.

ECONOMIC CRITERIA

Cost-Benefit Analysis

One author suggests that any siting criteria for location of low-level radioactive waste sites should consider and balance risk-benefit and cost-benefit analyses from state, regional, and national perspectives.

Cost-benefit analysis is a technique used in assessing the impact of a proposed project activity. The objective of the technique is to determine optimum levels of competing costs (risks) such that the total cost (risk) is minimized. While health effects are the factor of greatest concern in cost-benefit analyses of low-level radioactive waste facilities, many other factors must also be assessed (i.e., environmental effects, social needs, land resources).

> "Experience shows that shallow land burial sites generally provide regional and national benefits, and only indirectly benefit the state. It is my opinion that only in a state with several nuclear facilites would direct state benefits be recognized. Therefore, any siting criteria which are developed must consider and balance risk-benefit and cost benefit analyses from state, regional, and national perspectives."
>
> Hardin (Apr., 1977) p. 2-33

> "A common approach used in assessing the impact of a proposed or projected activity is cost-benefit, risk-benefit analysis. When dealing with radioactive waste management, this mode of analysis seems to break down. The more tangible benefits of nuclear and nuclear-related activities, i.e., those resulting in the generation of radioactive waste products, appear to be realized only in the present and immediate future, while the risks associated with the resulting wastes extend far into the future. The argument that future generations will benefit from present technological development assumes continuing technological growth, but this may be of little consolation if we leave to the future the responsiblitiy for handling both the present waste and that which will be generated in the course of the expansion."
>
> U.S. EPA (Feb., 1977) p. 3.3-3.4

> "'Acceptable risk' can be defined only with reference to the reason for taking the risk. A risk becomes acceptable at the level at which it reduces a competing risk by an equal amount. The reduction of a competing risk is usually referred to as a benefit, and the methodology for determining the optimum levels of multiple, competing risks is commonly called 'risk-benefit analysis' or 'cost-benefit analysis.' However, a more realistic term for the process might be 'cost minimization analysis,' since the ultimate objective is to determine optimum levels of competing costs (risks) such that the total cost (risk) is minimized. The obvious difficulty is in the measurement of all types of costs and risks in common units.

In the field of radiation protection we make two fundamental assumptions that permit us to compare the detrimental costs (risks) of radiation doses with the expenditures required to avoid radiation doses:

1. Every increment of radiation dose represents the same cost (risk) regardless of when, where, how, and to whom delivered. This is simply another way of stating the linear nonthreshold model for the biological effects of radiation.

2. The cost of a detrimental health effect is the same regardless of its cause."

Schiager (Apr., 1977) p. 2-46

"An overriding issue of concern with regard to criteria development for low-level and intermediate-level waste is the basic radiation protection objective in the disposal of these wastes. Should disposal be based on the premise of 'as low as feasible' or 'as low as practicable,' or should the objectives be tailored to fit each specific type of waste? Since the range of waste types includes high-activity, long-lived materials (transuranics), low-activity, long-lived materials (uranium mill tailings and phosphate wastes), and high-activity, short-lived materials (cobalt-60, stontium-90), it is apparent that the underlying factor is the associated risk, and that a determination should be possible through risk analysis (cost-benefit, risk-cost, etc.)."

U.S. EPA (Apr., 1977) p. 2-15

". . . there is likely to be a dislocation of benefits and risks in both time and space. In order to reduce overall risks, one would generally prefer to locate waste management facilities in low-population density regions and where land and resource values are not likely to be adversely affected. On the other hand, the activities from which the wastes arise involve larger investments, employ more people, and produce greater benefits--they are also more likely to be sited near population centers. Also the potential risks associated with sequestered radioactive wastes will persist beyond the time that discernible direct benefits are accruing. In both cases, it may be difficult to provide an equitable balance of benefits and costs, either in time or in space.

While health effects are the factor of most immediate concern in cost-benefit analyses of waste management systems, there are other factors that need to be considered in a holistic treatment. Social needs, environmental effects, ethical considerations, provisions for long-term control and periodic surveillance, contingencies for possible future remedial actions, resource and land commitments, and the costs of institutional arrangements also need to be considered."

Jacobs (1979) p. 230-232

Additional references include: Hebert et al., May, 1978, p. 1; North Carolina Rept., Jan. 12, 1980, p. ES-3; Subcommittee on Rural Development (Cunningham Testimony), Aug. 26, 1980, p. 40; Subcommittee on Rural Development (Davis Testimony), Aug. 26, 1980, p. 44; Subcommittee on Rural Development (Leahy Testimony), Aug. 26, 1980, p. 3; Tennessee Rept., Nov., 1980, p. 32-33; U.S. EPA, Apr., 1977, p. 2-96.

ECONOMIC CRITERIA

Labor Availability

Several authors note that increased employment opportunities associated with construction and operation of a low-level radioactive waste facility may be a beneficial impact of siting. They also stress that where possible, jobs should be offered to local residents before brining in new workers.

"3. Employment: The direct and indirect employment benefits of such a project and related development would not be significant. The important thing is that the employment be targeted for local residents. While some of the jobs may go to specialists brought in from outside, the special expertise needed in e.g., handling radioactive materials can be imparted to members of the native labor pool with minimal training. The site operator could provide the requisite on-site training. The targeting should not be limited to direct employees, but should include sub-contractors as well. Where specialized employees or contractors were needed, preference could be given to in-state individuals and firms. Not only will maximized local employment be perceived in and of itself as a benefit, but it will also minimize any disruptions associated with the project."

Murphy and Goldsmith (Feb., 1981) p. 20-21

Employment impacts:

"Expanding employment opportunities are generally viewed as one of the major beneficial consequences of a project for local residents."

Personal Affluence:

"As individuals who are currently unemployed or outside the labor force go to work, their family incomes increase dramatically."

Cluett et al. (Sept., 1979) p. 18

Additional references include: Cluett et al., Sept., 1979, p. 17.

