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EPA

Hazardous Waste Storage and Disposal in Geologic Repositories

Permit Guidance Under the Resource Conservation and Recovery Act

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HAZARDOUS WASTE STORAGE AND DISPOSAL IN GEOLOGIC REPOSITORIES

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EXECUTIVE SUMMARY

This manual was written to help preparers and reviewers of Resource Conservation and Recovery Act (RCRA) permit applications better understand the requirements that must be fulfilled to obtain a RCRA permit to store or dispose of hazardous waste in geologic repositories. Included in this manual is guidance to assist in facility siting, design, operation, and closure as well as the preparation of complete RCRA permit applications and no-migration petitions.

Regulatory Background

Regulations issued by the U.S. Environmental Protection Agency (EPA) under Title 40 of the Code of Federal Regulations, Part 264 (40 CFR 264), Subpart X contain general permitting requirements for "miscellaneous" hazardous waste management units not covered by other existing RCRA regulations. This guidance is intended to detail specific siting and performance criteria needed to satisfy the more general Subpart X requirements. Geologic repositories used for the storage or disposal of containerized and bulk non-liquid hazardous waste must demonstrate compliance with the Subpart X requirements through the permit application process, unless the facility is regulated under authority of the Safe Drinking Water Act (SDWA).

Underground injection control (UIC) regulations issued by EPA under SDWA govern the placement of fluids in repositories if the disposal method meets the regulatory definition of underground injection. Facilities obtaining a UIC permit for hazardous waste disposal receive a RCRA permit-by-rule after compliance with RCRA corrective action requirements. These facilities do not also need a Subpart X permit.

Facilities seeking a Subpart X permit for the underground disposal of mixed low-level radioactive and hazardous wastes are subject to the same requirements as facilities managing only hazardous wastes. Such "mixed waste" facilities will be

required to obtain additional authorizations or permits from the Nuclear Regulatory Commission.

RCRA Permit Application Review

EPA administers the RCRA permit programs unless a state seeks and obtains formal authorization to administer the program in lieu of EPA. Currently, because a provision in the 1984 Amendments to RCRA, EPA and authorized states may be jointly administering the RCRA permit program for an interim period. Thus, because each authorized state's role in the permitting process varies at the present time, the application for a RCRA permit may be reviewed by state authorities, EPA permit specialists or both, depending on the status of the state's authorization to administer the permit program.

Permit applications will initially be reviewed for completeness and, once determined to be complete, for technical adequacy. Based on the results of the technical review, a tentative decision will be made to either issue or deny the facility permit. This decision will be noticed to the public, comments solicited, and a public hearing held if warranted by the comments received. A final decision on permit issuance will then be reached based on the comments received and the application review findings.

Facility Siting

Geologic repositories should be sited in formations that will assure the structural stability and hydrologic isolation of the repository. Repositories used for the storage of hazardous wastes need only demonstrate such stability and isolation for so long as waste remains in the unit (i.e., the active life of the unit). The performance of disposal repositories must be demonstrated for the active life as well as a minimum of 30 years after closure (the post-closure care period). To obtain a no-migration variance, satisfactory performance must be demonstrated for as long as the waste remains hazardous. Extensive data concerning geologic and hydrologic conditions should be collected and evaluated to verify repository performance at the proposed site. The impacts of previous exploration and resource extraction activities at the site and the

potential for future such activities must also be considered to determine the potential for human-induced failure due to rock disturbances.

Repository Design and Operation

Repositories must be designed and operated to assure the protection of human health and the environment both during their active lives and after closure. Special design features and operating procedures related to fire protection, ventilation, and emergency escape should be employed in underground areas to protect workers. The cavern design, entranceway design, and waste emplacement method must be demonstrated to promote long-term structural stability and hydrologic isolation of the repository.

Waste Characterization

The types of wastes to be placed in the repository must be carefully screened to minimize threats to worker health and long-term repository performance. Reactive, volatile, ignitable, incompatible, and corrosive wastes, as well as wastes that may release extensive amounts of gases, should not be placed in the repository unless it can be demonstrated that the risks posed by their management are not significant.

Monitoring Requirements

The determination of the need for ground-water, surface water, or air monitoring and leachate detection or repository monitoring systems will be determined on a case-by-case basis. Such monitoring systems will typically be required unless it can be demonstrated that the facility siting, design, operating, and closure approaches will assure that releases to the environment will not occur. Special considerations will be required when monitoring ground water at repositories owing to the extensive depth of the units.

Contingency Planning

Contingency plans for repositories requiring an underground worker presence must provide special consideration to the emergency planning process and include measures

that adequately address probable emergency scenarios at the facility. A critical aspect of repository contingency plans will be coordination of evacuation from the repository. In addition, sufficient emergency equipment must be provided at strategically located underground sites to allow timely response to emergencies.

Repository Closure

Proper closure of geologic repositories will necessitate thorough sealing of all access shafts into the repository cavern if the nature of the wastes placed in the repository are such that hazardous leachate or gases could be generated within the repository after closure. This will require the construction of bulkheads or seals that will be effective at preventing the migration of water into areas where wastes are present and preventing the migration of hazardous waste, waste leachate, and gases from the repository that could have adverse impacts on human health or the environment. Repository seals must be designed to withstand the forces expected to be present due to rock creep, hydraulic pressure, and probable collapses within the repository. In addition, seal materials must be demonstrated to be chemically compatible with the host rock and any wastes and waste leachate that may come into contact with the seals.

Exposure Information

Permit applications for hazardous waste geologic repositories must evaluate the potential pathways for human exposure to hazardous waste or waste constituents associated with repository operation as well as after closure. Based on the identification of potential exposure pathways, the potential for releases to those pathways, and the nature of the wastes that may be involved, potential risks to human health must be considered.

SECTION 1.0

INTRODUCTION

Under Subtitle C of the Resource Conservation and Recovery Act of 1976 (RCRA), the U.S. Environmental Protection Agency (EPA) has issued regulations to ensure protection of human health and the environment through the proper management of hazardous waste. These regulations require the owners and operators of facilities that treat, store, or dispose of hazardous wastes to obtain RCRA permits for those activities. The application for a RCRA permit must contain sufficient information to assure EPA that the provisions for facility siting, design, operation, closure, and post-closure care satisfy the permitting standards.

This guidance manual was written to help preparers and reviewers of permit applications better understand the application information required of facilities that store or dispose of hazardous waste in geologic repositories. These facilities are regulated under Title 40 of the Code of Federal Regulations, Part 264 (40 CFR 264), Subpart X, which establishes standards for "Miscellaneous" units not covered by RCRA standards for tanks, containers, landfills, surface impoundments, waste piles, and incinerators. The Subpart X provisions contain broad performance standards that apply to a variety of hazardous waste management units, such as open detonation units and boilers used to thermally treat hazardous waste, as well as geologic repositories. This guidance manual assists in identifying the facility-specific criteria that must be addressed in a geologic repository facility permit application to demonstrate compliance with the Subpart X requirements. Included in this manual are descriptions of administrative procedures used in the permitting process (Section 2), a suggested format for permit applications (Section 3), a description of "no-migration" variances that may be applicable to a particular repository (Section 4), detailed guidance concerning aspects of RCRA permitting unique to repositories (Sections 5 through 11), and sources for obtaining additional information (Section 12).

This guidance is not a mandatory regulation, nor does it add to, or detract from, the permit standard, in Part 264, Subpart X, for geologic repositories. Rather, the use of this guidance manual in preparing a permit application should enable the applicant to efficiently organize and present the information needed by regulatory authorities to evaluate the application in a knowledgeable and expeditious manner. Under 40 CFR 264.1(f)(2), permits will be issued by EPA for new facilities in states with no authorized RCRA program or authorized states that have not yet expanded their programs to include Subpart X standards. Existing facilities with RCRA interim status may continue to operate under interim status provisions until a permit has been finally granted or denied. Applicants should consult their EPA Regional Administrator or state authority if they are uncertain about the status of a particular state program.

1.1 Regulatory Background

The facility permitting requirements issued under Subtitle C of RCRA contain detailed standards for the most common types of hazardous waste management facilities including tanks, container storage areas, surface impoundments, landfills, waste piles, and land treatment units. However, until October 1987, these regulations did not provide for the permitting of geologic repositories used to manage hazardous wastes.

On December 10, 1987, EPA issued final regulations governing the siting, design, operation, closure, and post-closure care of "miscellaneous" units not covered by other existing RCRA regulations. These regulations, contained in Subpart X of 40 CFR 264, provide the general standards, applicable through a unit- specific permit writing process, to underground disposal activities not regulated under the Safe Drinking Water Act (SDWA). The preamble to the Subpart X rulemaking (___Federal Register___, date) should be consulted for additional discussions of the background and intent of the Subpart X regulations.

1.2 Applicability

Although this manual addresses some ways to meet some requirements common to all RCRA permitting activities, its focus is helping the permit applicant to provide information relevant to the permitting requirements unique to geologic repositories.

Geologic repositories are considered to be land disposal units consisting of subsurface through a shaft, tunnel, or similar entryway. In general, geologic repositories are limited to man- made mines or tunnels in massive geologic formations. However, naturally occurring caves may also be suitable for conversion to repository use, provided compliance with 40 CFR 264 performance standards can be demonstrated in the permit application. In addition, caverns developed for other uses (such as mineral extraction or petroleum storage) may also be suitable repository candidates. However, the Agency believes that the stringent performance requirements that must be met by Subpart X facilities will preclude the use of most naturally occurring caves.

It is anticipated that most geologic repositories will require the construction of surface-based storage and/or treatment facilities to manage wastes before emplacement in the repository. Surface-based storage units such as tanks, waste piles, and container storage areas are likely to require RCRA permits. More information on the permitting of the above-ground portions of repository facilities can be found in the guidance documents and information sources listed in Section 12 of this manual.

Not all geologic repositories receiving hazardous wastes are to be governed by Subpart X promulgated under RCRA. Other underground injection control regulations promulgated by EPA under Safe Drinking Water Act (SDWA) apply to any repository that can also be classified as an underground injection well. The distinction between repositories regulated under Subpart X and underground injection regulations is based primarily on the physical state of the waste placed in the repository. The placement of bulk fluids and bulk pumpable slurries in a repository will be subject to the Underground Injection Control (UIC) regulations promulgated under SDWA and contained in 40 CFR 144. Although hazardous waste disposal in injection wells also requires a RCRA permit, a permit-by-rule system has been arranged (40 CFR 270.1(c)(L)(i)) for the convenience of the Agency and the owner or operator. In most cases, wells that comply with UIC requirements can receive a RCRA permit-by-rule without separate RCRA Part B permit proceedings (although some RCRA provisions may apply). Placement in underground mines that are not covered by a UIC permit is subject to Subpart X standards.

Some overlap exists between the two regulatory authorities, in that the UIC permit-by-rule covers wastes that are "fluids". However, fluid wastes could, in some cases, be soils, dry sludges, debris, or pellets that "flow" into the repository. These wastes would also fit the definition of "bulk nonliquid hazardous waste" regulated under Subpart X. Under RCRA, nonliquid wastes are those wastes that pass the Paint Filter Liquids Test contained in Method 9095 of Test Methods for Evaluating Solid Wastes, Physical/Chemical Methods (EPA Publication No. SW-846).

A recent court ruling in NRTA vs. EPA, Cons. Cases No. 85-1915 and 86-1096 contains interpretative language that may further broaden the scope of the UIC program. The opinion suggests that solids or containerized wastes lowered down a shaft could be considered "well injection" of "fluids" if contaminants in the waste form would ultimately "flow" or move to the accessible environment. The court was particularly concerned that EPA had not evaluated the relationship of the SDWA to the Nuclear Waste Policy Act (NWPA).

In the December 10, 1987 Subpart X regulations, however, EPA addressed the overlap of RCRA Subpart X and UIC geologic repositories with respect to this recent court opinion. The Agency stated that injection of noncontainerized liquids, slurries, and sludges would be regulated under UIC permitting (40 CFR Part 146 Standards). Other disposal practices, such as placement of containerized wastes or solids are not now covered explicitly under Part 146 permitting and would require standards on a case-by-case basis. EPA intends the standards for these latter practices to meet the requirements of both the SDWA and RCRA, whether a particular disposal practice is termed to be "underground injection" or not. The final Subpart X rule of December 10 provides standards for these miscellaneous management practices through the RCRA permit process. It also contains amendments to 40 CFR Part 144.31 that provide that a Subpart X permit will constitute a UIC permit for hazardous waste well injection for which Part 146 technical standards are not generally appropriate.

Wastes subject to Subpart X standards would include those that are nonliquid and properly containerized, and/or pelletized or granular waste, soils, and other debris.

Subpart X generally covers those wastes that are emplaced in the repository by means of elevators, trucks, carts, or other conveyances. For example, a room-and-pillar salt or limestone mine, in which nonliquid drummed wastes are emplaced by means of a front-end loader, would clearly be subject to Subpart X standards. Solution-mined salt domes are generally subject to a UIC permits, but may be permitted under Subpart X in those cases where waste is emplaced by means of an elevator or where a contaminated soil or other solid is poured down a shaft under normal pressure and temperature conditions.

Wastes that would likely be permitted under the UIC program include slurries and sludges. For example, a slurry that is injected into a solution-mined salt dome to harden later would be subject to UIC regulations.

Under section 3004(b)(1) of the Hazardous and Solid Waste Amendments of 1984 (HSWA), the placement of any noncontainerized or bulk liquid hazardous waste in any salt dome formation, salt bed formation, underground mine, or cave is prohibited until the Administrator has determined that such placement is protective of human health and the environment. Such activities would likely be permitted under the UIC program to the extent that Part 146 substantive permit standards apply. If Part 146 standards do not apply, then the statutory prohibition remains in effect since no RCRA regulations exist to lift the 3004(b)(1) ban.

Therefore, this manual is applicable to geologic repositories not subject to the 3004(b)(1) ban, which can be permitted under RCRA Subpart X. Also, this manual is applicable to geologic repositories not regulated under the UIC program that receive mixed low-level radioactive and hazardous waste (Mixed LLW) and that are not subject to the 3004(b)(1) ban. Mixed LLW is defined as hazardous waste that satisfies the definition of low-level radioactive waste in the Low-Level Radioactive Waste Policy Amendments of 1985 and contains hazardous waste that either (1) is a listed hazardous waste in 40 CFR 261 or (2) causes the waste to exhibit any of the hazardous waste characteristics identified in 40 CFR 261. EPA procedures and regulations governing the design, permitting, operation, closure, and post-closure care of repositories receiving Mixed LLW do not differ from those for units receiving only hazardous wastes. However,

EPA does not have exclusive jurisdiction over the management of Mixed LLW. The U.S. Nuclear Regulatory Commission (NRC) is also responsible for regulation of Mixed LLW management and may impose specific requirements on geologic repositories receiving Mixed LLW not addressed in this manual. In cases where documentation prepared by a permit applicant to comply with NRC requirements also addresses requirements applicable to Subpart X facilities, applicants are encouraged to submit that documentation with their RCRA permit application in lieu of performing extensive editing or rewriting of the NRC submittals.

Geologic repositories for hazardous wastes could potentially be constructed and operated under Research, Development and Demonstration (RD&D) permits issued by EPA. Such permits can be issued by the Agency to facilities for the demonstration of experimental and innovative technologies and processes that provide safe alternatives to land disposal of hazardous wastes as defined in 40 CFR 270.65. Subpart X permits are not available to any facility seeking an RD&D permit. Hence, this manual does not address the requirements applicable to facilities seeking RD&D permits. Applicants desiring further guidance concerning RD&D permits should consult EPA's Guidance Manual for Research, Development and Demonstration Permits under 40 CFR Section 270.65.

1.3 No-Migration Variances

Land disposal restrictions contained in 40 CFR 268.10 through 268.13 require that any hazardous waste to be placed in a geologic repository first be treated using best demonstrated available technology (BDAT) methods or the waste naturally meets BDAT based performance levels unless the repository owner or operator petitions for and receives a "no-migration" variance. The no-migration petition must demonstrate, to a reasonable degree of certainty, that hazardous constituents will not be at unacceptable levels beyond the unit boundary. This demonstration may involve analyses of the repository as well as surrounding geologic materials and/or structures that serve to prevent the migration of waste constituents to the accessible environment. If EPA determines that the petition adequately demonstrates no- migration potential, a variance can be issued that will allow the placement of hazardous wastes that exceed BDAT performance levels in the repository.

Because much of the information that must be included in a RCRA permit application must also be part of the no-migration petition, it is suggested that applicants develop documentation that can be used in both submissions with minimal editing or rewriting. Section 4 of this manual provides additional guidance on no-migration variances. In addition, Sections 5 through 10, which describe repository permit application content, also describe the demonstrations required in no-migration petitions, as appropriate.

1.4 Relationship to Other Federal Regulations

Geologic repositories applying for Subpart X permits must also comply with RCRA corrective action requirements. These requirements contained in Section 3004(u) of the Hazardous and Solid Waste Amendments of 1984 (HSWA) mandate corrective action for releases of hazardous constituents from solid waste management units at any facility seeking a RCRA permit. Compliance with these provisions must be demonstrated before a RCRA permit is issued to a geologic repository. Other HSWA corrective action authority, such as Section 3004(v) or 3008(h) may also apply. RCRA corrective action requirements are not addressed in this manual. Further guidance concerning corrective action requirements can be found in the EPA document RCRA Facility Assessment Guidance, and the RCRA Facility Investigation Guidance.