ECONOMIC CRITERIA

Perpetual Care Funds

The purpose of perpetual care funds is to insure the availability of funds for decommissioning and long-term maintenance and surveillance of low-level radioactive waste sites. Regulations published recently by the Nuclear Regulatory Commission require financial assurances from the site operators that site closure, stabilization, and monitoring activities will be performed for the period of active institutional control (100 years).

"The purpose of an extended care fund is to insure the availability of monies for the decommissioning and long-term maintenance and surveillance of the low-level waste (LLW) burial site. The importance of financial assurance for decommissioning was recognized by the Congress of the United States in the Uranium Mill Tailings Radiation Control Act of 1978. A new section, 161x, was added to the Atomic Energy Act of 1954, giving the NRC authorization to require that adequate financial arrangments be made to insure clean-up, reclamation, and long-term maintenance and monitoring of uranium mill tailings sites. Because the requirements for the decommissioning of LLW burial grounds and uranium mill tailings piles are similar, comparable extended-care funds must be established for LLW dump sites.

"61.62 Funding for Disposal Site Closure and Stabilization.

(a) The applicant shall provide assurances prior to the commencement of operations that sufficient funds will be available to carry out disposal site closure and stabilization, including: (1) decontamination or dismantlement of land disposal facility structures; and (2) closure and stabilization of the disposal site so that following transfer of the disposal site to the owner, the need for ongoing active maintenance is eliminated and only minor custodial care, surveillance, and monitoring are required. The assurances shall be based on Commission approved cost estimates reflecting the Commission approved plan for disposal site closure and stabilization. The applicant's cost estimates must take into account total capital cost that would be incurred if an independent contractor were hired to perform the closure and stabilization work."

Federal Register (July 24, 1981) p. 38098

"A burial site, typically, is operational over a period of 10-20 years. At the end of that time, all surface structures will be removed, and the location and contents of trenches marked with durable monuments. The environmental surveillance program established when the site was first opened will be continued, at a reduced intensity, to monitor the long-term performance of the site. Site control will likely be maintained through some form of fencing. A 'perpetual care' fund, established during site operations, will provide a source of revenue for this monitoring program, and any routine maintenance of the site. The expected time-duration of such maintainance (sic) and site control is not well defined, but may be thought of as 'as long as necessary.'"

Wheeler and Smith (1979) p. 17

"Part of long-term care is the question of proper funding for surveillance and maintenance. Currently site operators pay a fee, based on volume, to the states for funding long-term care. However, there is uncertainty concerning adequacy of funding, especially since federal regulations governing this have not been promulagted."

Tennessee Rept. (1980) p. 11

"The NRC Task Force recommended.....federal ownership of land for all disposal sites and establishing a federally administered perpetual care program."

Bishop et al. (1979) p. 41

The proposed site should be self-supported by disposal fees. The disposal fees are to be established by the disposal authority and should be based on volume and relative hazard (radioactive, physical, and chemical properties considered). In addition to charges to recover operating costs, disposal fees should include an assessment to recover during the expected life of the facility all preoperating costs, an assessment to accumulate an extended care fund, and a fee in lieu of taxes to be paid to local government entities to mitigate socio-economic impacts resulting from disposal site operation. The Department of Health should specifiy and review, at least annually, the assessment per cubic foot to be channeled to the extended care fund. The funds collected for extended care should be deposited with and managed by the Department of Health with the purposes of assuring proper decommissioning when the site is closed and assuring long-term maintenance and surveillance of the site."

TENRAC (1980) p. 4-5

"Sufficient funds must be made available to provide for: (1) decommissioning of the disposal facility, including dismantling surface structures on the site, (2) stabilization of the site and the buried waste to preclude ongoing active maintenance, and (3) the provision of surveillance and monitoring activities over a period long enough to show that the site conforms to expectations. The National Conference of Radiation Control Program Directors has recommended bonding and perpetual care trust funds as a means of assuring such funding (CRCPD, 1976). The NRC, in their proposed regulation (NRC, 1979b) concurs with this concept and discusses several financial surety arrangements, such as bonds, cash deposits, certificates of deposit and letters of credit, which would be acceptable."

Massachusetts Rept. (1980) p. 18

Additional references include: National Governors' Association (Aug., 1980) p. 18; Subcommittee on Rural Development, (Peelle Testimony), Aug. 26, 1980, p. 14; U.S. NRC, Feb., 1981, p. 28.

Human Considerations

ECONOMIC CRITERIA

Socioeconomic Issues

Several authors suggest that socioeconomic issues should be considered in any evaluation for siting of a low-level radioactive waste site.

Socioeconomic effects include all the impacts on individuals, communities, and institutions that can be caused by the siting of a low-level radioactive waste facility. While the impacts of those facilities are small compared to those of high-level sites, they are quite site specific and are considered by the NRC in environmental impact statements for each site.

> "The resolution of socioeconomic issues related to nuclear waste management is as essential as the resolution of technical issues and must be addressed by the Nation as a whole. Studies of the following socioeconomic issues are underway to support the development of rules, standards, and guidelines for Federal, State, and local cooperation in nuclear waste management: waste facility siting; worker health and safety; use of other resources near waste sites; local economic impacts; assessment of storage costs; liability for accidents; long-range planning."
>
> U.S. DOE (Mar., 1980) p. 213

"1. A comprehensive socioeconomic impact assessment must be undertaken to provide credible information regarding the potential effects of the facility upon the local community.

Steps

(1) Baseline description of existing socioeconomic situation.

A study area should be defined and major historical and current socioeconomic trends should be presented.

(2) Socioeconomic projections of the study area without the facility must be made.

In order to accurately assess potential impacts of the facility, it is first necessary to determine what the socioeconomic situation of the area would be if the facility were not built.

The specific characteristics of the facility which may have socioeconomic implications must be delineated.

(3) Various aspects of the facility in all three stages - construction, operation, decommissioned - will have socioeconomic ramifications. All such aspects should be specified as completely as possible.

(4) Population impacts of the facility should be the first socioeconomic impact assessment.

Population is typically the 'prime mover' in socioeconomic phenomena. Accordingly, standard accepted demographic methods should be used to project population changes which would be associated with the facility.

(5) Socioeconomic effects of the facility and the associated population should be addressed along four key dimensions:

(a) Demands on community services and facilities,
(b) Economic impacts in terms of income, employment, taxation and fiscal variables,
(c) Land use impacts and changes,
(d) Cultural, social, psychological and 'life style' impacts."

Clemente et al. (1978) p. 36-37

"The site shall be selected giving due consideration to social and economic impacts on communities and regions affected by the repository.

(1) The site shall be located so that adverse social and/or economic impacts resulting from repository construction and operation can be accommodated by mitigation or compensation strategies.

Social and economic impacts include both positive and negative effects on individuals, communities, and institutions, such as: the influx of new workers into a town, the effect of population growth on housing markets and community services, the fiscal burden on the local government, the impacts on governmental processes, and changes in land use patterns. Some impacts may remain for which compensation or mitigation may be necessary."

NWTS Program Office (Feb., 1981) p. 11

"We believe the socioeconomic impact of commercial low-level waste facilities are relatively small compared to those of high-level waste facility, primarily because the handling facilities do not require the degree of shielding and because excavation is not nearly as extensive and is typically carried out incrementally as waste is received.

The impacts of such facilities are quite site specific, however, and are considered by the NRC in an environmental impact statement for a given proposed low-level waste site."

Subcommittee on Rural Development (Davis Testimony)
(Aug. 26, 1981) p. 34

"The standard approach to facility siting is to select that site which minimizes social and environmental impacts at acceptable cost levels. In the case of waste facilities the national benefits are obvious but the local benefits are few."

Cluett et al. (Sept., 1979) p. 112-113

"...the most serious socioeconomic risks are also the most likely to be poorly understood. Many socioeconomic risks will be apparent only in the long term, and the number of them will be essentially irreversible in nature. Socioeconomic risks will also prove extremely resistant to quantification as a basis for calculating compensation. Residents of rural communities are among the most vulnerable members of our society.

Subcommittee on Rural Development (Kasperson Testimony)
(Aug. 26, 1980) p. 9

Additional references include: Hebert et al., May, 1978, p. 20; Murphy and Goldsmith, Feb., 1981, p. ii.

Human Considerations

GEOGRAPHIC AND LAND-USE CRITERIA

Any site evaluation for location of a low level radioactive waste disposal facility should include the present and projected uses of the land, water, and other natural resources of the region.

Geographic factors such as dègree of remoteness, proximity to generators, competing uses of land, and concern for the natural resources of the area are important. Areas of value for historic, cultural, esthetic, agricultural, architectural or recreational value should also be considered. (See also "Site Impacts to the Environment - ESTHETIC, CULTURAL, NATURAL, AGRICULTURAL, HISTORICAL AND RECREATIONAL VALUES.)

For clarity and completeness, the geographic and land use references are divided into present, past and future groups. Each group is then divided into more specific topic areas. The topic of future land use received the most attention in the literature and will be presented first. The subsections of this group in order of importance are: resource potential, irrigation, buffer zone availability and distance from restricted land use.

Future Land Use

"The site shall be evaluated with respect to the present and potential future character and activities of the human population of the regions. Such evaluation should include consideration of present and projected future uses of land, water, and natural resources."
U.S. NRC (Feb., 1981) p. 13

"This evaluation should also include the present and projected uses of the land, water and other natural resources of the area and the proximity and type of transportation routes available for the shipment of LLW."
Massachusetts Rept. (1980) p. 19

"The site should be selected with consideration given to current and projected land use and resource development."
Falconer (1981) no pages given

"In gèneral, 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."

Panel on Land Burial (1976) p. 68

"11. THE SITE SHOULD BE SELECTED WITH CONSIDERATION GIVEN TO CURRENT AND PROJECTED LAND USE AND RESOURCE DEVELOPMENT.

The site should not be unique in its economic or aesthetic value for industrial, agricultural or recreational uses. A site located in such an area could interfer (sic) with future land requirements and increase the likelihood of human contact with the waste after institutional control has lapsed. Natural resources, such as fuels, ores, and groundwater, are available in finite quantities. Waste disposal should not prevent the recovery of resources of present or potential economic value."

Falconer (1981) no pages given

The future use of land adjacent to a site should be considered also. In addition to the reference below, a specific example concerning groundwater is found in the section on dams.

"Construction activities adjacent to the burial grounds have also altered the hydraulic flow patterns."

Jacobs, Epler, and Rose (1980) p. 5

No additional references.

Human Considerations

GEOGRAPHIC AND LAND-USE CRITERIA

Future Land Use

Resource Potential

Resource potential is the most important land use concern identified in the literature for site evaluation criteria. There are two reasons for this: the importance of resources for our economic future and the potential for disturbance or damage to the site because of exploration for resources.

"The site should not contain natural resources of future potential interest."

Illinois Rept. (1980) p. 17

"The site should not be within areas involved in or likely to be involved in extensive economic activity such as major mining or civil engineering projects."

Gibbs (1980) p. 488

"The site should be located with due consideration for nearby mines, major excavations, boreholes, dams, and proximity to mineral resources."

Klingsberg and Duguid (1980) p. 66

"The site should not have any extensive natural resources beneath it or have such high potential for subsequent other uses of the land that immediate intrusion into the site after active institutional controls are removed is likely."

U.S. NRC (Feb., 1981) p. 14

"The level of evaluation necessary to access the likelihood of human intrusion will increase with the value of and the proximity of the site to exploitable features or resources such as water, thermal energy, petroleum, or minerals."

NWTS Program Office (Feb., 1981) p. 9

"Suggested geologic and hydrologic criteria for shallow burial of hazardous wastes in New Mexico include: (1) rock type and permeability;...(2) absence of known aquifers below or adjacent to site and minimum depths to the watertable exceeding 100-200 feet (31 to 62 m); (3) surface stability in terms of water and wind erosion, with minimum land surface ages in the 10,000 to 100,000-year range; the site should also be stable in terms of seismic and solution subsidence processes; (4) absence of known mineral and geothermal resources whose development could be affected by disposal operations."