In addition to RCRA, geologic repositories must comply with all other applicable Federal laws. Compliance with the following Federal laws must be confirmed, if applicable, prior to issuance of a RCRA permit (40 CFR 270.3):

- The Wild and Scenic Rivers Act
- The National Historic Preservation Act of 1966
- The Endangered Species Act
- The Coastal Zone Management Act
- The Fish and Wildlife Coordination Act.

Facilities seeking to store or dispose of hazardous wastes in geologic repositories may be regulated under several other Federal laws, including:

- The Clean Air Act
- The Clean Water Act
- The Mine Safety and Health Act
- The Occupational Safety and Health Act
- The Emergency Planning and Community Right-to-Know Act of 1986 (SARA Title III).

The regulations issued under the Mine Safety and Health Act (MSHA) and the Occupational Safety and Health Act (OSHA) are particularly noteworthy. The MSHA requirements for mine design and construction may govern the development of repository space if the mined materials are sold. In addition, EPA considers the operational safety standards contained in the MSHA regulations, such as those regarding ventilation and fire protection requirements (30 CFR 57), to be appropriate guidelines for ensuring the safety of persons entering the repository.

Recently promulgated regulations under OSHA establish safety guidelines to protect workers from exposure to toxic constituents of hazardous waste (Federal Register, December 19, 1987, pp. 45654-45675). The OSHA requirements are applicable to both surface and subsurface repository operations that result in any potential for worker exposure.

SARA Title III requires facilities with certain chemical types to notify regional authorities on the nature and types of chemicals present and participate in regional response plan activities. These requirements may be applicable to geology repositories.

Compliance with these regulations and other applicable Federal laws may be required before a permit will be issued for the construction and operation of a geologic repository. Some Federal agencies are self-regulated and need not comply with

OSHA, MSHA, and other federal regulations. Descriptions of the specific designs, systems, and procedures employed to achieve compliance and otherwise safeguard human health and the environment are integral components of the Part B submittal.

SECTION 2.0

ADMINISTRATIVE PROCEDURES IN THE PERMITTING PROCESS

This section outlines the activities entailed in applying for and obtaining a RCRA permit for a hazardous waste management facility. An understanding of these procedures will enable applicants to expedite the permitting process.

Facilities that store or dispose of hazardous waste in geologic repositories must apply for and obtain a RCRA permit (unless a UIC permit will operate as a RCRA permit-by-rule). The application for a RCRA permit consists of two parts, Part A and Part B. Owners and operators of certain facilities (i.e., those in existence before November 19, 1980), were required to submit Part A applications by November 19, 1980, upon which they automatically gained interim status standing that allows continued operation of the facility until final administrative action is taken on the Part B permit. Owners and operators of new facilities must submit both Part A and Part B at least 180 days before the planned initiation of physical construction. Construction cannot commence until a permit is issued.

2.1 Coordination With States

EPA administers the RCRA permit program unless a state seeks and obtains formal "authorization" to administer the program in lieu of EPA. Currently, because of HSWA, EPA and states may be jointly administering the RCRA permit program for an interim period. Thus, each state's role in the permitting process varies according to the status of its authorization to administer the Federal hazardous waste permit program. Unless granted an extension, RCRA regulations require authorized states to modify their programs to adopt Subpart X regulations by July 1, 1989. However, the effective date for RCRA authorization of the state to issue Subpart X permits in lieu of EPA will be at least several months after July 1, 1989. Applicants should familiarize themselves with the state's permitting process and be aware that EPA permit

writers will be communicating with the State Agency at appropriate stages in the permit process.

2.2 Submitting RCRA Permit Applications

Applicants should contact their EPA Regional Office to obtain the forms and other applicable information prior to completing the permit applications. These include:

- Part A application forms
- Copy of Part 264 and Part 270 Regulations
- Notice of applicants' right to claim confidentiality
- Notice of right to question EPA Regional staff about application requirements
- Names and phone numbers of appropriate contacts including State authorities
- Information on the number of copies of the applications required and location where application should be filed.

The Agency strongly recommends that the applicant contact the EPA Regional Office in the early stages of preparing the Part B application to ensure a clear understanding of what information is required. Consultants or staff responsible for application preparation should participate in these joint meetings and visits, since they provide an opportunity to discuss the application and facility requirements necessary for the facility to be permitted. Depending on the depth and complexity of the issues, the EPA or the applicant may find it useful to schedule conferences or periodic meetings. These preliminary contacts can facilitate the permitting process by identifying problems early and enabling their timely resolution.

2.3 Claims of Confidentiality

At the time of submittal, applicants for a RCRA permit may assert a claim of business confidentiality for proprietary information included in the application. General EPA regulations governing claims of confidentiality are found in 40 CFR 2. Specific provisions for claims of confidentiality submitted with permit applications are found in 40 CFR 270.12.

Applicants should limit their requests for confidential treatment to such material that, if released, is likely to cause substantial harm to the competitive position of their respective companies. Claims of confidentiality should not be asserted for information that is reasonably obtainable without the applicant's consent (for example, standard engineering designs). A claim of confidentiality for the entire permit application is likely not justifiable and such claims may be rejected.

To facilitate the review and revision of permit applications, confidential materials should be bound separately from nonconfidential application information and their cover pages appropriately marked to allow ready identification. To aid in review, complete cross-reference notation should be included in the nonconfidential portions of the application to direct the reviewer to specific pages in the confidential binders. Similarly, notations should be made in the confidential binder(s) as to the portions of the application to which each page or group of pages apply.

2.4 EPA's Review of Part A and Part B Applications

RCRA permit application and issuance procedures are generally found in 40 CFR Part 121. When the EPA Regional Office receives a RCRA permit application, it reviews the application for administrative and technical completeness (see Figure 2-1). The completeness review should take 60 days for existing facilities and 30 days for new ones (40 CFR 124.3(c)). If the application is incomplete, the EPA will request the missing information through a Notice of Deficiency (NOD) letter. This letter details the information needed to complete the application and specifies the date for submission of these data.

The Agency will issue a warning letter to accompany the NOD requiring submission of the necessary information within a specified additional period of time. If the applicant receives a Notice of Deficiency and responds with additional information, each page of this response should fully identify the portion of the original application to which it applies. When the EPA has received all the necessary information, it will notify the applicant in writing that the application is complete.

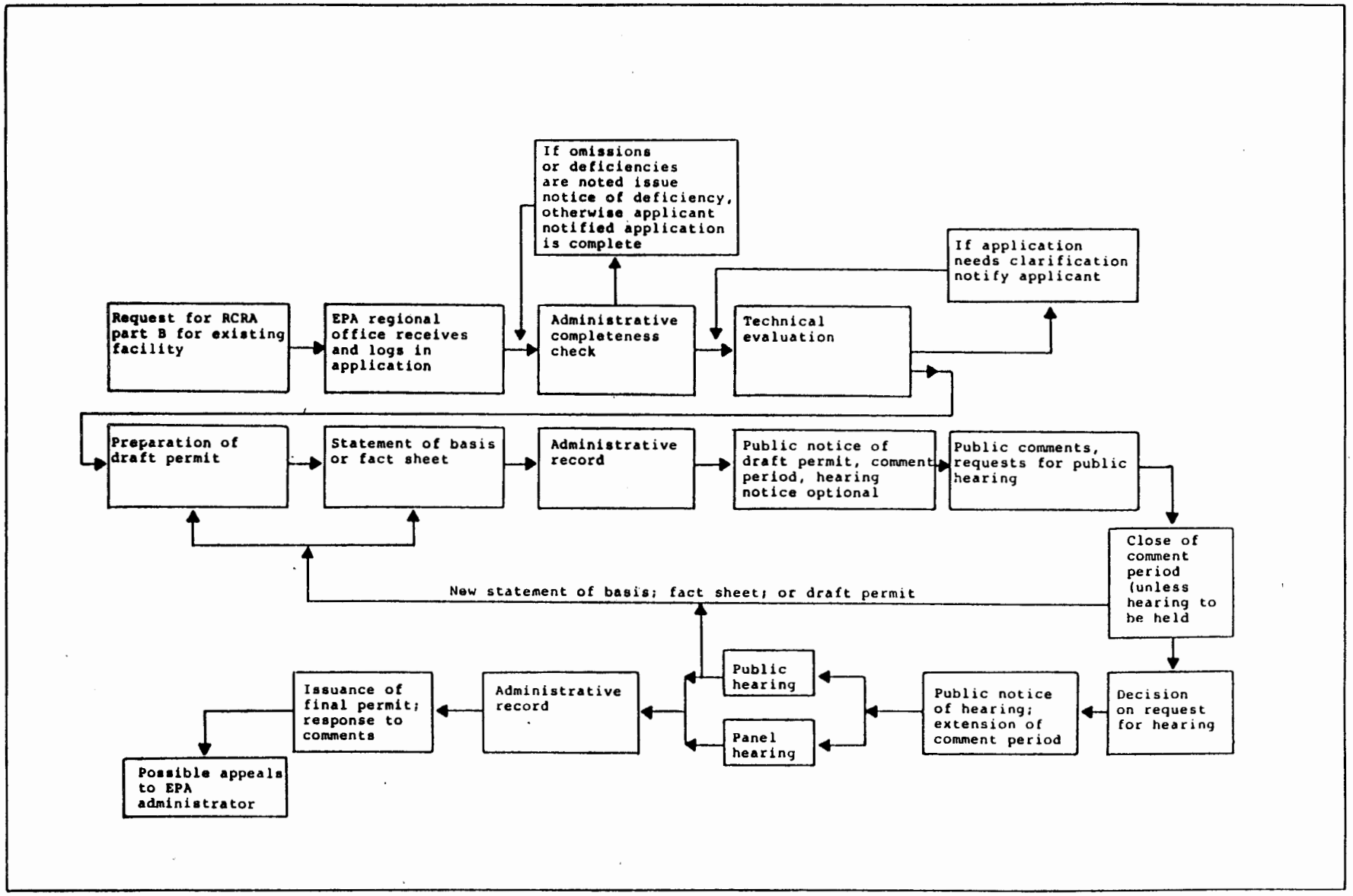

FIGURE 2–1: Flow Diagram of the RCRA Permitting Process

The EPA then performs a technical review of the application to determine whether the facility has satisfied the requirements of the standards promulgated under 40 CFR 264, and should be granted a RCRA permit. The technical review may also result in the need for additional information from the applicant.

2.5 Draft RCRA Permits and Permit Denials

Upon completion of the technical review, the EPA Regional Administrator tentatively decides whether to issue or deny a RCRA permit. If the tentative decision is to issue the permit, the EPA regional staff prepares a draft permit for public review.

The draft RCRA permit specifies all the limitations, requirements, and conditions the facility would have to meet. The Regional Office also prepares a fact sheet or a statement of basis, which explains in simple language each condition included in the draft permit and the reasons for each condition.

A permit may be denied for the following reasons:

- The facility cannot meet the requirements of the standards set forth in 40 CFR 264.
- Activities at the facility would endanger human health or the environment.
- An applicant is believed to have not fully disclosed all relevant facts in the application or during the RCRA permit issuance process.
- An applicant has misrepresented relevant facts at any time.
- The application did not fully meet the requirements of 40 CFR 270.

If the Regional Administrator tentatively decides to deny a RCRA permit, a notice of intent to deny a permit is prepared. This notice is considered a type of draft permit and follows the same procedures as any draft permit under 40 CFR Part 124. These procedures include preparation of a statement of basis or fact sheet containing reasons supporting the tentative decision to deny the permit, public notices of the

denial, acceptance of comments, a possible hearing, preparation of a final decision, and possible receipt of a request for appeal.

2.6 Public Notice, Comments, Informal Public Hearings, Panel Hearings

All draft RCRA permits are subject to public notice, public comments, and public hearings, if requested. Public notice provides interested persons a minimum of 45 days to comment on the draft permit. Persons interested in commenting on the permit may contact the state or regional EPA office to obtain a copy. If written opposition to the Agency's intent to issue a permit and a request for a hearing are received during the comment period, a public hearing may be held. Notification of the hearing is issued at least 30 days prior to the scheduled date, and the public comment period is extended until the close of the public hearing.

2.7 Final Permits

After the close of the public comment period (which includes the public hearing period), the Regional Office either prepares and issues a final RCRA permit of denies the permit application. In either case, the applicant, those submitting written comments, and those requesting notification will be so notified, including information regarding appeal procedures. Normally, RCRA permits become effective 30 days after the date of the public notice of final permit decision unless a later date is specified in the permit or administrative review is requested under 40 CFR 124.15(b). At the time the final RCRA permit is issued, the Regional Office also issues a response to any significant public comments received and indicates any provisions of the draft permit that have been changed and the reasons for the changes. The response to comments becomes part of the administrative record.

2.8 Appeal to the EPA Administrator

Persons who submitted comments on the draft RCRA permit or participated in any public hearing are allowed 30 days after the final permit decision to file a notice of appeal and a petition for review with the EPA Administrator in Washington, D.C. Persons who did not participate are allowed to file an appeal on a narrower basis, 40

CFR 124.19(a). The Administrator will review and then grant or deny the petition within a reasonable time. If the Administrator decides to conduct a review, the parties are given the opportunity to file briefs in support of their positions. Within the 30 day period, the Administrator may, on his/her own motion, decide to review the decision to grant or deny a hearing. The Administrator then notifies the parties and schedules a hearing. On review, the Administrator has several options regarding the final decision. It may be summarily affirmed without opinion, modified, set aside, or remanded for further proceedings. This petition for review is a prerequisite for judicial review of the Administrator's final decision. Details of appeals of RCRA permits are found in 40 CFR 124.19.

SECTION 3.0

PERMIT APPLICATION FORMAT AND CONTENT

The general content of RCRA permit applications is specified in 40 CFR 270.13 and 270.14. The Part B application content requirements unique to miscellaneous units, including geologic repositories, are contained in 40 CFR 270.23. This section summarizes the elements of permit applications common to all units and identifies the additional information required of repositories.

The regulations in 40 CFR do not identify a specific format for presenting information in the Part B application. In this section, we describe a suggested approach to organizing the application that has been demonstrated to be effective and is utilized by most states and EPA Regional offices. However, prior to preparing an application, state and/or EPA staff should be contacted to determine if a format differing from the one presented is desired. State and EPA permit writers will typically be able to provide application outlines containing significantly more detail than is presented in this section.

3.1 Application Presentation

Several methods for presenting the permit application information have been found to improve the efficiency of the review process while facilitating any required application revisions. These include:

- Organize the application by sections in a 3-ring binder.
- Number the pages in each section independently from other sections (e.g., B-1, B-2, etc.).
- Place a header on each page of the application containing the revision number; the initial submission should be labelled "Revision 0."

- As application information is revised, submit only those pages or application sections that have changed, labelling the revised pages accordingly (e.g., Revision 1, Revision 2, etc.)

It is suggested that these or comparable methods be employed to simplify the permitting process.

3.2 Application Format and Content

It is suggested that application information be organized into the following broad categories:

A. Part A Application
B. Facility Description
C. Waste Characteristics
D. Process Information
E. Groundwater Monitoring
F. Procedures to Prevent Hazards
G. Contingency Plan
H. Personnel Training
I. Closure and Post-Closure Requirements
J. Corrective Action for Solid Waste Management Units
K. Other Federal Laws
L. No-Migration Petitions
M. Exposure Information Reports
N. Part B Certification.

The remainder of this section provides a brief description of the suggested content of each of the above application sections. Included in these descriptions are discussions of the information required of all RCRA facilities and the information requirements unique to repositories.

3.2.1 Part A Application

The Part A application consists of several pages of forms providing general information concerning facility location, ownership, wastes managed, waste management units, and unit capacities. The forms are the same for all facilities. Copies of the forms and instructions for their completion can be obtained from any of the EPA Regional offices listed in Section 12 of this manual.

3.2.2 Facility Description

This section of the application presents a general description of operations conducted at the facility and the sources of the wastes managed as well as detailed descriptions of the facility location. Traffic patterns of hazardous materials to and from facilities, as well as within the facility, must be provided and traffic controls utilized at the facility described in this section. Locational information common to all hazardous waste management facilities that must be provided includes waste unit siting relative to floodplains and seismically active areas, demonstrations of flood protection for units located within the 100-year floodplain, and topographic maps showing relevant surface features.

Geologic repositories should provide additional detailed siting information demonstrating the suitability of the selected site. Required information unique to repositories, described in Section 5 of this manual, includes descriptions of regional and local geology and ground-water and surface water hydrology.

3.2.3 Waste Characteristics

The application must provide detailed characteristics of the wastes to be managed in the repository and a waste analysis plan describing the procedures for routinely verifying waste compositions. Section 7 of this manual identifies waste characteristics that should be included in the waste analysis plan for wastes managed at geologic repositories.