Hawley and Gallaher (1981) p. 561

Additional reference include: Falconer, 1981, no pages given; Klingsberg and Duguid, 1980, p. 66; Lipschutz, 1980, p. 75, 76, 105, 106; Massachusetts Rept., 1980, p. 19; NWTS Program Office, Feb., 1981, p. 11; Panel on Land Burial, 1976, p. 68; U.S. NRC, Feb., 1981, p. 13.

Future Land Use

Irrigation

Irrigation would probably not be practiced near a low-level radioactive waste facility. However, irrigation in the vicinity of a site could change groundwater flow directions and rates.

> "If a contaminated region includes a productive aquifer, water uptake for irrigation may result in exposure."
>
> Jacobs, Epler, and Rose (1980) p. 44

> "Irrespective of the way the radionuclide penetrates into the plant, irrigation by sprinkling is the most important source of contamination."
>
> OECD (1972) p. 67

Additional references include: Lipschutz, 1980, p. 105, 106; Panel on Land Burial, 1976, p. 68.

GEOGRAPHIC AND LAND-USE CRITERIA

Future Land Use

Buffer Zone Availability

The availability of a buffer will mitigate the effects of nearby land use and aid in the monitoring of contamination.

"The site should include a three-dimensional buffer zone of size calculated to allow unrestricted human use beyond its boundary, including withdrawal of water from aquifers."

Falconer (1981) no pages given

"Buffer zones between the actual burial trenches and the site perimeter would increase the opportunity for detection and control of radionuclide migration."

Jacobs, Epler, and Rose (1980) p. 7

At the Sheffield, Illinois site -

"No radionuclide migration from the disposal area has been detected. Nuclear Regulatory Commission inspectors have noted that placement of the monitoring wells is not optimal for detection of migration. Another concern is the lack of a buffer zone around the perimeter of the site."

U.S. DOE (Mar. 13, 1981) p. 22

Additional references include: Barnes, 1979, p. 14.

Future Land Use

Distance from Restricted Land Use

Other important considerations for siting are the land use restrictions of nearby lands and plans for future restrictions through zoning or other methods.

"The investigations included in this report are:

1. The land use and zoning in the area.
2. The topography, drainage, and groundwater movement in the area.
3. The surficial soils and subsurface materials and bedrock in the area.
4. The biological and historical-cultural setting of the area.
5. A description of the nature, origin, and volume of the wastes to be disposed of.
6. Preliminary engineering plans for proposed site development."

Donohue and Associates (1980) p. 1

No additional references.

Human Considerations

GEOGRAPHIC AND LAND-USE CRITERIA

Present Land Use

The topics in the category of present land use include: location; accessibility; population; distance to nearest water table; and availability of construction material. The quotations directly following are of a more general nature.

"This evaluation should also include the present and projected uses of the land, water and other natural resources of the area and the proximity and type of transportation routes available for the shipment of LLW."

Massachusetts Rept. (1980) p. 19

"The site should be selected with consideration given to current and projected land use and resource development."

Falconer (1981) no pages given

"1. Site Characteristics - Data required include local meteorology, topography, vegetation, surface streams, land and water use, population density and accessibility."

Steger (1979) p. 669

"The soil provides good ion exchange characteristics to minimize percolation of radioactivity which may be leached from the solid waste to the groundwater. There is no nearby use of groundwater or well water downstream from the site. The site and its vicinity have the characteristically slow water movement through the soil in a direction in which there is little or no land use."

U.S. Atomic Energy Commission (1974) p. G-7

"The site must be selected to meet both short-term, or operational, considerations, and long-term performance objectives. The proximity of established transportation routes to facilitate the safe and economic transport of LLW, the quantity of land available, the ease of acquisition, and public acceptance must all be considered as short-term conveniences. The long-term performance objective of the disposal facility after closure is to assure that all LLW is contained within the facility for the required lifetime of that waste.

This long-term performance objective will be met by a site-specific system of barriers to LLW migration including the specified form of the buried waste, engineered barriers, natural characteristics of the site and its environs, and control over the use of the land upon which the site is located."

Massachusetts Rept. (1980) p. 18

Additional references include: Cartwright et al., 1981, p. 13; Illinois Rept., 1980, p. 17; Klingsberg and Duguid, 1980, p. 66; Macbeth et al., 1979, p. 29; OECD, 1972, p. 67; U.S. AEC, 1974, p. 6, 7; U.S. NRC, Feb., 1981, p. 13, 34, 35.

Human Considerations

GEOGRAPHIC AND LAND-USE CRITERIA

Present Land Use

Location

The authors state that the location of the site with respect to surrounding land use is the primary land-use consideration, even though there are few references that state it as such. Also, the site should not be located so that the operation of nearby facilities could adversely impact the isolation capability of the disposal facility, or mask the environmental monitoring program.

> "In addition to the natural factors outlined above, geographic factors, such as location, size and shape of the area, communications, population density and distribution, and water use downstream from the site, must be considered."
>
> Morton (1968) p. 29

> "Site Characteristics
>
> (6) Location to other facilities. The site should not be located so that the operation of nearby municipal, government, or commercial facilities could adversely impact the isolation capability of the disposal facility, nor significantly mask the environmental monitoring program."
>
> U.S. NRC (Feb., 1981) p. 15

> "A LLW facility should not be allowed
>
> ...if any structure (a-g), other than an airport, is located within 0.25 miles of site boundary or within 10,000 feet of a runway used by turbojet aircraft or within 5,000 feet of a runway used by only piston-type aircraft.
>
> Not allowed within 20 miles of any facility such as a nuclear generation station, research facility, or coal generating station, which could mask any monitoring program.
>
> A LLW facility should not be located if there are any schools, hospitals or more than five residences along the transportation corridor.
>
> The heavy volume of truck traffic used in transporting wastes and supplies to a facility dictates consideration be given to safety, noise and disruption."
>
> Environmental Resources Management, Inc.
> (Sept. 19, 1980) no pages given

Present Land Use

Accessibility

An important consideration in evaluating any potential site for disposal of low-level radioactive wastes is the accessibility of the site for waste delivery, monitoring and long-term maintenance. (See also "Transportation.")