3.2.4 Process Information

This section of the application describes the design and operation of hazardous waste management units at the facility. Included are detailed design drawings of the units and related control equipment, operating procedure descriptions, and unit capacities. Section 6 discusses the specific information required for geologic repositories, including demonstrations of structural stability, hydrologic isolation, repository ventilation, designs to provide fire protection, and repository access. Section 8 of this manual describes the monitoring programs that may be required at repositories. Analyses of the need for such monitoring and descriptions of the systems to be employed to meet those needs (other than ground-water monitoring) should be included in the Process Information section of the application.

3.2.5 Ground-Water Monitoring

Land treatment, storage, and disposal facilities required to monitor ground water must provide detailed descriptions of the equipment and procedures to be employed to meet those requirements. Section 8 discusses the need for ground-water monitoring at repositories and identifies special considerations for facilities at which ground-water monitoring is required.

3.2.6 Procedures to Prevent Hazards

All facilities must provide adequate security, maintain appropriate emergency equipment and communication systems, provide safeguards necessary to properly manage ignitable and reactive wastes, and employ routine inspection procedures to assure the continued safe operation of the facility. The preparedness and prevention procedures unique to repositories that should be addressed in this section of the application are described in Sections 6 and 9 of this manual.

3.2.7 Contingency Plans

Contingency plans, required for all hazardous waste management facilities, must describe the procedures to be implemented in responding to fires, explosions, and waste releases. Section 9 identifies suggested emergency equipment and procedures unique to

repositories, including the provision of emergency equipment in underground areas and repository evacuation procedures.

Under SARA Title III, the facilities managing hazardous waste in repositories may be required to prepare facility emergency response plans and participate in regional emergency response planning activities. The RCRA contingency plan and SARA emergency response plans will share similarities and may under certain circumstances be one in the same document.

3.2.8 Personnel Training Plans

Personnel training appropriate to employee responsibilities and potential site hazards must be provided in accordance with an established training program. Employee training programs for geologic repositories should reflect the operating, safety, and emergency measures described in Sections 6 and 9 of this manual.

3.2.9 Closure and Post-Closure Plans/Financial Requirements

The closure and post-closure plans must describe how a facility will be closed at the end of its operating life and maintained thereafter. Guidance concerning recommended closure designs for repositories and demonstrations to be included in the closure and post-closure plans is provided in Section 10.

Permit applications must also provide documentation showing the availability of financial resources sufficient to implement the closure and post-closure care plans as well as documentation of compliance with applicable liability requirements for sudden and non-sudden accidental occurrances.

3.2.10 Corrective Action

In accordance with 3004(u) of the Hazardous and Solid Waste Amendments of 1984, corrective action for past and ongoing environmental releases of hazardous constituents from solid waste management units at facilities seeking a RCRA permit for treatment, storage, or disposal of hazardous waste must be provided for in the permit when issued.

Hence, the permit application must contain information related to the assessment of any releases from solid waste management units. Although some geologic repositories will be constructed at new facilities, this permitting requirement must be met.

3.2.11 Other Federal Laws

Permit applications will generally include a statement attesting to the facility's compliance with all applicable Federal laws. No requirements unique to repositories have been identified that require modification of the procedures normally employed in providing this demonstration.

3.2.12 No-Migration Petitions

Although not required, it is suggested that copies of petitions for no-migration variances from the requirement to pretreat wastes that fail to meet BDAT performance levels be included in the Part B application. Section 4 discusses the general content of no-migration demonstrations and Sections 5 through 10 provide additional details concerning petition requirements.

3.2.13 Exposure Information Reports

An assessment of the potential exposure pathways associated with the operation of land disposal units is required in the permit application. Section 11 describes the content of the report and discusses features of repository siting, design, and operation that should be considered in preparing the assessment.

3.2.14 Certification

All permit applications must be accompanied by a certification, signed by a duly authorized representative of the organization, attesting to the validity of the information contained in the application. The required wording of this certification is identical for all facility types.

SECTION 4.0

NO-MIGRATION VARIANCES

Under the Hazardous and Solid Waste Amendments of 1984 (HSWA), RCRA sections 3004(d), (e), (f), and (g) prohibit land disposal of all listed and characteristically hazardous wastes unless they are first treated to a level set under 3004(m). Wastes included in the EPA's land disposal prohibitions will have to be treated to meet levels based on best demonstrated available technology (BDAT) unless a no-migration variance is obtained. Prohibited wastes that fail to meet the performance level cannot be stored in a geologic repository (unless storage is for the purpose of accumulating sufficient quantities to facilitate proper recovery, treatment, or disposal) without a no-migration variance. The land disposal prohibitions become effective on the dates indicated in Table 4.1.

A complete schedule of the land disposal prohibitions can be found in 40 CFR 268.10 through 268.13. These prohibitions apply to all hazardous wastes identified under RCRA as of November 8, 1984. For hazardous wastes identified in 40 CFR 261 after that date, EPA must make prohibition determinations within 6 months of the date of listing or identification of the new hazardous wastes. However, the statute does not impose an automatic prohibition on land disposal if EPA misses a deadline for any newly listed or identified waste.

4.1 No-Migration Definition

A no-migration variance is a formal decision that can be rendered by the EPA to allow the disposal of specific, prohibited wastes not meeting the treatment standards established by EPA at a specific land disposal unit. Facility owners and operators may elect to petition EPA for a no-migration variance from the requirement to treat wastes prior to placement in a geologic repository that fail to meet performance levels.

Table 4-1. Effective Dates of Land Disposal Prohibitions

Date	Prohibited Waste
November 7, 1986	Solvents
July 8, 1987	California List*
August 8, 1988**	At least one-third of all other listed wastes
June 8, 1989**	At least two-thirds of all other listed wastes
May 8, 1990	All remaining listing wastes and all characteristic wastes

* Based on regulations developed by the California Department of Health Services for hazardous waste land disposal restrictions in the state of California.

** EPA is currently developing standards for these listed wastes. A permitted new facility would be able to receive untreated wastes until May 1990.

Obtaining a no-migration variance does not exempt a facility from the requirement to obtain a RCRA permit. The EPA has adopted the statutory language requiring anyone pursuing a no-migration variance to demonstrate "...to a reasonable degree of certainty that there will be no migration of hazardous constituents from the disposal unit or injection zone for as long as the waste remains hazardous."

4.2 Content of No-Migration Petitions

Prior to preparing a petition, petitioners are strongly encouraged to meet with EPA to determine the nature and extent of the information that must be included in the

petition. The principal components expected to be required in all no-migration petitions for geologic repositories include:

- Waste descriptions
- Facility descriptions and operating plans
- Repository and waste monitoring plans
- Site characterizations
- Waste mobility modeling
- Environmental risk assessment
- An analysis of infrequent and uncertain events
- Quality assurance and control plans.

A more detailed checklist of petition requirements is presented in Exhibit 4-1, at the end of this section, illustrating the nature and complexity of the information that may be required in petitions.

EPA's publication "No-Migration Variances to the Hazardous Waste Land Disposal Prohibitions: A Guidance Manual for Petitioners" which should be available in early 1989 should be used as a starting point for assessing the level of detail that will be required for each element of the petition. Because the nature and level of detail of information required in the petition will be very site-specific, the Agency recommends that petitioners meet with EPA staff prior to preparation of the petition to assure that appropriate demonstrations are included in the petition.

No-migration petitions must clearly demonstrate that disposal in the repository as proposed is protective of human health and the environment. As stated previously, this requires showing, to a reasonable degree of certainty, that there will be no migration of hazardous constituents from the unit for as long as the wastes remain hazardous. The Agency anticipates that such demonstrations will be based on one or more of the following factors:

- Repository setting relative to ground water

- Hydrologic isolation achieved by repository location and engineered features
- Immobility of the wastes as placed in the repository.

No-migration variances may be allowed in cases where the repository setting will effectively preclude releases to the environment. For example, repositories in geologic formations that are not hydrological connected to existing or potential underground sources of drinking water (USDWs) appear to be suitable candidates for variances, provided the petition can demonstrate the repository's hydrologic isolation.

Repositories located in geologic formations that are in contact with potential or existing drinking water sources may also be suitable no-migration candidates. For such facilities, the Agency would expect the no-migration petition to provide a rigorous demonstration of the integrity, stability, extent, and homogeneity of the host formation. In other instances, facilities may demonstrate that waste constituents will not migrate past unit boundaries. Such demonstrations would require that hazardous constituents in the waste be shown to be immobile under the chemical and physical conditions that may be encountered in the repository.

For example, placement of wastes in a repository located in a geologic formation that is in contact with a USDW may be acceptable, provided the hazardous constituents present in the waste cannot be mobilized by groundwater and migrate outside the repository. Such demonstrations would require a detailed understanding of the geothermal and geochemical properties of surrounding groundwater and its ability to mobilize the hazardous constituents present in the water.

Migration to air, surface water, and soil must be considered in the petition. The potential for migration via pathways other than ground water is anticipated to be greatest during the active life of the repository. No-migration petitions must clearly show that releases to air, surface water, and soil will also be prevented through proper facility design, construction, and operation.

4.3 Petition Review Process

EPA anticipates that many facilities will submit no-migration petitions concurrent with their RCRA Part B permit application. No-migration petitions should be submitted directly to the EPA Administrator in Washington, D.C. for review by EPA Headquarters' staff. Although Part B applications are submitted to and reviewed by state and/or EPA Regional offices, EPA will coordinate such concurrent reviews to assure the continuity of the review processes.

EPA's review of no-migration petitions is very similar to the review process for Part B applications discussed in detail in Section 2.4 of this manual. The principal elements of the review are:

- Completeness check
- Technical evaluation
- Public notice of proposed decision
- Receipt and evaluation of public comments
- Publication of decision and response to comments in Federal Register.

Unlike the Part B process, EPA will not hold public hearings as part of the no-migration petition review process.

4.4 No-Migration Variance Timetables

A no-migration variance only becomes effective after EPA reviews the petition, solicits public comments, and publishes a final determination in the Federal Register. Variances will be effective only after issuance; submittal of a petition will not exempt a facility from complying with applicable land disposal prohibitions. Variances will be valid for up to 10 years, but not longer than the term of the facility's RCRA permit. The variance will automatically expire upon termination or denial of the RCRA permit, or when the volume of waste for which the variance was issued is reached.

In addition, unsuccessful petitioners will be provided advanced notice of EPA's intent to deny waivers and will be afforded the opportunity to withdraw petitions prior

to public notice of EPA's decision. Figure 4-1 illustrates the no-migration petition review process.

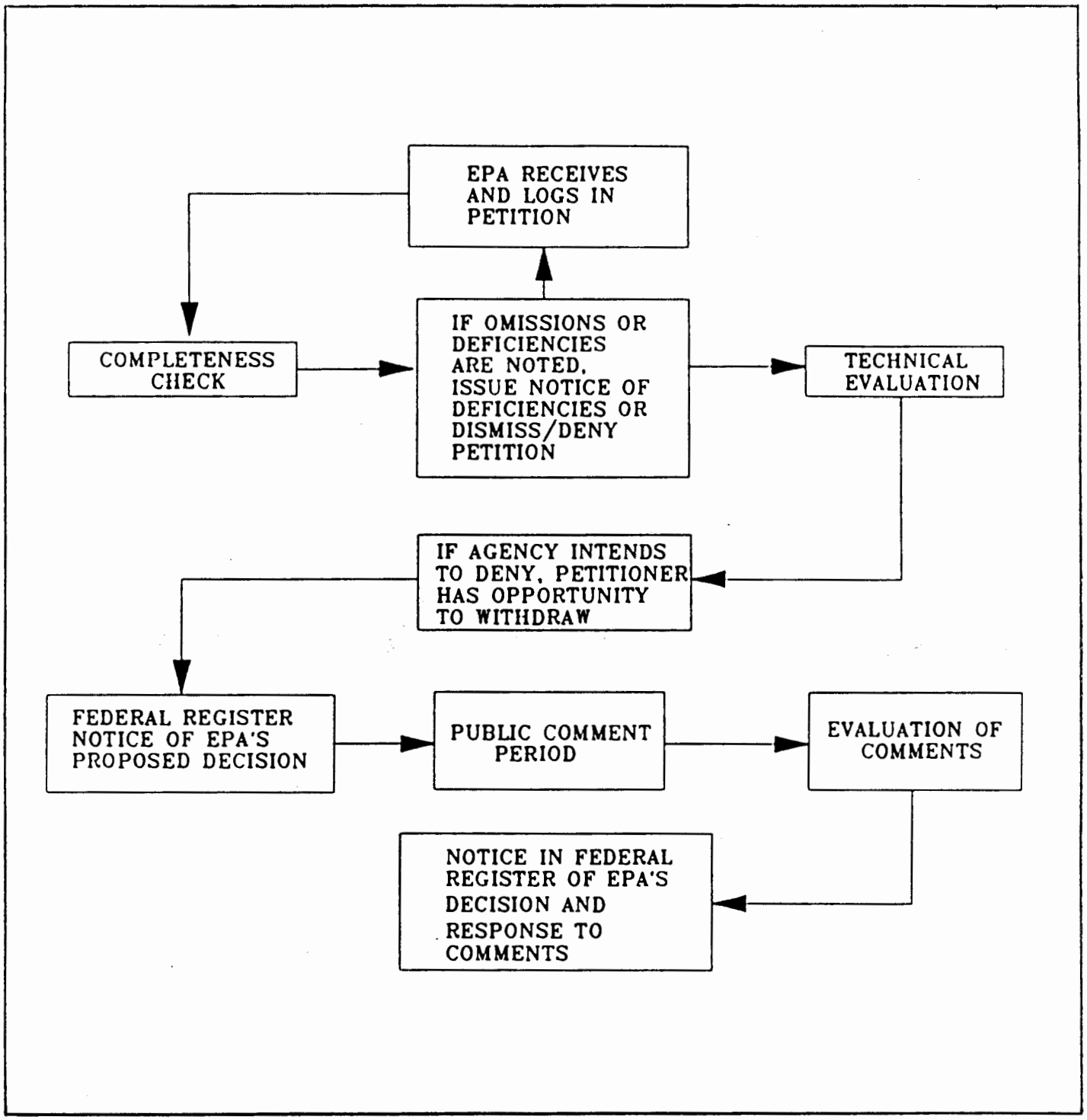

FIGURE 4–1: EPA's Petition Review Process

EXHIBIT 4-1

CHECKLIST OF INFORMATION NEEDS

The following informal checklist is a comprehensive, but not all-inclusive, list of information needs. Individual petitions may require more or less information than that presented below. The level of detail required will depend on site-specific factors.

Facility Description

- _ Name of facility
- _ Address of facility
- _ Name of owner/operator
- _ Proper Signatory
- _ Anticipated period of operation
- _ Status of RCRA permit application
- _ Location map
- _ Detailed site plan
- _ Aerial surveys
- _ Advantages/disadvantages of location
- _ Evaluation of storage/disposal units
  - _ Design objective
  - _ Design criteria
  - _ Design performance projection
  - _ Materials specifications
  - _ Detailed drawings and specifications
  - _ Documentation of unit construction
  - _ Documentation of unit operation
- _ Closure Plans
- _ Post-Closure Plans
- _ Cover Design
- _ Design QA/QC Demonstration (testing & inspection)
- _ Facility Operation QA/QC Demonstration

Waste Characteristics

- _ Waste type by name
- _ Processes that produced the waste
- _ Hazardous properties
- _ Physical Characteristics
- _ Chemical characteristics
- _ Biological properties
- _ Constituents and percentage of constituents
- _ Analytical methods and results
- _ Projection of waste volume to be disposed
- _ Quantity of banned waste being disposed
- _ Frequency of disposal
- _ Period of time waste has been and will be disposed
- _ Handling procedures
- _ Waste treatment before, during and after disposal
- _ Liquid phase mobility information
- _ Gas/particulate mobility
- _ Solid phase mobility
- _ Dust generation potential
- _ Gas-liquid phase interactions
- _ Persistence/degradation potential in unit and environment
- _ Waste information QA/QC demostration

Waste Transformation and Immobilization

- _ Estimation of quantity and quality of leachate formation
- _ Waste/waste compatibility, interaction, reaction products
- _ Waste/liner compatibility
- _ Assessment of biodegradation potential
- _ Assessment of oxidation/reduction potential
- _ Assessment of volatilization potential

EXHIBIT 4-1 (Continued)

CHECKLIST OF INFORMATION NEEDS

_ Assessment of immobilization due to insolubility
_ Assessment of photodegradation potential
_ Assessment of immobilization due to hydrolysis
_ Assessment of immobilization due to adsorptivity

Site Characterization

_ Surficial geology and soils (regional and local)
  _ Topography
  _ Soil Types
  _ Soil properties
  _ Depth to bedrock
_ Bedrock geology (regional and local)
  _ Stratigraphy and lithology
  _ Seismic activity of area
  _ Assessment of ground motion potential and degree
  _ Geologic cross sections
  _ Degree of bedrock faulting and fracturing
  _ Rock characterization
_ Groundwater hydrology (regional & local)
  _ Water table map
_ Seasonal variations in the winter table
  _ Identification of all aquifer and aquitards
  _ Characterization of all aquifers
  _ Vertical and horizontal hydraulic conductivity
  _ Aquifer interconnection
  _ Description of groundwater monitoring program
  _ Monitoring QA/QC documentation
_ Surface water hydrology
  _ Location of all watersheds
  _ Map of drainage patterns
  _ Map of floodplain
  _ Flood Analysis
_ Meteorology/climatology
_ Wind rose
_ Precipitation records
_ Temperature records
_ Relatiave humidity records
_ Maps of storm tracks

Water Mobility

_ Unsaturated zone soils
  -- Soil sampling
  _ Soil testing
_ Unsaturated zone physical properties
  _ Volumetric water content
  _ Degree of water saturation
  _ Bulk density
  _ Pressure potential
  _ Relative permeability
  _ Unsaturated hydraulic conductivity
  _ Water capacity
  _ Water diffusivity
_ Leachate characteristics affecting mobility
  _ Leachate characterization
  _ Leachate interactions
_ Secondary leachate evaluation
_ Evaluation of transport mechanisms
_ Evaluation of fate of contaminants in unsaturated zone
_ Vapor concentration of constituents at the source
_ Vapor pressure of constituents
_ Solubility data for constituents
_ Activity coefficient
_ Henry's Law constant
_ Background measurements for air

Modeling Evaluation

_ Verify model accounts for all transport mechanisms

EXHIBIT 4-1 (Continued)

CHECKLIST OF INFORMATION NEEDS

- _ Model is appropriate for petitioned waste
- _ Data input is accurate and verified
- _ Model has been tested under field conditions
- _ Model accuracy over long time periods
- _ Limitations of model
- _ Model inputs adequately documented
- _ Model outputs appropriate and reasonable

Environmental Risk Assessment

- _ Identification of all exposure pathways and routes
- _ Identification of all potential receptors
  - _ Wildlife
  - _ Vegetation
  - _ Identification of sensitive or endangered species
- _ Assessment of bioaccumulation through the foodchain

Uncertainty Analysis

- _ Natural Events
  - _ Climatic fluctuations
  - _ Glaciation
  - _ Stream erosion
  - _ Magmatic activity
  - _ Epeirogenic displacement
  - _ Orogenic diastrophism
  - _ Diagenesis
  - _ Static fracturing
  - _ Dissolution
  - _ Sedimentation
  - _ Flooding
  - _ Undetected features (i.e., faults, la va tubes)
  - _ Meteorites
  - _ Fires
  - _ Hurricanes
  - _ Tornados
  - _ Earthquakes
  - _ Ground motion
- _ Waste/facility-induced events
  - _ Thermal effects
  - _ Chemical effects
  - _ Mechanical effects
  - _ Modification of hydrologic regime
- _ Human-induced events
  - _ Improper design or operation
  - _ Past intrusions
  - _ Future intrusions
  - _ Intentional intrusion
  - _ Perturbation of ground-water system
  - _ Biosphere alterations

SECTION 5.0

FACILITY LOCATION AND SITING REQUIREMENTS

This section describes location and siting considerations for geologic repositories. Included in this discussion are:

5.1 General Facility Standards
5.2 Geology
5.3 Hydrology

Much of this information is technical and many terms may be unfamiliar. Therefore, a glossary of geologic terms used in the following discussions is provided at the end of this section (Exhibit 5-1). It is strongly recommended that a qualified geologist be employed to provide the technical expertise necessary to prepare the geologic sections of the permit application.

5.1 General Facility Standards

General location standards applicable to all facilities seeking a RCRA permit also apply to geologic repositories permitted under Subpart X. These standards are found in 40 CFR 264.18 and include flood and seismic standards. Guidance for meeting these standards and the application information requirements is found in Permit Writers' Guidance Manual for Hazardous Waste Land Storage and Disposal Facilities, Phase I Criteria for Location Acceptability and Existing Applicable Regulations and in Permit Applicants' Guidance Manual for the General Facility Standards of 40 CFR 264. These documents provide guidance applicable to both surface and subsurface portions of repositories.

Additional technical guidance concerning facility siting relative to ground water is provided in the EPA document Criteria for Identifying Areas of Vulnerable Hydrogeology Under the Resource Conservation and Recovery Act Statutory Interpretive Guidance - Guidance Manual for Hazardous Waste Land Treatment, Storage and Disposal Facilities. That document supports the statutory provisions of RCRA Section 3004(o) that require EPA to issue technical guidance on disposal unit siting relative to areas of vulnerable hydrogeology. It is particularly applicable to geologic repositories and should be consulted during the facility siting efforts.

5.2 Geology

The stability of the repository structure and the degree of waste isolation are directly affected by the geology at the site. The regional and local geologic setting must be fully characterized in order to assess the performance of the repository. The principal factors to be considered in the geologic characterization of the site include:

- Stratigraphy
- Structure and Tectonics
- Mineralogy/Geochemistry
- Rock Characteristics
- Natural Resources.

Each of these subject areas are discussed in detail below with regard to (1) the type of information/data to be collected, (2) characterization methods, (3) limitations to the characterization, and (4) presentation of data and are summarized in Table 5-1.

5.2.1 Stratigraphy

Stratigraphic information provides the foundation for a three-dimensional view of the geologic repository. Quantitative predictions of the repository performance can be derived from this information.

Property	Information Needs	Characterization Methods	Limitations to the Characterization	Presentation of Data
Stratigraphy	- Lateral and vertical extent of unit. - Nature of the contacts between units. - Other stratigraphic discontinuities.	- Review existing geologic maps/ cross-sections. - Field mapping. - Surface geophysical survey.	- Structural complexity of the region. - Poor structural/chemical contrast between units. - Limited number of geophysical or borehole sampling points.	- Geological maps with regional strike/dip, surface elevations, major structural features. - Site geological map at scale of about 1:5000-1:12,000. - Cross-sectional maps, depth interval of about 50-100 feet to a sufficient depth: o sedimentary facies o structural features o petrological facies (igneous/meta rocks) - Isopach maps with about 10 foot contour intervals and each stratigraphic member.
Structure and Tectonics	- Structural discontinuities: o Faulting and folding of regional and local area. o Past tectonic activity. o Regional plate tectonics. o Present temperature, confining pressure conditions, pore fluid pressures. o In-situ state of stress.	- Field mapping. - Drill core and sampling. - Geophysical sampling. - Remote image interpretation. - Hydraulic fracturing (for in-situ stress measurements).	- Small scale variability of subsurface structures. - Limitations on the number of geophysical or borehole sampling points.	- Geologic maps at scale of about 1:5000-1:12,000 o structural and tectonic features o rock outcrops patterns o structural attitudes at exposed rock units. - Structural fence diagrams. - Rose diagrams or stereonets for surface and drill-core fracture orientations. - Core analysis and fracture histograms for each drill hole. - Detailed text and tables describing all observed structural features, their mode of formation, distribution, and relation to the sites containment qualities, and the methods by which they were mapped and analyzed.

TABLE 5-1: Geologic Information for Repository Performance Analysis

Property	Information Needs	Characterization Methods	Limitations to the Characterization	Presentation of Data
Mineralogy/Geochemistry	- Mineral content and composition. - Heterogeneity of rock composition. - Presence of fluid inclusions, fracture filling, and alteration zones. - Rock textural features.	- Laboratory studies. o petrographic analysis o x-ray diffraction o electron microprobe analysis - Geophysical sampling.	- Solution-mined o Limitations on the number of borehole sampling points near repository site. - Existing mine o poor definition of the formation away from the mine itself.	- Graphics and figures for geophysical and rock coring data. o graphs for mineral component percentages o photos of petrographic thin-sections o figures for microprobe analysis o Geologic cross-sections for location of fluid or gas pockets.
Rock Characteristics	- Geomechanical parameters o Density, porosity and water content. o Plasticity o Undrained shear strength o Compressibility o Swelling potential o Angle of internal friction o Maximum low strain shear modules o Soil corrosiveness	- Laboratory tests o triaxial/uniaxial compressive load test o creep test o stress-strain test o strain rate test o direct shear test - In-situ tests o in-situ stress tests o in-situ creep tests	- Inability to accurately recreate in-situ conditions. - Poor understanding of in-situ stress mechanisms. - Uncertainties in laboratory values for various parameters.	- Standard stress-strain diagrams should be used. - Creep curves plotted. - Creep measurements plotted versus time. - Detailed text.
Natural Resources	- Number, location, depth and present state of artificial penetrations. - Geologic/hydrogeologic resources o type of resource o accessibility, quality, and present and future demands o mineral rights ownership in the area.	- Literature searches - Visual inspection of site - Geophysical methods	- Quality of records for penetration. - Seismic data may not resolve small-scale features.	- Geologic maps/cross sections for seismic data. - Reports on penetrations/backfilling activities should be provided. - Raw data from geophysical surveys. - Listing of all penetrations through repository formations.

TABLE 5-1: Geologic Information for Repository Performance Analysis (Continued)

5.2.1.1 Information Needs

Information that should be obtained on both a regional and local basis includes the following:

- o A stratigraphic column
- o Lateral and vertical extent of units
- o Orientation of strata (i.e., strike and dip)
- o Nature of the contact between units.

Each of these factors are discussed in detail below, along with examples.

Identifying the different lithologies in the region and local vicinity of the repository sets the stage for further geologic and hydrologic characterization. Rocks are divided into different lithologic units based on rock type (sedimentary, igneous, metamorphic) and general mineralogy. The lithologic terms used to identify rocks of similar origin and mineralogy are, in order of subdivision, Group, Formation, and Member. Lithologies identified in the area should be correlated to the regional Group, Formation, and/or Member (Figure 5-1).

Since different rock types have different structural, mechanical, and chemical properties, their lateral and vertical extent in the stratigraphic column must be defined. A relatively strong, non-porous, unfractured rock unit (or units) that is over 1,000 feet thick and extends laterally for tens to hundreds of miles is likely to provide a higher degree of waste isolation capability over time than one that is only 100 feet thick and surrounded by more pervious or fractured rock. An example of massive and extensive rock units are salt domes, which extend vertically to great depths below the surface and extend laterally from 1 to 50 miles. Limestone and evaporite beds may also have suitable thicknesses of several thousand feet and extend for hundreds of miles. Sedimentary strata can be lenticular and thin laterally, or they may be truncated by new sedimentary facies. Granitic batholiths and plutons are similar in geometry and extent to salt dome intrusives.

ERA	SYSTEM	SERIES	GROUP	FORMATION
CENOZOIC	QUATERNARY			RECENT FLUVIAL AEOLIAN AND LACUSTRINE DEPOSITS
	TERTIARY			OGALLALA AND LACUSTRINE DEPOSITS
MESOZOIC	CRETACEOUS	COMANCHE	WASHITA	
			FREDRICKSBURG	
			TRINITY	
	TRIASSIC		DOCKUM	TRUJILLO (Santa Rosa)
				TECOVAS
PALEOZOIC	PERMIAN	OCHOA		DEWEY LAKE (Quartermaster)
				ALIBATES
		GUADALUPE	ARTESIA (WHITEHORSE)	SALADO - TANSILL
				YATES
				SEVEN RIVERS
				QUEEN-GRAYBURG
			PEASE RIVER	SAN ANDRES (BLAINE)
		LEONARD		GLORIETA
			CLEAR FORK	UPPER CLEAR FORK
				TUBB
				LOWER CLEAR FORK
				RED CAVE
			WICHITA	
		WOLFCAMP		
	PENNSYLVANIAN	VIRGIL	CISCO	
		MISSOURI	CANYON	
		DES MOINES	STRAWN	
		ATOKA	BEND	
		MORROW		
	MISSISSIPPIAN	CHESTER		
		MERAMEC		
		OSAGE		
	ORDOVICIAN	CANADIAN	ELLENBURGER	
	CAMBRIAN		UNNAMED SANDSTONE	
	PRECAMBRIAN			