> "1. Site Characteristics - Data required include local meteorology, topography, vegetation, surface streams, land and water use, population density and accessibility."
>
> Steger (1979) p. 669

> "At the time sites are selected for intensive investigation, if not before, numerous nontechnical factors will be considered. Sites might be disqualified because of lack of social acceptance, high population density, or difficulty of access. Large areas of the country might be ruled out by nongeologic factors, totally independent of their attractiveness from a technical perspective. In contrast, certain areas might be highly favored by nongeologic factors; indeed, the importance of such considerations cannot be overestimated."
>
> Klingsberg and Duguid (1980) p. 67

> "The site should be located as centrally as possible to the bulk of the users so no licensee has to transport long distances, the location should be easily accessible by major highways or by rail, and routing of shipments should be possible without transporting through large populated areas. The site should not contain natural resources of future potential interest. In planning for a site consideration must be given to an area large enough so that a buffer zone (State or Federally-owned) can be established and maintained."
>
> Illinois Rept. (1980) p. 17

> "Factors important in locating a shallow land burial facility include distances to ground and surface water systems, meteorology and climatology of the area, degree of remoteness, geologic stability, proximity to the sources of waste, competing uses of the land, and ownership for long-term control."
>
> Macbeth et al. (1979) p. 29

Human Considerations

GEOGRAPHIC AND LAND-USE CRITERIA

Present Land Use

Population

The evaluation of any potential site for disposal of radioactive wastes should also include the population density and distribution, as exhibited by the nearby land use. (See also the section "Demographic Criteria.")

> "The site shall be located to minimize the potential risk to and potential conflict with the population."
>
> NWTS Program Office (Feb., 1981) p. 11

> "In addition to the natural factors outlined above, geographic factors, such as location, size and shape of the area, communications, population density and distribution, and water use downstream from the site, must be considered."
>
> Morton (1968) p. 29

> "1. Site Characteristics - Data required include local meteorology, topography, vegetation, surface streams, land and water use, population density and accessibility."
>
> Steger (1979) p. 669

Additional references include: Barnes, 1979, p. 14.

Human Considerations

GEOGRAPHIC AND LAND-USE CRITERIA

Present Land Use

Distance to Nearest Water Use

Sites selected for disposal of low-level radioactive wastes should be located far from public water supplies.

The words "water use" in this criterion are used liberally in this case and include aquifers with wells, lakes or surface water bodies and streams. Distance has a direct influence on the time it takes potential contamination from a site to move to a water source. Depending on the site and the type of water path, rather large distances may be required.

> "The key parameters are: 1. distance to a water supply, 2. depth to water table, 3. hydraulic gradient, and 4. permeability sorption, as indicated by the geologic setting."
>
> LeGrand (1980) p. ii

> "The hydrology must be such that flow from the disposal site does not lead to areas which provide potential pathways to man, such as fractured bedrock, public waterways, and aquifers used for water supply;"
>
> GAO Rept. (1976) p. 11

> "The following hydrogeologic features are considered favorable for management of contaminants near the land surface.
>
> 1. Sufficient permeability of surface soils to allow infiltration and thus prevent overland movement of contaminants.
> 2. Sufficient clay in the path that contaminants will take so that retention or sorption of contaminants is favorable.
> 3. A deep water table, which allows for sorption of contaminants on earth materials, slows subsurface movement of contaminants, and facilitates oxidation or other beneficial 'die-away' effects.
> 4. A great distance between wells and waste sites so that advantages of the above factors can accumulate.
> 5. A gradient of the water table beneath a waste site away from nearby wells."
>
> LeGrand (1980) p. 17-18

> "In addition to the natural factors outlined above, geographic factors, such as location, size and shape of the area, communications, population density and distribution, and water use downstream from the site, must be considered."
>
> Morton (1968) p. 29

"The current IEPA guidelines require, in addition to a permeability barrier at the bottom and sides of trenches, a minimum of 500 feet from the nearest water well. To protect surface water, siting on a floodplain is prohibited, surface runoff must be controlled, and the site must be at least 500 feet from a body of surface water."

Cartwright et al. (1981) p. 3

Additional references include: Cherry et al., 1979, p. 1024-1025; GAO Rept. 1976, p. 43; LeGrand, 1980, p. 17; Steger, 1979, p. 669.

Present Land Use

Availability of Construction Material

Another important land-use criterion is the availability of construction materials. It is important to know not only the location of the nearest supply of construction materials, but also whether the present and projected use of the land will permit the extraction of these resources during construction of the site.

"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."

Panel on Land Burial (1976) p. 68

No additional references.

GEOGRAPHIC AND LAND-USE CRITERIA

Past Land Use

The topic of "past land use" has received less attention in the literature than the topics of "present" or "future land use." However, the potential problems of not understanding past land use (for example, the location of previous drilling) could affect site performance.

> "The site shall be located so that the exploration history or relevant past use of the site or adjacent areas can be determined and can be shown to have no unacceptable impact on system performance."
> NWTS Program Office (Feb., 1981) p. 10

> "The site should be located with due consideration for nearby mines, major excavations, boreholes, dams, and proximity to mineral resources."
> Klingsberg and Duguid (1980) p. 66

Additional references include: Barnes, 1979, p. 14.

GEOGRAPHIC AND LAND-USE CRITERIA

Dams

The effect of a dam in the vicinity of a low-level radioactive waste site could be significant for surface water, groundwater, land-use and safety.

"No area adjacent to an actual or potential major dam site should be considered as a potential site for a repository."

Frye et al. (1978) p. 15

"Evaluation of the geohydrologic regime shall include consideration of surface conditions or features such as impoundments or glaciers, and changes in subsurface conditions induced, for example, by aquifer pumping or injection, or thermally-induced ground-water flow."

NWTS Program Office (Feb., 1981) p. 7

"The site should be located with due consideration for nearby mines, major excavations, boreholes, dams, and proximity to mineral resources."