Explanation

~~~~~~ Unconformable Boundary

-- -- -- Boundary in Dispute

( ) Formation Name in Outcrop

FIGURE 5-1: Stratigraphic Column of the Palo Duro Basin (*Source: EA, Deaf Smith County Site, TX*)
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Determining the orientation (e.g., strike and dip) of bedding in the area of the host repository rock, and defining changes in the orientation, characterizes the general stratigraphic, structural, and tectonic setting of the repository site. Undisturbed sedimentary beds generally will have horizontal or gently dipping strata. However, beds that have experienced compressional tectonic activity may have steeply sloping or folded beds that may vary in strike or dip within the vicinity. Sedimentary strata around salt domes are often gently dipping near the intrusive contact. In general, areas that are extensively deformed (i.e., with abundant folded and faulted formations) are not well-suited to repository development, while those in slightly faulted or undisturbed terrain are better candidates for siting geologic repositories.

The nature of the contacts between lithologies should be characterized in order to assess potential migratory pathways for waste constituents from the repository. Strata that were formed in a continuous depositional environment (i.e., as deep marine sediments) will have conformable or gradational contacts between vertical beds. If the rocks were subaerially exposed at any time, the bedding surface may be marked by erosional irregularities and subsequent strata may form unconformable (irregular) contacts with the eroded strata. Angular unconformities may also occur when rock strata is subjected to a discreet sequence of tilting (during an orogenic event), uplift, erosion, and subsequent deposition of horizontal sedimentary beds. Contacts between sedimentary facies are often jagged and irregular, and result from changing fluvial or marine environments in the same location over time.

5.2.1.2 Characterization Methods

Stratigraphic information can be obtained by reviewing existing geologic maps and supplementing such information with additional field mapping and geophysical surveys. Regional stratigraphic information may be obtained from existing geologic maps and cross-sections developed by the U.S. Geological Survey and/or private firms involved in subsurface exploration in the area. Stratigraphic information may also be obtained from district or state authorities. The MSHA district office may be consulted for geologic information about an existing mine in a mining district. In the case of repository siting in existing mined space, detailed geologic maps and cross-sections

may already be available for the immediate vicinity of the mine. In the case of repository siting in a salt dome to be solution-mined, detailed maps may exist from other oil and gas or sulfur mining activities in the area.

If existing information does not adequately define the local stratigraphic setting at the site, additional field mapping of surface and near surface rock outcrops will be necessary. Any ambiguities about subsurface extent of a lithologic unit or the nature of contact between units must be addressed by rock coring or geophysical methods. Surface geophysical methods (e.g., seismic, electrical) are the preferred method for characterizing subsurface stratigraphy in the immediate vicinity of the repository site as they can generally identify major structural and stratigraphic relationships without penetrating the subsurface environment. However, in some instances, resolution of discrete subsurface sedimentary beds and facies may be poor, due to similar mineral and physical properties of the beds. In these cases, boreholes should be drilled and cored to depths below the waste emplacement elevation, and electrical logs taken to provide additional subsurface structural and stratigraphic information similar to that shown in Figure 5-2. Downhole geophysical methods should also be utilized to further characterize subsurface features. The number of bore holes should be minimized and the borehole locations restricted to areas that are at a sufficient distance from the repository site to ensure the integrity of the repository and host rock.

In the case of repositories to be sited in salt domes, it is recommended that such boreholes be situated at least 500 to 1000 feet from the salt dome boundary. After sampling, these boreholes should be surveyed, their locations recorded, and the holes 100% plugged and capped.

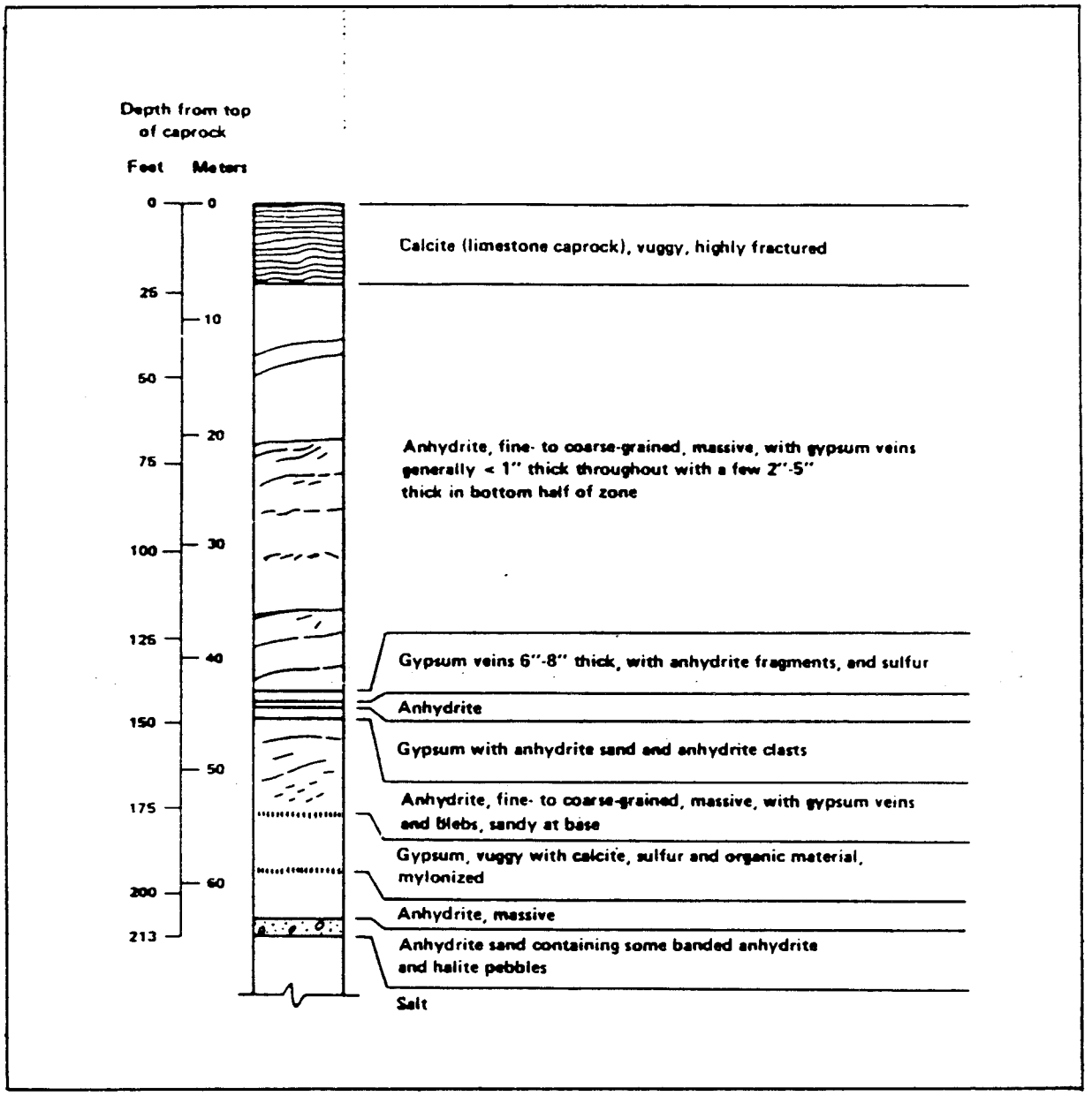


FIGURE 5–2: Caprock Stratigraphy (Source: EA, Richton Dome Site, MS)

5.2.1.3 Limitations to the Characterization

The subsurface stratigraphy at the site cannot always be fully characterized. Factors that may limit the extent of subsurface stratigraphic characterization include:

- Geologic structural complexity of the region
- Poor structural and/or chemical contrast between units (affecting geophysical resolution)
- Limitations on the number of geophysical or borehole sampling points.

Areas that have been intensely folded and faulted are, in general, undesirable settings for a repository due to the likelihood of conduits for migration, which are difficult to characterize. Regardless of the complexity of a region, uncertainties in the subsurface stratigraphic correlation between sampling points are unavoidable. Although uncertainties/limitations exist, repositories can be sited in terrains that are relatively unfaulted and unfractured with a high degree of confidence in the nature of the repository's stratigraphic setting and, hence, the long-term integrity and performance of the facility. Therefore, geophysical surveys and boreholes sampling plans must be developed that, together, maximize the amount of subsurface stratigraphic control and minimize the number of subsurface penetrations in the vicinity of the repository site.

5.2.1.4 Presentation of Data

The format for presenting stratigraphic information depends on site-specific geologic characteristics. However, a combination of maps, cross sections, and text is suggested as the ideal method for all cases. The general level of detail necessary to allow reasonable portrayal of stratigraphic conditions is provided in the following list:

- Geologic maps at a scale of about 1:24,000 showing regional strike and dips of bedding, surface elevations, and major structural features
- Site geologic map at a scale of 1:5000-1:12,000 showing strike and dip of bedding at the site, and important structural features at the site

- Cross-sections at a scale of about 1:24,000 with depth intervals of about 50-100 feet to a sufficient depth to include:

  - Stratigraphic facies
  - Structural features
  - Petrologic facies (igneous and metamorphic rocks).

In the specific case of a salt dome, the suggested depth of mapping is 4000-5000 feet.

- Isopach maps with about 10-foot contour intervals for each stratigraphic member (Figure 5-3)

- Site topographic map (preferably prepared for the permit application by photogrammetric methods) at a scale of 1:5000-1:12,000 and with contours at sufficient intervals to delineate surface features (preferably no greater than 5 feet)

- Stratigraphic columns (Figure 5-4) and correlation fence diagrams (orthogonal at minimum).

Detailed text describing all lithologic units, their mode and time period of formation, geometrical relationships, methods of analysis, and relationship to the site's containment qualities should be provided.

5.2.2 Structure and Tectonics

The geologic information collected for the stratigraphic characterization should identify the major structural regimes and features in the rocks around the repository site. Additional field mapping and geophysical surveys should be performed in order to identify and characterize the structural features and discontinuities, including faults, fractures, folds, and joints that are caused by rock deformation (extensional or compressional tectonics). Characterizing these features provides an idea of past and present tectonic activities at the site that may affect the structural stability and/or the waste isolation capability of the repository. Also, present and future temperature and pressure conditions of the repository rocks should be discussed.

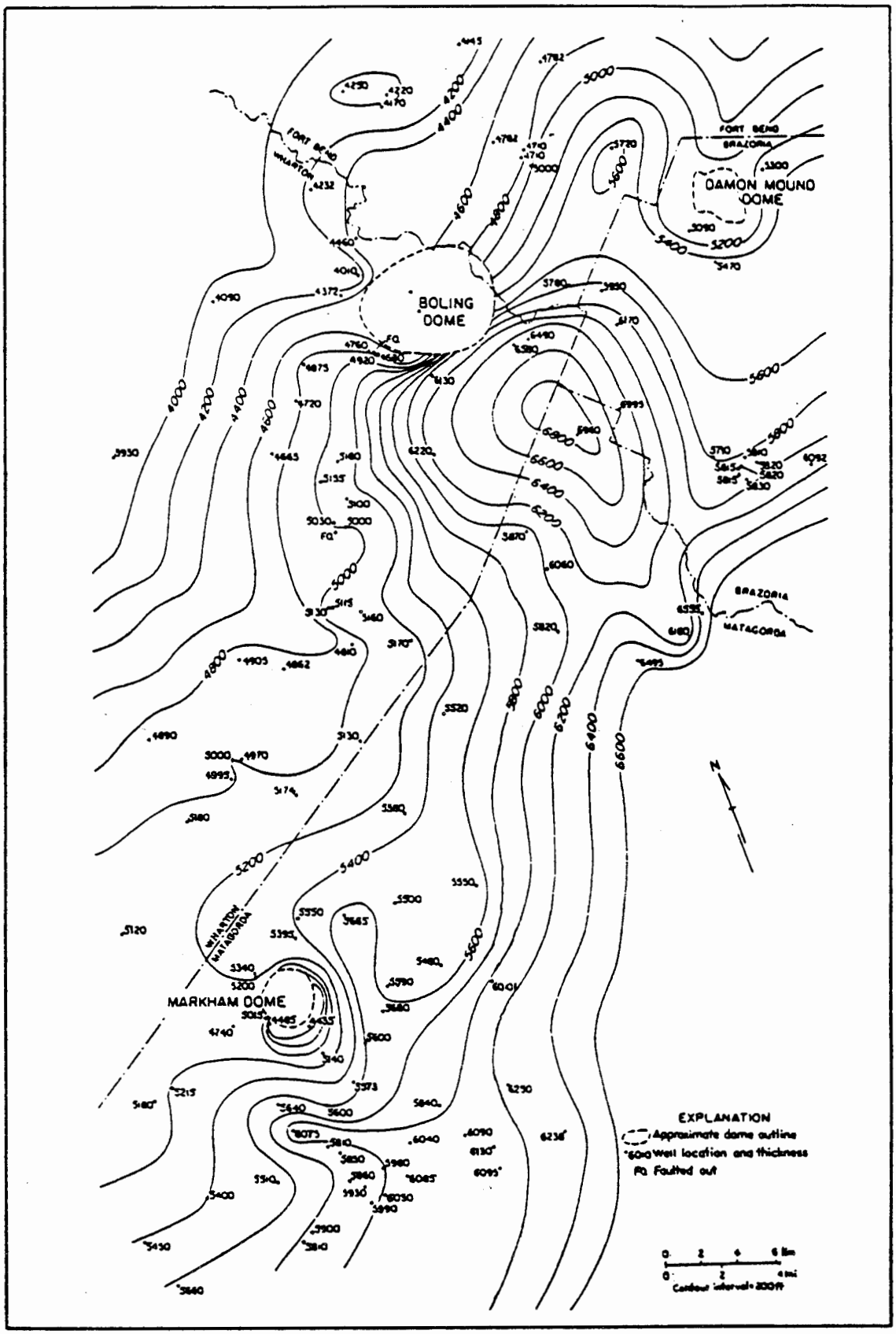


FIGURE 5–3: Isopach Map Showing Thickness of Miocene and Post–Miocene Strata, Area Around Boling, Markham, and Damon Mound Domes. (Source: Seni, et al., 1985)

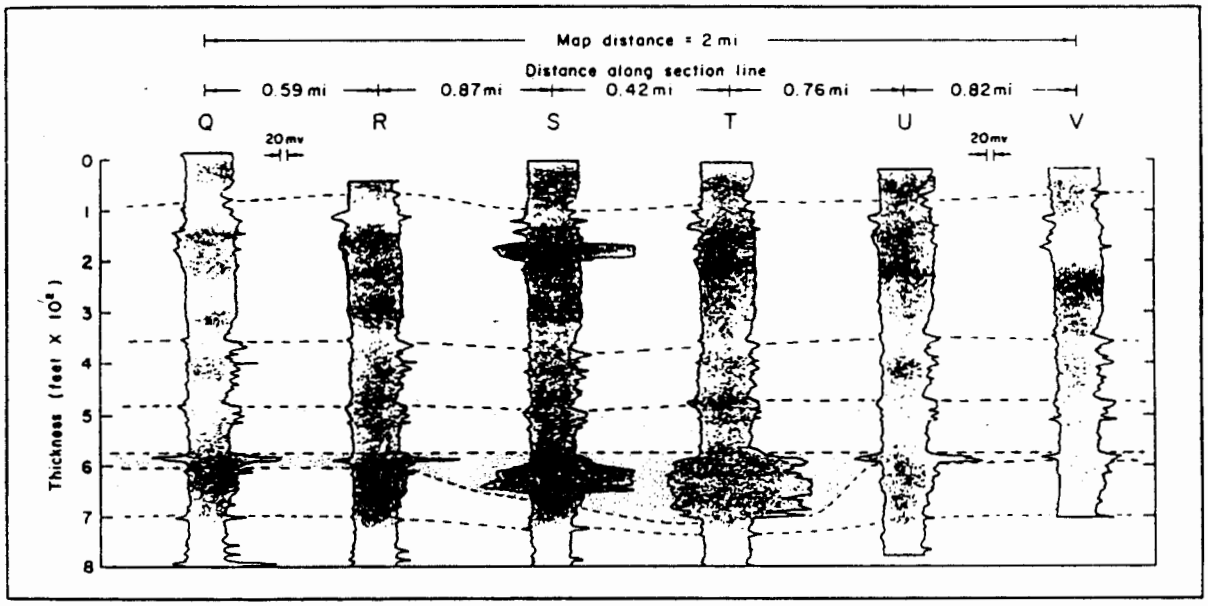


FIGURE 5–4: Correlation of Stratigraphic Layers by Sample–Calibrated Electric Log Data. (Source: Friedman, Sanders, 1978)

5.2.2.1 Information Needs

Data to be collected to characterize the structural discontinuities of the affected rock units include:

- Faulting and folding of regional and local area
- Past tectonic activity (including uplift and subsidence)
- Regional plate tectonics
- Present temperature, confining pressure conditions, and pore fluid pressures
- In-situ state of stress.

An assessment of structural stability and potential release pathways for the repository should be based on this information.

Faults, folds, joints, and fractures result from regional crustal extension or shortening events or localized igneous or salt dome intrusive events. In either case, the location, type, geometry and subsurface extent should be determined for all major structures and most minor structures.

Strike and dip orientations of faults and folds should be measured at the surface and any change in orientation with depth noted. Orientation of these features should be correlated to the regional or local tectonic setting.

Tectonic events which have produced the structures observed in the region should be described with respect to type, age, and general temperatures and pressure regimes of the deformation event. For example, in the southeast Gulf Coast area, the structural and stratigraphic features have resulted mainly from localized salt dome intrusions that have produced localized uplift and subsidence. The density and distribution of brittle radial tear faulting in the supradomal strata is indicative of slow gradual uplift at low temperatures. Many of these salt stocks have been rising through the strata for millions of years and are still experiencing growth. The extent of radial block faulting and stratigraphic isopach data can be used to determine past and present growth and uplift rates for the salt dome and supradomal strata.

An understanding of the regional plate tectonics is important in that repositories (specifically salt domes) that have a younger growth history are less stable structures than older domes which characteristically undergo an exponential decline in the rate of growth with time (Seni, et al., 1985). Supradomal strata above these younger domes are presently, and will be in the future, under stress and may be seismically active. Many domes have pierced or nearly pierced the ground surface and are, or will be, subjected to subaerial erosion and dissolution processes. These domes do not provide suitable long-term stability or hydrologic isolation and should not be used for waste disposal activities.

Present temperature and pressure conditions of the area around and including the repository should be determined. This information is important in understanding present and future tectonic activity, the stability of the repository, and the environment in which the wastes are to be emplaced.

An average geothermal gradient for the earth's crust is 1°F/50 feet which, when taking into account the mean annual temperature at ground surface and the depth of the repository, can be used to derive an estimate of the in-situ repository temperature conditions. Anomolously high geothermal gradients do occur, particularly around formerly or presently active volcanic chains.

An average lithostatic overburden pressure can be similarly calculated for the repository by multiplying the average density of the overlying strata times the depth of the repository. This confining pressure can be assumed to exist in all directions for rocks that are undeformed. Porous media, such as sandstone, that contain fluids will have a back pressure, or fluid pressure, which is an opposite stress vector to confining pressure. Therefore, the effective confining pressure of lithologic units containing fluids will be less than that calculated for the overburden and will affect the mechanical behavior of the rock to applied stress field. (Additional detail on this topic is provided in Section 5.2.4.)

Rocks that are undergoing uplift and/or deformation (compressional or extensional) will have in-situ tensile, compressive, or shear stresses in excess of the confining pressures (Figure 5-5). These differential stresses produce faults, folds, and fractures with orientations that are indicative of the direction of the deformational stresses. Therefore the current magnitude and direction of stresses in the repository rock should be determined and correlated to the temperature, pressure conditions, rock strength, and tectonic setting.

5.2.2.2 Characterization Methods

Methods used to define the surface and subsurface structural setting include the following:

- Remote image interpretation
- Field mapping
- Drill core and sampling
- Geophysical sampling
- Hydraulic fracturing (for in-situ stress measurements).

Aerial photographs can provide information on major and, in some cases, minor surface and subsurface fractures and fracture zones. Fracture-trace methods using aerial and satellite images have been used in the past to find suitable locations for ground water, oil, or gas wells in fractured bedrock. The method is particularly effective in rural or undeveloped areas where natural surface lineaments are not obscured by man-made features (e.g., buildings, railroads, electrical power lines, roads). Surface lineaments indicative of subsurface fractures include stream channels, linear topographic depressions, changes in soil color or vegetation type (as a result of greater soil moisture). Interpretation of aerial or satellite photos, however, must be closely correlated with field data to yield accurate fracture zone traces that are distinct from other man-made or geologic features (e.g., bedding planes, folds).

Field mapping can delineate most major structures of concern and provide a statistical sample of regional trends of small-scale features. Features to be mapped

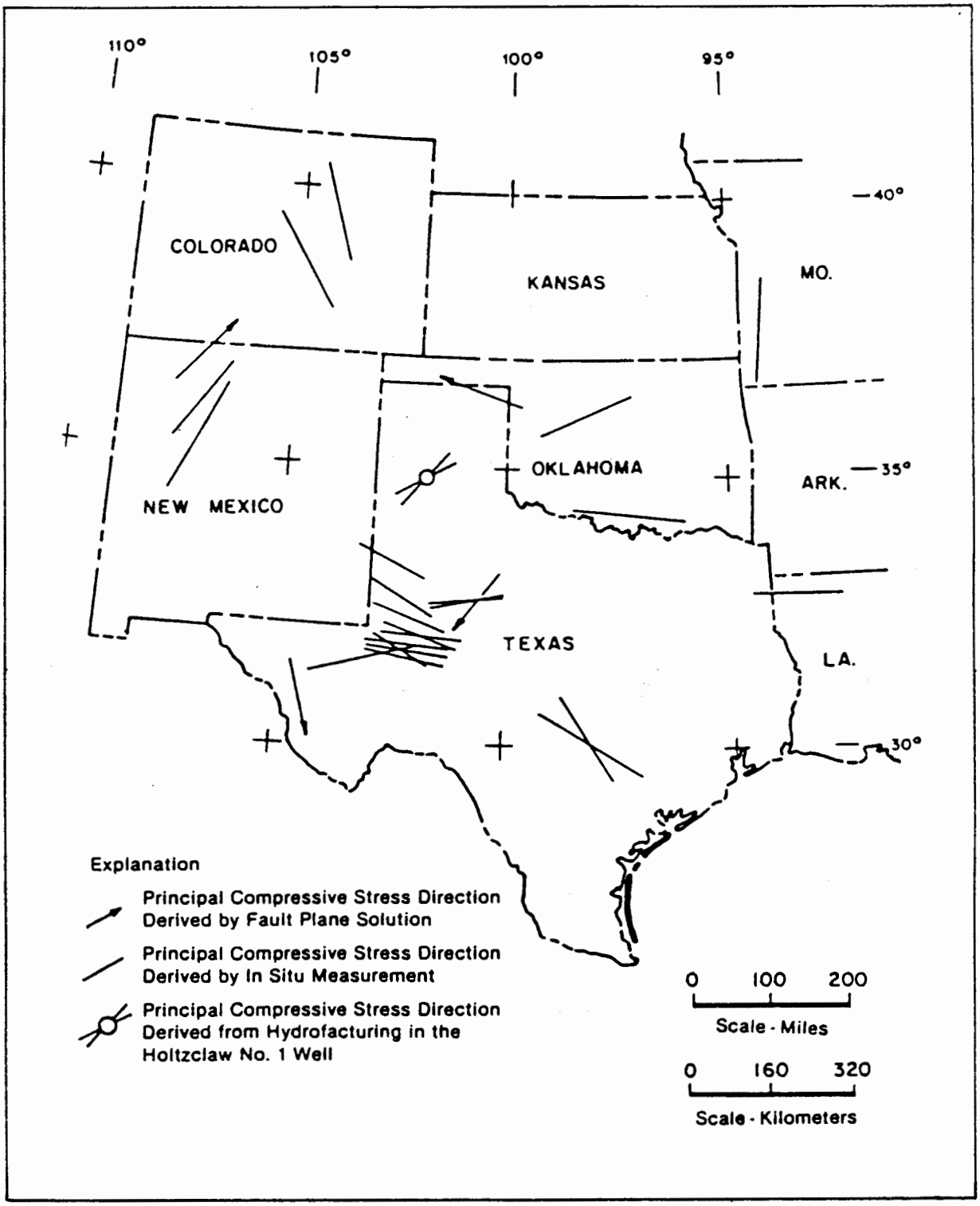


FIGURE 5–5: Principal Compressive Stress Directions. (Source: EA, Deaf Smith County Site, TX)

include location, attitude, and magnitude of observable faults and fold axes; frequency and attitude of statistically-sampled joints and discontinuities; and distribution and attitudes of all lithologic units. Low priority should be placed on detailed surface characterization of minor structures.

Analyses of oriented drill cores will include determination of the attitude, frequency, and conditions of all macroscopically and selected microscopically-observable foliations, fractures, breccia zones, slickensides, and vein fillings (See Exhibit 5-1 for the definition of terms).

Downhole geophysical sampling can provide clues about the overall fracture conditions at depth. However, because interpretation of this data does not yield unique characterizations for the subsurface conditions results from the geophysical survey should be evaluated with respect to other field data, such as those methods described above.

Observed drill-core fracture patterns should be correlated, if possible, with data from borehole logs and surface geophysical surveys.

Extensometer and flat-jack measurements of stress may be useful in drill holes and in the existing mine excavations at the site. Geothermal information may be obtained in many cases through previous regional surveys around volcanic chains or be calculated in areas where normal gradients are expected. Electrical resistivity measurements may be conducted in the absence of site or regional geothermal data.

5.2.2.3 Limitations to the Characterization

The limits to structural characterization depend on many of the same factors as stratigraphic characterization. Understanding of structure and tectonics cannot be separated from that of stratigraphy.

Although individual structures are produced by rock body stresses acting over an entire region, small spatial variations in resistance to these stresses cause the

localization of myriad individual structural features. One can predict that the host rock will probably be fractured to a certain degree; however, the character, location, and even existence of individual unobserved structures is highly conjectual. Structures cannot be correlated across broad regions, because each feature is discrete and physically separated from adjacent as well as distant structures. Therefore, structures can only be projected geometrically for limited distances.

The prediction of structural features likely to be encountered at repository depths depends on the scale of the feature of interest. For example, large folds and faults with relative vertical displacements of tens of feet and horizontal surface traces of thousands of feet can usually be observed in the field and projected to the subsurface with a fairly high degree of confidence, although possible changes in orientation with depth must be considered. On the other hand, many smaller surface structures such as joints and fractures can be mapped only where a soil cover does not mask the rock surface, and then only at the expense of a great deal of time. Confident projection of small-scale surface structures to the subsurface, beyond a few hundreds of feet, is not always possible.

A common approach that avoids complete mapping of all exposed fractures is to sample selected locations and develop rose diagrams which are presumed to statistically characterize the fracture pattern throughout the region of interest. Nevertheless, the desire to limit the number of exploratory drill holes in the vicinity of a repository almost guarantees that unpredicted small-scale structural ''anomalies'' will be encountered during excavation of the repository. Thus, during excavation, new data should be analyzed and integrated with existing data to upgrade understanding of the setting. New data may confirm or contradict assumptions about the structural setting. Repository design and even siting may need to be changed if structures encountered during excavation will cause the repository to be unstable.

5.2.2.4 Presentation of Data

The suggested format for presenting structural information includes:

- Geologic maps at a scale of about 1:5000-1:12,000 (consistent with stratigraphic and hydrologic map scales) and cross sections showing:
  - Structural and tectonic features (Figure 5-6)
  - Rock outcrop patterns
  - Structural attitudes at exposed rock units
- Structural fence diagrams
- Rose diagrams or stereo nets for surface and drill-core fracture orientations (Figure 5-7)
- Core analysis and fracture histograms for each drill hole
- Detailed text and tables describing all observed structural features, their condition, mode of formation, distribution, and relation to the site's containment qualities, and the methods by which they were mapped and analyzed.

Calculations used to derive pressure, stress, and temperature conditions should be presented and uncertainties in the values discussed. Models used to predict future conditions should be described with respect to empirical and site-specific data inputs, assumptions and equations used.

5.2.3 Mineralogy/Geochemistry

Understanding the mineralogy/geochemistry of the host repository rock (and cap rock in the case of salt domes) is critical to predicting the long-term structural stability and waste isolation capability of the repository. Mineral content and texture of the rock should be characterized in order to understand rock mass properties. Chemical composition of the different minerals and any impurities or inclusions should be discussed with respect to waste-rock chemical stability. Any fluid or gas inclusions or alteration zones should be characterized with respect to chemical stability of the natural and man-made materials to be used and emplaced in the repository.

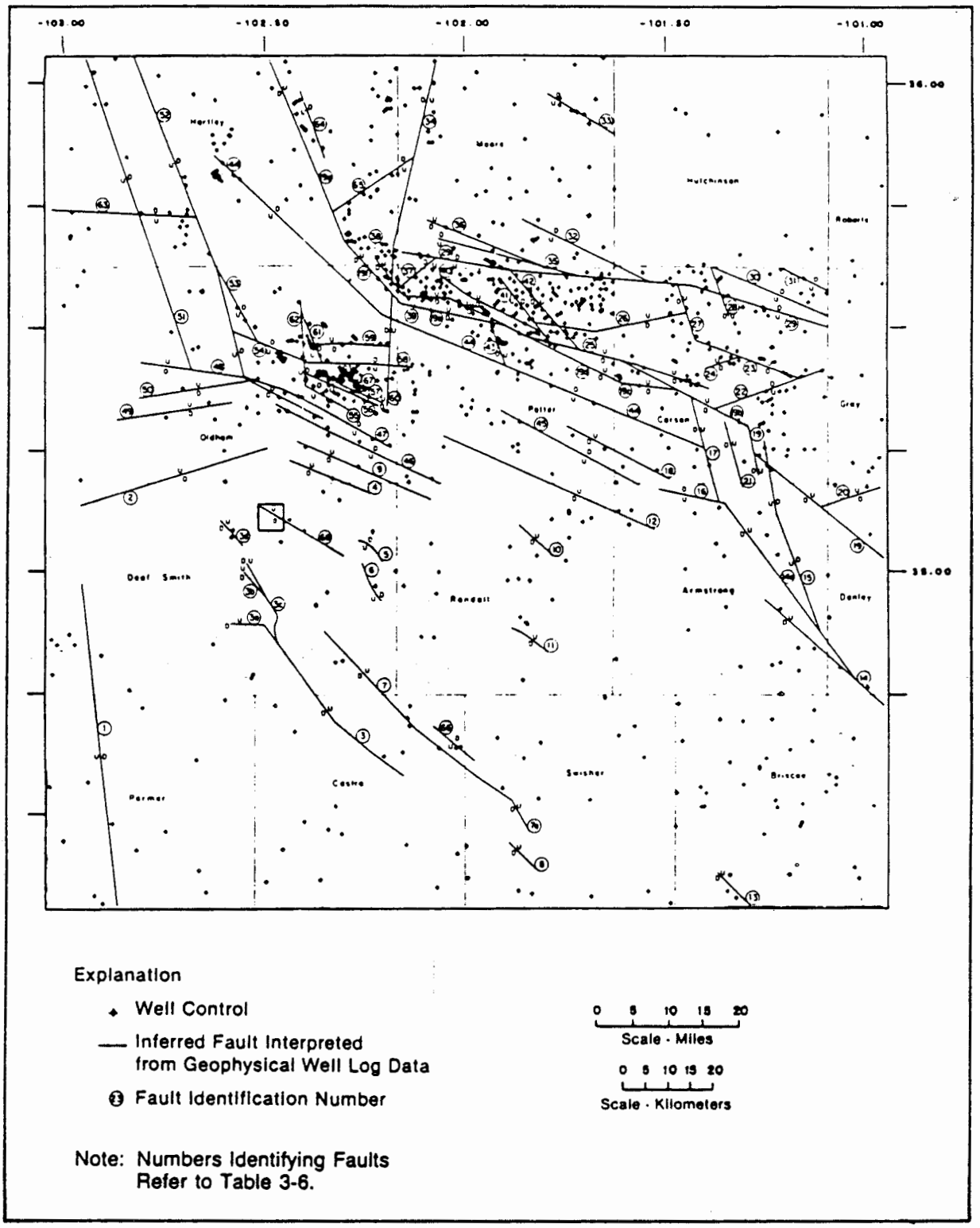
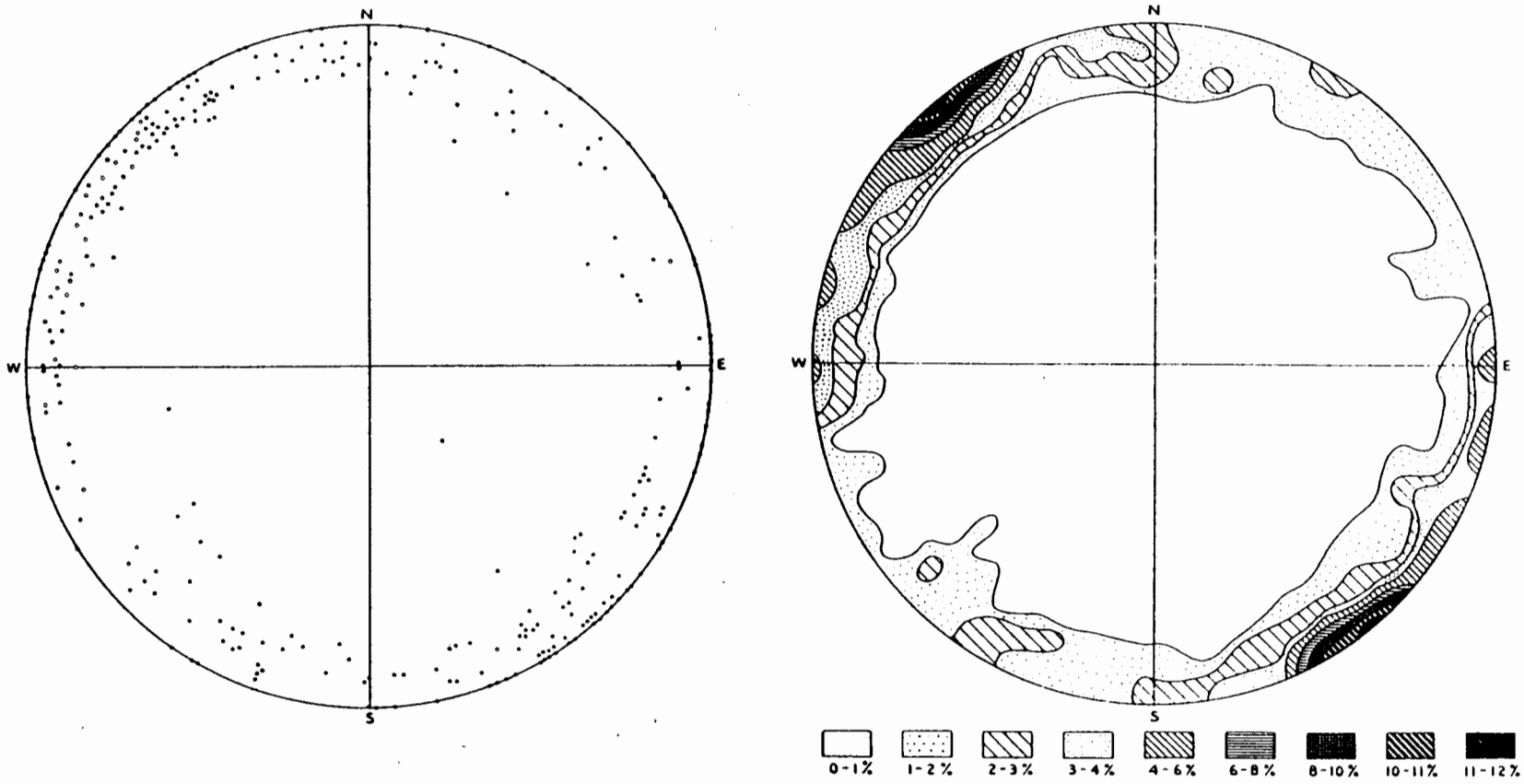


FIGURE 5-6: Inferred Faults in the Northern Palo Duro Basin. (Source: EA, Deaf Smith County Site, TX)



Point diagram of 311 joints

Contour diagram of 311 joints

FIGURE 5-7: Point Diagram and Contour Diagram of 311 Joints, plotted on lower hemisphere. (Source: Billings, 1970)

5.2.3.1 Information Needs

Factors to be considered in defining the mineralogy of the host repository rocks (and cap rock over salt domes repositories) are:

- Mineral content and composition
- Heterogeneity of rock composition
- Presence of fluid inclusions, fracture filling and alteration zones
- Rock textural features.

Mineral content of the host rock may be defined by major and minor minerals in the rock. For instance, salt domes contain halite as the dominant mineral with minor amounts of anhydrite, dolomite, quartz, and calcite. The percentage of major and minor minerals comprising the host rock should be correlated with observed rock mass characteristics. Chemistry of the individual minerals should be described for the host rock. For example, dolomite may contain calcium and magnesium with minor amounts of iron, manganese, sodium, and potassium. Mineral chemistry is important in defining waste-rock and rock-water chemical interactions.

Impurities are common to most rock types. Their distribution (i.e., evenly or in distinct zones) can affect observed mechanical and chemical behavior of the host rock. For instance, quartz may occur as random grains in salt deposits, or may occur in distinct sandstone and siltstone stringers or zones within the host rock formation. Similarly, dolomite may be a minor constituent throughout the limestone rock or it may occur in distinct replacement zones within the strata. Space in fractures may be filled with clay minerals or replaced with hydrothermal or magmatic veins and dikes. In general, formations that have higher impurity content or have distinct mineralogical variations are more difficult to characterize with respect to chemical and mechanical behavior of rock mass than formations that have more uniform mineralogy.