Klingsberg and Duguid (1980) p. 66

No additional references.

Human Considerations

TRANSPORTATION CRITERIA

In evaluating sites for location of low-level radioactive waste facilities, transportation is a key criterion, as emphasized in the literature.

The transportation of low-level radioactive waste presents a hazard to public health and safety. The Department of Transportation and the Nuclear Regulatory Commission regulate the packaging and handling of low-level wastes and vehicle safety and maintenance. The authors make the following recommendations: 1) low-level waste sites should be located with access to major all weather highway and rail routes; 2) sites should be as far as possible from population centers, and as close as possible to waste generators; 3) proximity to generators will minimize the risks to public health and the costs of waste transport; and 4) the creation of regional disposal sites will reduce both the risks of possible transportation accidents and the costs of transport.

> "12. TO THE EXTENT CONSISTENT WITH OTHER GUIDELINES, THE SITE SHOULD BE SELECTED WITH CONSIDERATION GIVEN TO LOCATION OF WASTE GENERATION, ACCESS TO ALL-WEATHER HIGHWAY AND RAIL ROUTES, AND ACCESS TO UTILITIES.
>
> The risks and costs associated with the transportation of low-level radioactive waste can be minimized by considering points of waste generation and transportation routes in disposal site selection. In addition, access to the utilities required for site operation should be considered."
>
> Falconer (1981) no pages given

> "Currently, truck transportation offers the preferable service for moving LLW. With the projected growth of nuclear energy through the year 2000, other transportation modes (particularly rail) may become competitive."
>
> Lamb (1979) p. 50-51

> "Sites in which road and rail access routes encounter steep grades, sharp switchbacks, slope instability, or other potential sources of hazard to incoming waste shipments should be avoided."
>
> NWTS Program Office (Feb., 1981) p. 10

> "The location of an appropriate site for operation of a facility and for burial in Massachusetts should take into consideration the transport routes that would be involved in getting the LLW to the site. While the transportation of LLW does not pose a significant hazard, proper routing, including the use of all of the Commonwealth's major highways, should minimize unnnecesary transport through communities."
>
> Massachusetts Rept. (1980) p. 13

> "Commercial low-level waste is transported from the waste generator to disposal sites in two primary ways. Some shipments are made directly from the waste generators to the disposal site by common carriers, while other waste generators use the services of commercial waste handling firms (brokers). Shipments of low-specific activity (typically 55-gallon drums) and higher activity waste are packaged in accordance with U.S. Department

of Transportation regulations. Commercial waste handling firms collect the waste from individual generators, store it for a period of time, and make bulk shipments to disposal facilities. These firms, using both their own equipment and common carriers, ship both types of waste requiring no shielding and that waste requiring shielded casks for transport."

U.S. DOE (Nov., 1980) no pages given

"The U.S. Department of Transportation has issued routing regulations for radioactive waste shipments, which will become effective February 1, 1982. This will allow a year for states to prepare their own regulatory programs and for generators and shippers to develop compliant routes. ....It is, however, generally accepted that packaging technology, transportation, and regulatory codes are adequate to protect the public health and safety. Enforcement of existing regulations appears to be the primary problem area. An effective enforcement program of Nuclear Regulatory Commission and Department of Transportation regulations presents a significant incentive for generators and shippers to comply with all applicable requirements."

U.S. DOE (Mar. 13, 1980) no pages given

"The Department of Transportation regulates the transport of all hazardous materials, including radioactive wastes. Department of Transportation regulations pertain to the packaging and handling of low-level wastes and to vehicle safety and maintenance. The Nuclear Regulatory Commission is responsible for the regulation of highly radioactive materials in transit and for developing performance standards for large quantity shipments. ....The U.S. Coast Guard regulates the transport of waste over water, and the Departments of Defense and Energy control waste shipments in noncivilian vehicles, aircraft, and ships.

U.S. DOE (Nov., 1980) no pages given

"Although experience has clearly demonstrated that the packaging and transportation of all types of radioactive material provide a level of safety equal to or exceeding that for other hazardous materials, we cannot afford to relax in our efforts to assure complete and adequate protection to transportation workers, the general public, and the environment.

Each shipper should review his method of operation periodically and examine the relative merits of those packaging and transportation alternatives that offer the best potential for assuring safety, reducing costs, and improving service. Effective transportation management is an important consideration in administering (sic) a safe and efficient LLW operation."

Lamb (1979) p. 51

"The Nuclear Regulatory Commission has implemented a comprehensive plan to improve the packaging, transporting, and disposal of low-level nuclear wastes through appropriate enforcement action. Key points of this plan are as follows:

- Inform all generator/shippers of their responsibility for compliance with the regulations for shipment of wastes.

- Assist shippers in learning the proper regulatory requirements for compliance.

- Conduct an inspection program at the waste generator/shipper facilities to detect deficiencies.

- Perform routine inspections of incoming waste shipments at the commercial waste burial sites.

- Institute a program of civil penalties for significant violations."

U.S. DOE (Mar. 13, 1981) p. 30-31

"The recent rash of incidents which have focused attention on and spawned anxiety about LLW disposal have, in most cases, involved infractions of transportation and packaging regulations. Specific violations have included radiation dose rates in excess of allowable limits, improper or damaged containers, incorrect labeling, and vehicle safety infractions."

TENRAC (1980) p. 12

"Waste form is an important factor in minimizing radionuclide releases. The mobility of liquid and gaseous wastes makes them undesirable waste forms for shallow land burial. Most burial ground operators are not authorized to bury liquid or gaseous wastes, but they often receive wastes with free-standing liquid (BL79). Recently Richland and Beatty were closed by action of the respective state governors because the packaging did not meet acceptable standards for transport."

Jacobs, Epler, and Rose (1980) p. 8

"Risks from transportation can be reduced if all states ship waste to a regional site which is nearby; long distance inter-regional transportation is minimized."

Tennessee Rept. (Nov., 1980) p. 42

"Low-level wastes (LLW) consisting of residues or solutions from chemical processes, building rubble--metal and wood; sludges and acids; equipment; and paper, rags, and the like which are solidified and/or compacted and packaged in strong tight containers present no significant hazards during transportation because of the very low concentrations of radioactivity. These materials can be readily transported by truck, rail, or water depending upon volume and weight.