Many rocks will have micro- and/or macro-fluid or gas inclusions. Salt and limestone deposits often have pockets of saturated aqueous solutions as well as intergranular fluids. Salt domes and caprock are also known in some cases to contain

inclusions of oil, methane, and sulfur-rich gases. Salt domes known to contain methane or sulfur-rich gases present health risks and explosion hazards, and should not be sited for development as hazardous waste repositories.

The texture of the rock refers to the grain size, orientation, and nature of the boundary between grains. Limestone formed by calcium carbonate precipitation will have interlocking grains that distinguishes it from limestone that formed by cementing shells and corals. Similarly, the texture of salt dome rock is characterized by recrystallized interlocking halite grains, as opposed to cemented salt and impurities in salt beds. The rock texture is an important characteristic when defining the natural rock porosity and mechanical behavior.

5.2.3.2 Characterization Methods

Mineralogical investigations mainly involve laboratory analyses of rock core samples of the host rock formation. Additional geophysical surveys may be required to locate and identify large-scale zones of impurities or inclusions.

Laboratory studies include petrographic analysis, X-ray diffraction, and/or electron microprobe analyses. Petrographic studies, using thin-sections of the core samples under the optical microscope can identify rock textures and derive statistical abundances and distribution of the major and minor minerals. Impurities and intergranular matrix may also be identified under the optical microscope or with X-ray diffraction techniques. Fluid inclusion and mineral chemistries may be determined using an electron microprobe.

5.2.3.3 Limitations to the Characterizations

Mineralogical detail of the host repository rock is severely hampered in the case of solution-mined caverns, since the drill coring activities must be minimized and restricted to areas that are at sufficient distance from the repository site. In this case, the mineralogy and distribution of impurities and inclusions must be either inferred from existing rock core analyses or from other remote sensing techniques. Geophysical methods, such as gravity, magnetic, and seismic, are also limited by the

extent of spatial resolution achieved and physical- chemical contrast of the impurity or inclusions, and may only be able to detect very large-scale features.

In the case of repository siting in an existing mine, detailed mineralogical information may be obtained from samples of the wall rock in the mine; however the mineralogy of the rest of the host formation may be less well-defined, especially between sampling points. The uncertainties in the laboratory and geophysical investigations should be fully characterized in the discussion of the data.

5.2.3.4 Presentation of Data

Laboratory data and results from rock coring and geophysical sampling should be presented in the form of graphs, figures, and tables (Table 5-2). Mineral component percentages can be illustrated in bar graphs, histograms, or pie graphs. Photos of petrographic thin-sections may be used to illustrate textural features. Mineral, impurity, and inclusion chemistries may be discussed in the text, and raw data from the microbe analyses presented in figures. Location of large-scale fluid or gas pockets in the host rock (and/or cap rock in the case of salt domes) may be illustrated in geologic cross-sections along with raw data from the geophysical sampling.

5.2.4 Rock Mass Characteristics

Mechanical behavior of the host repository rock should be evaluated with respect to existing environmental conditions and projected construction and operational conditions. Specifically, the strength of the rock mass and stress-strain relationships should be established in order to ensure structural stability of the repository under in-situ and operating conditions. The design of a repository in an existing mine should be based on a thorough understanding of these properties and factors controlling rock mass behavior.

In the case of siting a repository in a salt dome or bed, the rate of salt creep, or creep closure rate, should be calculated from observed stress-strain relationships and estimated in-situ stress, temperature and pressure conditions. Creep closure rates vary widely among different salt domes and beds and may vary locally within the salt

GEOHYDROLOGIC UNITS	GEOLOGIC UNITS	LITHOLOGIC CHARACTER	MINERALOGY	ORGANIC MATTER
Upper Aquifer	Alluvium	Quartz sand, chert and quartz gravel, and silty clay	Quartz, feldspar	Lignite
	Terrace Deposits			
	Citronelle	Silty, clayey sand grading into gravel	Montmorillonite, illite, kaolinite	
	Pascagoula-Hattiesburg	Interbedded gravelly sand, sand silty clay and lignite		
	Catahoula	Silt, clay, fine- to medium-grained sand, gravel, lignite and a marker Heterostegina Zone (Tatum limestone member)	Calcite, dolomite	
Vicksburg-Jackson	Chickasawhay	Argillaceous to sandy limestone, interbedded with clay and marl	Quartz, feldspar Calcite, dolomite Montmorillonite, illite, kaolinite Glauconite	
	Vicksburg Group	Limestone, sandstone, and clay		
	Forest Hill Sand/Red Bluff Clay	Sandy to silty carbonaceous clay and partially indurated fossiliferous marl		
	Jackson Group	Variably limy, glauconitic, sandy and silty clay, with basal chalky limestone (Ocala Facies)		
Upper Claiborne	Cockfield	Limestone, sand streaked, lignitic-bearing clay and silt	Calcite, dolomite Montmorillonite, illite, kaolinite Quartz, feldspar Glauconite	
	Cook Mountain	Loosely cemented, porous carbonate sand, glauconitic clay shale, and calcrenitic limestone		
	Kosciusko (Sparta)	Limestone with thin beds of clay, locally sandy		
Lower Claiborne	Zilpha Clay	Interbedded glauconitic clay shale, chalk, and chalky limestone	Montmorillonite, illite, kaolinite Quartz, feldspar Calcite Glauconite, pyrite, chlorite	Lignite
	Winona Sand	Clay shale containing chalk or marl lenses		
	Tallahatta Formation	Glauconitic and limy siltstone and claystone interbedded with clay shale		
Wilcox	Meridian Sand	Sand with sandy shale and lignitic clay	Quartz, feldspar Montmorillonite, illite, kaolinite Chlorite, pyrite	Lignite
	Wilcox Group	Silty, lignitic shale interbedded with silt, sand, lignitic siltstone, and fine to medium-grained sandstone		
Midway	Porters Creek Clay	Interbedded shales, lignite, silt, siltstone, and sandstone	Montmorillonite, illite, kaolinite Quartz, feldspar Calcite Glauconite	
	Clayton	Sandy, glauconitic marl, marly chalk, or calcareous clay		

TABLE 5-2: Mineralogy of Sediments Adjacent to Richton Dome, Mississippi. (Source: EA, Richton Dome Site, MS)

formation. Measuring the amount of strain increase over time under a constant applied stress on core samples in the laboratory will provide information on potential creep closure rates present in the salt formation. Large strain increases over time indicate rapid salt creep rates; hence those formations demonstrating relatively low strain rates are more suitable for hazardous waste disposal.

Stress-strain properties of rocks are generally evaluated in laboratory rock deformation experiments. Mechanical behavior of rocks have generally been described using stress-strain diagrams. Figure 5-8 depicts stress-strain curves for different materials. Strain is the behavior of the rock subjected to stress and is often defined by the percent shortening or lengthening of the sample. Rock bodies under an applied tensile or compressive stress over short periods of time generally pass through three stages of deformation: elastic (the rock body can return to original shape and size if stress is withdrawn), plastic (the deformed rock cannot return to its original shape when stress is withdrawn), and brittle (the rock ruptures or breaks). Brittle rocks are rigid bodies that rupture before any plastic deformation takes place. Ductile rocks are those that undergo extensive plastic deformation before rupturing.

5.2.4.1 Information Needs

The geomechanic properties important to the design, construction, operation, closure, and post-closure phases of a repository are the elastic parameters, yield or failure strength, and time-dependent deformation. The specific parameters to be evaluated include:

- Density, porosity, and water content
- Plasticity
- Undrained shear strength
- Compressibility
- Swelling potential
- Angle of internal friction

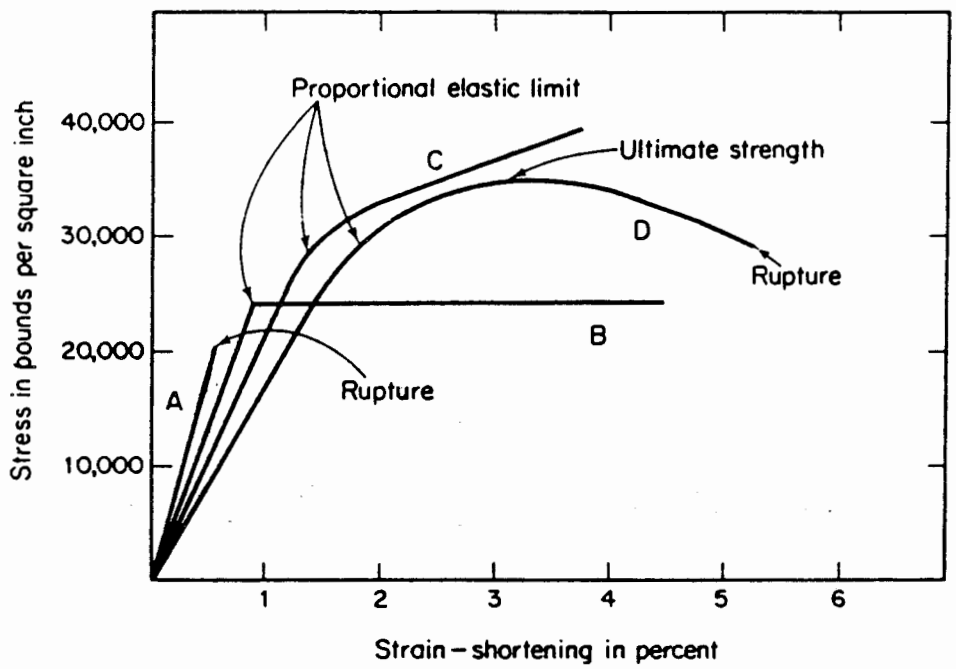


FIGURE 5–8: Stress–Strain Curves for: (A) Brittle Substances, (B) Ideal Plastic Material, and (C) and (D) Plastic Materials. (Source: Billings, 1972)

- Maximum low strain shear modules
- Soil corrosiveness
- Thermal conductivity.

Ranges in values for each parameter should be specified based on existing environmental conditions (temperature, pressures, in-situ state of stress), projected operating conditions, rock mass anistropy, mineral and structural heterogeneities (discontinuities), and the presence of fluids. These factors affect the mechanical properties of the rock mass and should be considered when evaluating long-term structural stability of the repository.

5.2.4.2 Characterization Methods

Laboratory experiments should be performed on site-specific rock cores. Undeformed and deformed (fractured) rock samples should be tested at different orientations, and the deformation experiments should be conducted at repository environmental and operating conditions (temperature, pressure, in-situ stress and moisture content). Values obtained from these tests should be compared to those reported in the literature for similar rock types. Uncertainties in the laboratory results should be identified.

Triaxial and uniaxial compressive load tests on cylindrical rock specimens are common deformation experiments. According to Paterson (1978), the most frequent types of rock mechanical experiments are:

(1) A creep test - an axial differential stress is built up rapidly on the specimen and held constant as the specimen deforms. Strain (change in length) is then measured as a function of time (Figure 5-9). Rock samples showing lower strain rates (i.e., samples from the Richton Salt Dome) indicate areas within the salt formations that have lower creep rates. These tests should be used to predict creep closure rates and to demonstrate suitability of the host rock.

(2) A stress-strain test - the differential stress is applied in such a way that the rate of strain is constant and changes in the applied stress are plotted against strain.

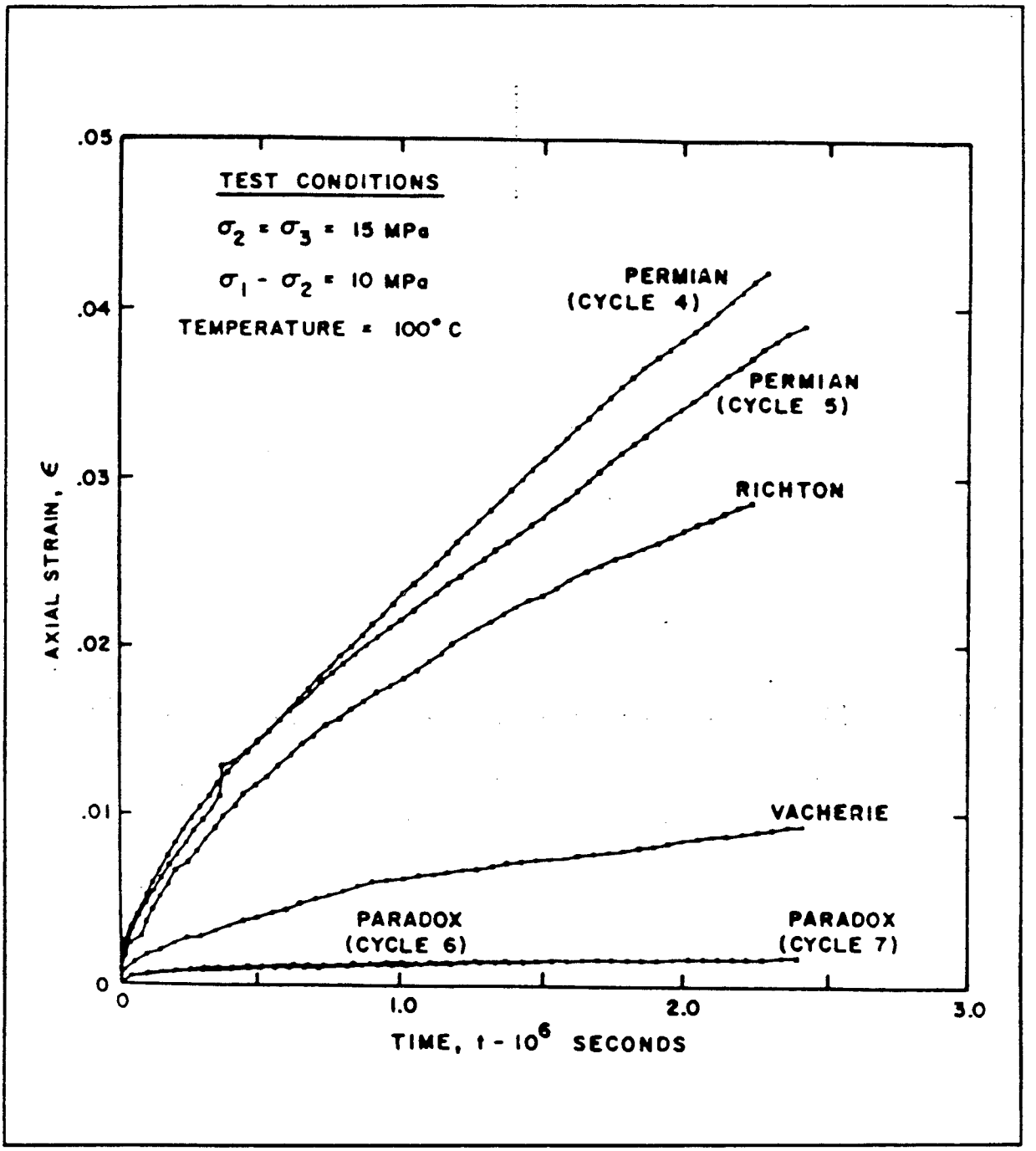


FIGURE 5–9: Axial Creep Strain. (Source: EA, Deaf Smith County Site, TX)

(3) A strain rate (E) test - a constant differential stress is applied and the rate of strain is measured. The results are plotted as differential stress vs. strain rate (Seni, et al., 1985 b).