Additional references include: Environmental Resources Management, Inc., Sept. 19, 1980, no pages given; Illinois Rept., 1980, p. 17, 24; Massachusetts Rept., 1980, p. 3-4, 18; Montague, Jan., 1979, p. 22; National Waste Terminal Storage Program Office, Feb. 1981, p. 11; North Carolina Rept., Jan. 12, 1980, p. 44, 46, 54-56; Straub, 1970, p. 45; TENRAC, 1980, p. 68-69; U.S. DOE, Mar. 13, 1981, p. 2.

IX. APPENDIX

Definitions of Low-Level Radioactive Waste

"Low-level radioactive wastes are legally defined* as radioactive waste material that (1) is not high-level waste** and (2) is contaminated with less than 10 nanocuries per gram of transuranic elements.*** Furthermore low-level wastes do not include wastes from the mining and milling of uranium ores."

"*See Nuclear Regulatory Commission regulations, Title 10 of the Code of Federal Regulations, Part 50."

"**High-level wastes are spent fuel from nuclear reactors and the wastes directly produced in the reprocessing of spent fuel."

"***Wastes contaminated with more than 10 nanocuries per gram are transuranic wastes."

EG & G. Inc., Idaho (1980) p. 1

"Briefly, low-level waste is all radioactively contaminated waste other than 'high-level' (resulting from the first stage of fuel reprocessing) and 'transuranic' (containing concentrations of transuranic elements above 10 nCi/gm."

Wheeler and Smith (1979) p. 14

"The second recommended item relates to the categorization of 'other than high-level waste.' I have purposely ignored the term 'low-level' waste, since I do not believe that such a broad term is appropriate for the kind of waste we are discussing. I believe that 'other than high-level,' waste could be categorized into 'intermediate-level' and low-level waste. For discussion purposes I suggest the following:

Intermediate-Level: All treated waste (e.g. solidified waste or ion exchange resins), high specific activity waste (e.g. one curie per cubic foot or greater), and long half-life waste (30 years or greater).

Low-Level: All other waste, with the exception of waste resulting from disturbing the earth, such as mill tailings that do not fall into the above category."

Hardin (1979) p. 834

"Low-Level Contaminated Wastes do not contain significant amounts of TRU (10 nCi/g) nuclides and have relatively low levels of radioactivity. Such contaminated waste may come from a wide variety of sources, including manufacturing, processing, testing, and research. Depending on its origin, it may be contaminated with almost any radioactive isotope in small amounts. The kind of materials being handled are equally varied, ranging from paper towels and laboratory gloves to materials of construction from obsolete nuclear facilities."

U.S. DOE (March, 1980) p. 86

"Commercial LLW is a byproduct of nuclear power reactor operation, medical and industrial use, and R & D activities. Typical examples of solid LLW are discarded equipment, metals, filters from the cleanup of liquid wastes, liquid wastes that have been converted to solid and miscellaneous trash such as paper, rags, glassware, and protective clothing."

U.S. DOE (March, 1980) p. 150

"In this report, the term 'low-level wastes' refers to all radioactive wastes other than the high-level wastes already defined."

Panel on Hanford Waste (1978) p. 51

"The category of low-level and intermediate level radioactive waste is generally understood to include those radionuclides of both short and long half-lives, including transuranics, which by virture of their activity, radiotoxicology or form are currently considered to be amenable to disposal on or near the surface of the earth within certain engineered and environmental barriers. It includes wastes from most operations of the uranium fuel cycle and wastes from commercial, research, medical, and government sources. These wastes vary widely in composition and radioactivity and area function of the operations that generate them."

U.S. EPA (April, 1977) p. 2-3

"Materials that are normally disposed of in shallow land burial have been classified by the Energy Research and Development Administration (ERDA) as 'solid radioactive waste other than solidified high-level wastes.' Included in this classification are such diverse materials as paper, rags, rubber, wood, glassware, carcasses and excreta of contaminated eqiupment, rubble from dismantled buildings, and irradiated components. These wastes, except for the last named, are contaminated with various radionuclides such as cobalt-60, tritium, strontium-90, cesium 137, radium-226, and, at some sites, transuranics."

U.S. EPA (April, 1977) p. 2-3

"Low-Level Waste--Waste containing types and concentrations of radioactivity such that shielding to prevent personnel exposure is not necessary.

Intermediate - Level Wastes--Waste requiring some kind of action to protect personnel from radiation."

U.S. EPA (April, 1977) p. 2-31

"Low-level waste is a catch-all term that includes all radioactive waste other than irradiated reactor fuel and products of spent fuel processing (called high-level waste), uranium mill tailings and material containing more than 10 nanocuries per gram of transuranic radioisotopes. Therefore, the spectrum of materials included spans the range from the very innocuous residues of human tissue subjected to radioisotopic analysis to the relatively dangerous remains of high activity irradiation sources and discarded reactor system components."

TENRAC (1980) p. 8

"Several years ago, the official federal definition of low-level wastes was changed, the low level wastes were renamed 'nonhigh level wastes' and were defined to include any waste that is not high level and contains less than ten nanocuries of alpha activity per cubic foot."

Lipschutz (1980) p. 125

"The term low-level waste is used to refer to all solid radioactive waste other than high-level waste, transuranic waste and mill tailings. A limit of 10 nCi/gram was assumed as a working number to limit transuranic content. The only other limits assumed were that PWR core barrels and shrouds from decommissioning of reactors would not go to the burial grounds because of their high specific activity."

Bishop et al. (1979) p. 31

"The term, 'low-level non-transuranic,' is ill-defined. For the purposes of this paper, low-level non-transuranic waste is defined as waste that contains less than 10 nCi of long-lived alpha radiation per gram and has a gamma radiation level sufficiently low to require only minimal biological shielding and remote handling."

Alexander and Blomeke (1979) p. 55

"In the past, low-level radioactive wastes received for burial in shallow earthen trenched in six states were generated at hospitals, research facilities, and industries using radioisotopes. In the future however, the low-level wastes will be produced predominantly by the nuclear power industry. (33) These nuclear power wastes will contain large quantities of plutonium-239 and other long-lived, extremely toxic radionuclides if, reprocessing and plutonium recycle are permitted in the future. Indeed, some calculations show that the amounts of plutonium, one of the more toxic materials known to man, in the low-level wastes are comparable to or even greater than the amounts in the high-level wastes. (34) Since the low-level wastes are buried under conditions much less safe (e.g., shallower depth of burial and lower integrity of containers) than those that will likely pertain to high-level waste burial facilities, there is reason for grave concern over the long-term safety of these facilities. (35)."

Lash (May 17, 1977) p. 19

"...excluded from burial at the Sheffield site are all wastes containing more than one curie per cubic foot. This unique criterion insures a low-level site."

Blackburn and Ed. (1979) p. 838

X. GLOSSARY

Adsorption	Adhesion of molecules or gases, or of ions or molecules in solutions, to the surfaces of solid bodies with which they are in contact.
Aquifer	A subsurface formation or geological unit containing sufficient saturated permeable material to yield significant quantities of water.
Biosphere	The zone of earth which contains living organisms.
Buffer Zone	A portion of the disposal site that surrounds the facility and is composed of essentially undisturbed geologic and surficial environment.
Cavern	A subterranean hollow or underground cavity.
Corrosivity	The ability of a material to be corroded.
Creep	An imperceptibly slow, more or less continuous downward and outward movement of slope-forming soil or rock.
Criterion	A standard on which a judgment or decision may be based.
Diffusion	The spreading out of molecules, atoms, or ions, into a vacuum, a fluid, or a porous medium, in a direction tending to equalize concentration in all parts of a system.
Dilution	The process of thinning down or weakening by mixing with water or another liquid.
Discharge Areas	Areas in which water is discharged or leaves the zone of saturation, usually in the context of discharging to the surface as a spring or lake.
Dispersion	The spreading out or dispersing of a contaminant or other solute as it moves along a flow path direction.
Dispersity Coefficient	The coefficient that describes or qualifies the dispersion characteristics of a particular medium or material.

Disposal	Operations designed to isolate waste from people and the environment, with no expectation of retrieval after emplacement.
Dissolution Voids	Voids or openings created by the dissolution or dissolving of material.
Engineered Barrier	An addition to the geologic environment which has been designed, fabricated, and emplaced to minimize or preclude radionuclide transport.
Evapotranspiration	A term embracing that portion of the precipitation returned to the air through direct evaporation or the transpiration of vegetation.
Faulting	The movement which produces relative displacement of adjacent rock masses along a fracture.
Fractures	Breaks in rocks due to intense folding or faulting.
Geochemistry	The study of the chemical characteristics of materials which constitute the earth.
Geophysics	The science of the earth with respect to its structure, composition, and development.
Glaciation	The alteration of the earth's solid surface through erosion and deposition by glacier ice.
Half-Life	Time required for a radioactive substance to lose half of its activity by decay. Each radionuclide has a unique half-life.
High-Level Waste	Used reactor fuel or the radioactive wastes produced during the reprocessing of used reactor fuel.
Hydraulic Conductivity	Ration of flow velocity to driving force for viscous flow under saturated conditions of a specified liquid in a porous medium.
Hydrology	The science which studies the properties, distribution, and circulation of water on the surface of the land, in the soil and underlying rocks, and in the atmosphere.
Incineration	The burning or thermal destruction of wastes.

Infiltration	The flow or movement of water through the soil surface into the ground.
Ion Exchange	A chemical process in which ions are interchanged between a solution and a solid material. Ions are atoms or molecules that have lost or gained one or more electrons and have thus become electrically charged.
Isolation	Segregation of wastes from the accessible environment (biosphere) to the extent required to meet applicable radiological standards.
Isotopes	Elements having an identical number of protons in their nuclei, but differing in the number of their neutrons.
Karst	A type of topography that is formed over limestone, dolomite, or gypsum by dissolving or solution, and that is characterized by closed depressions or sinkholes, caves, and underground drainage.
Leachate	A solution obtained by leaching, as in the downward percolation of meteoric water through soil or solid waste and containing soluble substances, such as a landfill.
Mass Wasting	The process by which masses of earth and rock material are moved by gravity either slowly or quickly from one place to another.
Minerology	The science of the study of minerals.
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.
Permeability	The capacity of a rock for transmitting fluids.
Radionuclide	Any species of atom that emits radiation and therefore has a defined half-life.
Radiotoxicities	The toxicity of radioactive nuclides or wastes.
Reactivity	The ability to react, usually chemically, with other materials.
Recharge Areas	Areas in which water is absorbed and added to the zone of saturation, either directly into a formation, or indirectly by way of another formation.

Retrievability	The capability to remove waste from its place of isolation using planned engineering procedures.
Salinity	The measure of the quantity of total dissolved solids in water.
Seismicity	The spatial distribution of earthquake activity.
Shallow Land Burial	The disposal of wastes in the ground in shallow trenches with a cover of soil approximately 4 to 10 feet thick.
Solubility	The equilibrium concentration of solute when undissolved solute is in contact with solution.
Sorption	A term including both adsorption and absorption. Sorption is basic to many processes used to remove gaseous and particulate pollutants from an emmission and to clean up oil spills.
Subsidence	Movement in which there is no free side and surface material is displaced vertically downward with little or no horizontal component.
Surficial	Characteristic of, pertaining to, formed on, situated at, or occurring on the earth's surface.
Tectonics	The study of the broader structural features of the earth and their causes.
Toxicity	The state and degree of being toxic or poisonous.
Transmissivity	The rate at which water is transmitted through a unit width of aquifer under a unit hydraulic gradient.
Transuranic Wastes	Those elements with atomic numbers greater than that of uranium (92).
Unattenuated Pollutants	Pollutants that are not adsorbed or otherwise attenuated by the medium through which they move.

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