These tests are generally conducted in a Griggs rig apparatus. Mechanical properties of fractured pillar rocks in a room-and-pillar mine can be evaluated using direct shear tests in a small shear box, where the normal stress is held constant and a direct shear stress is applied along the fracture plane until the sample shears (Miller, 1980). Figure 5-10 shows the Envelope Curve and Mohr's Circles at failure for a specific salt dome. The effect of orientation of the fracture plane on the normal and shear strengths of the rock can be determined from these direct shear tests and should be assessed in the case of fractured repository rock (and cap rock over a salt dome).

For existing mine sites, field stress-strain measurements can also be performed. Photoelastic, electrical, mechanical, or hydraulic instruments have been employed in open structures and boreholes that measure strain, from which in-situ stresses are deduced. Figure 5-11 depicts in-situ creep curves for a room-and-pillar mine in salt. These field studies require long time periods relative to laboratory studies, but the results may be more accurate.

5.2.4.3 Limitations to the Characterization

Extrapolation of laboratory data to the field is generally hampered by inadequacies in experiment duration, sample size, and simulation of in situ conditions, namely the rate and magnitude of applied stress (Seni, et al., 1985). In particular, salt creep kinetics and mechanisms and in situ state of stress are poorly understood, and laboratory closure rates are not validated by field observations of cavern closures. Uncertainties in laboratory values for the different parameters listed above should be expressed in terms of minimum and maximum values.

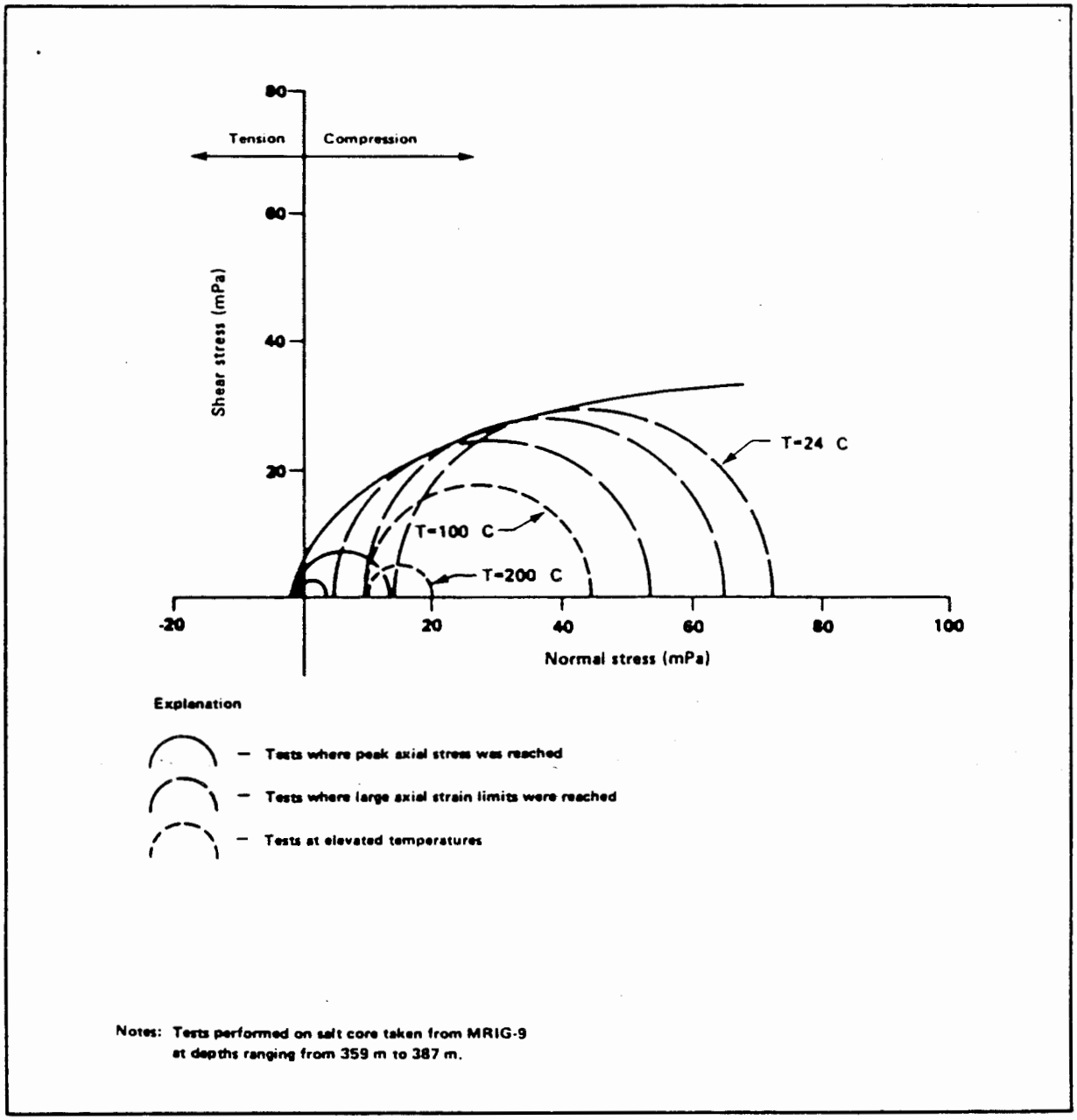


FIGURE 5–10: Envelope Curve and Mohr's Circles at Failure for Salt. (Source: EA, Richton Dome Site, MS)

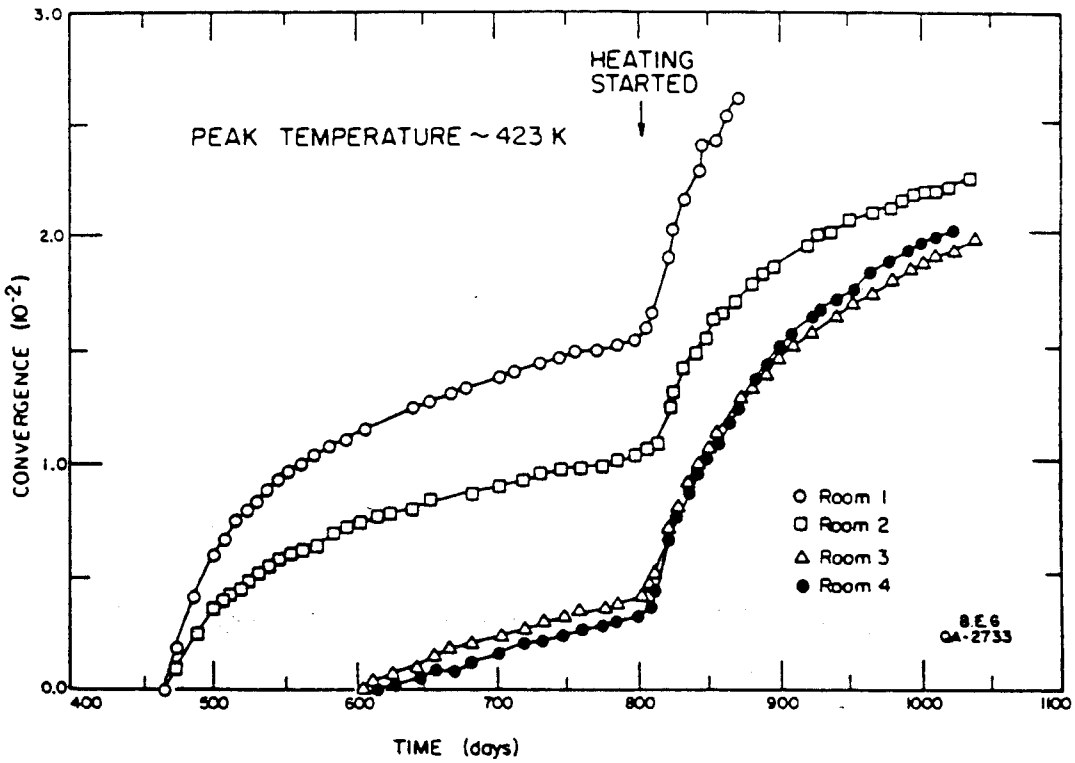


FIGURE 5–11: In–situ Creep Measurements of Floor and Ceiling Convergence in an Underground Salt Mine. Data from Empson, et al., 1970. (Source: Seni, et al., 1985)

5.2.4.4 Presentation of Data

The rock characteristics should be presented in a tabular format along with detailed text describing the different properties and their effects on the repository (Table 5-3). Calculations used to derive the values should be presented and uncertainties in the values discussed.

5.2.5 Natural Resources

Man-made penetrations result in structural discontinuities. Like natural discontinuities, these penetrations may affect the structural integrity and hydrologic isolation of the repository. However, unlike natural features which occur over geologic time, man-made penetrations introduce stresses over a rapid time period and can potentially introduce an element of stress imbalance, which may result in surface land subsidence or other sudden rock movements. Figure 5-12 illustrates potential affects of sulfur mining in caprock on the salt dome structure and resulting surface subsidence. Unplugged wells around a salt dome repository site also provide pathways for surface precipitation or groundwater into subsurface strata, causing massive dissolution of salt dome or cap rocks. Therefore, all artificial penetrations in the vicinity of the site, such as test boreholes, wells, and mines, should be identified, characterized, and properly sealed. Boreholes should be 100% sealed and capped and mines closed with double cement bulkheads with monitoring holes between bulkheads. All mineral, energy, and water resources in the area should also be evaluated with respect to present and future demands, resource quality and overall abundance.

Future resource development activities should be restricted to areas at sufficient distance from the repository site.

5.2.5.1 Information Needs

Artificial penetrations (such as wells, exploratory drill holes, and shafts) and geologic/hydrologic resources should be identified in the general vicinity of the site. The following factors should be considered in the evaluating the suitability of the site for a geologic repository:

Hattiesburg Layer and Depth Interval	Description	Density (D)[b] Porosity (N) and Water Content(W) (4)	Fine-Grained Soil (Silt and Clay): Plasticity (7)	Undrained[c] Shear Strength (3, 7, 8)	Compressibility[c] (7)	Swelling Potential[c] (10)	Coarse-Grained Soil (Gravel and Sand), Angle of Internal Friction (2, 5, 12, 8)	Maximum Low Strain Shear Modulus[b] (1, 5, 8, 13)	Soil[e] Corrosiveness (9)	Thermal Conductivity (6)
1A 0 to 12 m	Clay with some silty or clayey sand interbeds; ranges from a clay with 50% clay fraction to a very silty fine sand with 35% silt content[a]	No data	Medium[b] to high	60-140[g]	High beyond maximum past overburden stress, moderate otherwise. Maximum past overburden is about 620 kN/m^2 higher than current overburden	High	35-40[c]	48,000 to 144,000kN/m^2	No data	No data
1B 12 to 20 m	See Layer 1A[a]	D = 2.0 to 2.2 g/cm^3 N = 30 to 45% W = 16 to 30%	Medium[b] to high	160-310[g]	See Layer 1A	High	35-40[c]	120,000 to 240,000kN/m^2	Very corrosive	Sand 0.7[d][h] to 1.0 Clays: 1.4 to 1.9
1C 20 to 44 m	See Layer 1A[a]	See Layer 1B	Medium[b] to high	160-360[g]	See Layer 1A	High	35-40[c]	383,000 to 719,000kN/m^2	Very corrosive	See Layer 1B[b]
1D 44 to 53m	Clayey sand, sand content increasing with depth[a]	See Layer 1B	Medium[b] to high	--	--	--	35-40[c]	359,000 to 671,000kN/m^2	Mildly corrosive	See Layer 1B[b]
2 53 to 94 m	See Layer 1A[a]	See Layer 1B	Medium[b] to high	240[g]	See Layer 1A	High	35-40[c]	407,000 to 766,000kN/m^2	Very corrosive to moderately corrosive	See Layer 1B[b]
3 94 to 126 m	Sand and clay layers coarser than Layers 1	See Layer 1B	Medium[b] to high	240[g]	See Layer 1A	High	35-40[d]	498,000 to 944,000kN/m^2	Corrosive to mildly corrosive	See Layer 1B[b]
4 126 to 169 m	Sand, fairly clean very little clay[b]	See Layer 1B	--	--	--	--	35-40[d]	450,000 to 853,000kN/m^2	Corrosive to mildly corrosive	See Layer 1B[b]

NOTE: These estimates were based on limited data and should not be used for design purposes. The letters in parentheses indicate the basis upon which each estimate was made.

(a) Direct information from MRIG-9 or from the same horizon in nearby borings.
(b) Based on empirical correlations.
(c) Based on more than one level of empirical correlation or extrapolated correlation charts.
(d) Based on extrapolated data.
(e) Corrosion potential of buried metallic structures, based on soil resistivity measurements.
(f) All values given in kN/m^2.
(g) All values given in watt/m-C.

SOURCES:

(1) Anderson and Stokoe, 1978, pp. 66-90
(2) de Beer, 1965, pp. 165-169
(3) U.S. Department of the Navy, 1982, pp. 7.1-85-91
(4) Ertec, 1983, ONWI-481; pp. 21-23
(5) Imai and Tonouchi, 1982, pp. 67-72
(6) Lade and Lee, 1976, pp. 107, 108
(7) Lambe and Whitman, 1969, pp. 318, 451
(8) LETCo, 1982, ONWI-167
(9) Peabody, 1969, pp. 5-17
(10) Portland Cement Association, 1971, Vol. II, p. 15
(11) Terzaghi and Peck, 1967, p. 347
(12) Vesic and Clough, 1968, pp. 661-688
(13) Ohsaki and Iwasaki, 1973, pp. 61-73.

TABLE 5-3: Estimated Geomechanical Characteristics of the Overburden, Richton Dome. (Source: EA, Richton Dome Site, MS)

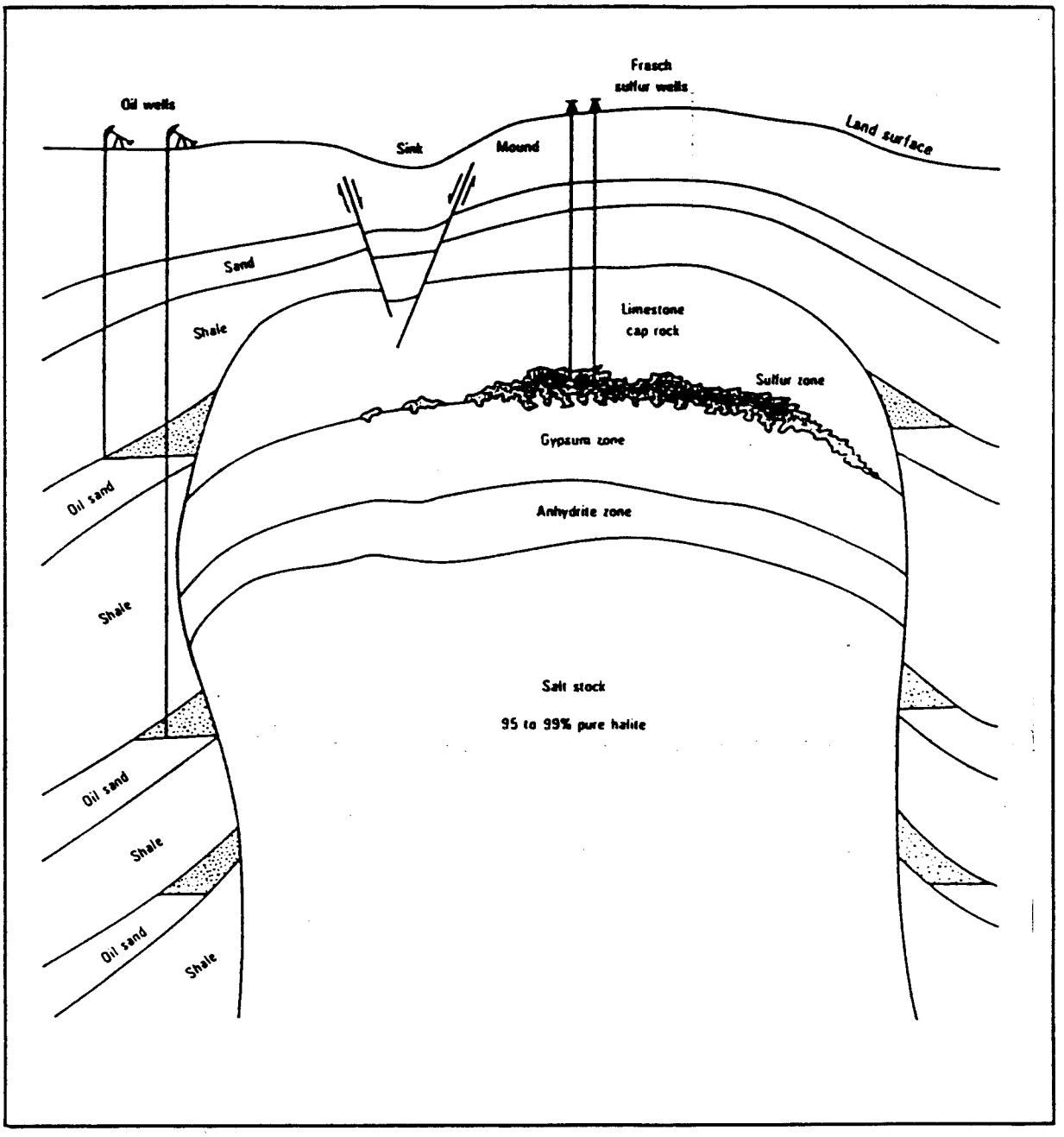


FIGURE 5-12: Cross-section of a Salt Dome Showing Surface Subsidence. (Source: Underground Injection Operations in Texas, Texas Department of Water Resources, 1984)

- Number, location, depth and present state of artificial penetrations
- Type of resource
- Accessibility, quality and present and future demands
- Mineral rights ownership in the area.

Impacts of the penetrations on land surface stability above the repository, the repository itself, and the waste isolation capability of the repository should be discussed. Any impacts of the repository on existing and future quality and availability of natural resources should also be determined.

Suitable sites for geologic repositories are generally those for which good structural and stratigraphic control can be achieved (i.e., little structural or stratigraphic complexity). However, areas that have been extensively mined add a degree of complexity to the setting with respect to predicting rock stability and hydrologic isolation. Nevertheless, these regions of previous exploration and development activities are often better characterized with respect to the local stability and hydrology than those that have not been explored. Many of the salt domes that are potential candidates for new solution-mined repository caverns are also the site of oil and gas wells, hydrocarbons storage caverns, brine disposal wells, and sulfur-mining activities. In summary, the probability of siting repositories in previously unexplored or undeveloped areas is low.

All subsurface artificial penetrations and mining activities within the area around the repository should be located and the depth and lithologic units affected reported. Any unplugged openings to the surface should be properly sealed (e.g., sealed with double cement plugs with monitoring holes between plugs). In the case of repositories in abandoned mines, any unused shafts to the surface or drifts and/or lower portions of the mine should be backfilled and sealed to maintain the structural integrity and prevent water penetrations.

Natural resources should be characterized with respect to present and future demand for those resources, the relative abundance of the resources in the nation and

world, and the accessibility and quality of the resources. The economic and social value of the site as a repository for waste should be weighed against the economic and social value of the resources available.

In addition, the mineral rights ownership at the site and in the immediate vicinity should be identified, and agreements and/or transfer of ownership to these mineral rights arranged, so that the repository host and surrounding lithologies are not subjected to exploration and resource development activities in the future.

5.2.5.2 Characterization Methods

A literature search of state and regional geologic and hydrologic resource information should be conducted. In the case of locating water wells in the area, the State water resources authority or environmental and public health departments should be consulted for information on location, depth, and current status. For example, the Texas Water and Railroad Commissions have information pertaining to water wells, injection wells, oil and gas wells (Figure 5-13), and solution-mined storage caverns in salt domes throughout the state. The well records generally date back to about the 1920's and 1930's. MSHA offices in the sixteen mining regions have information on mining activities within their areas of responsibilities.

In addition to literature and document review, a field survey of the area around the site should be conducted in order to both verify location and status of each opening and locate any unreported holes in the ground. Drifts and shaft openings in mines to be used for waste disposal should be inspected and, if unused, properly backfilled and sealed.

When records of depths and lithologic units involved are incomplete, the best current available technology for void detection should be analyzed to determine the depth and geometry of the opening.

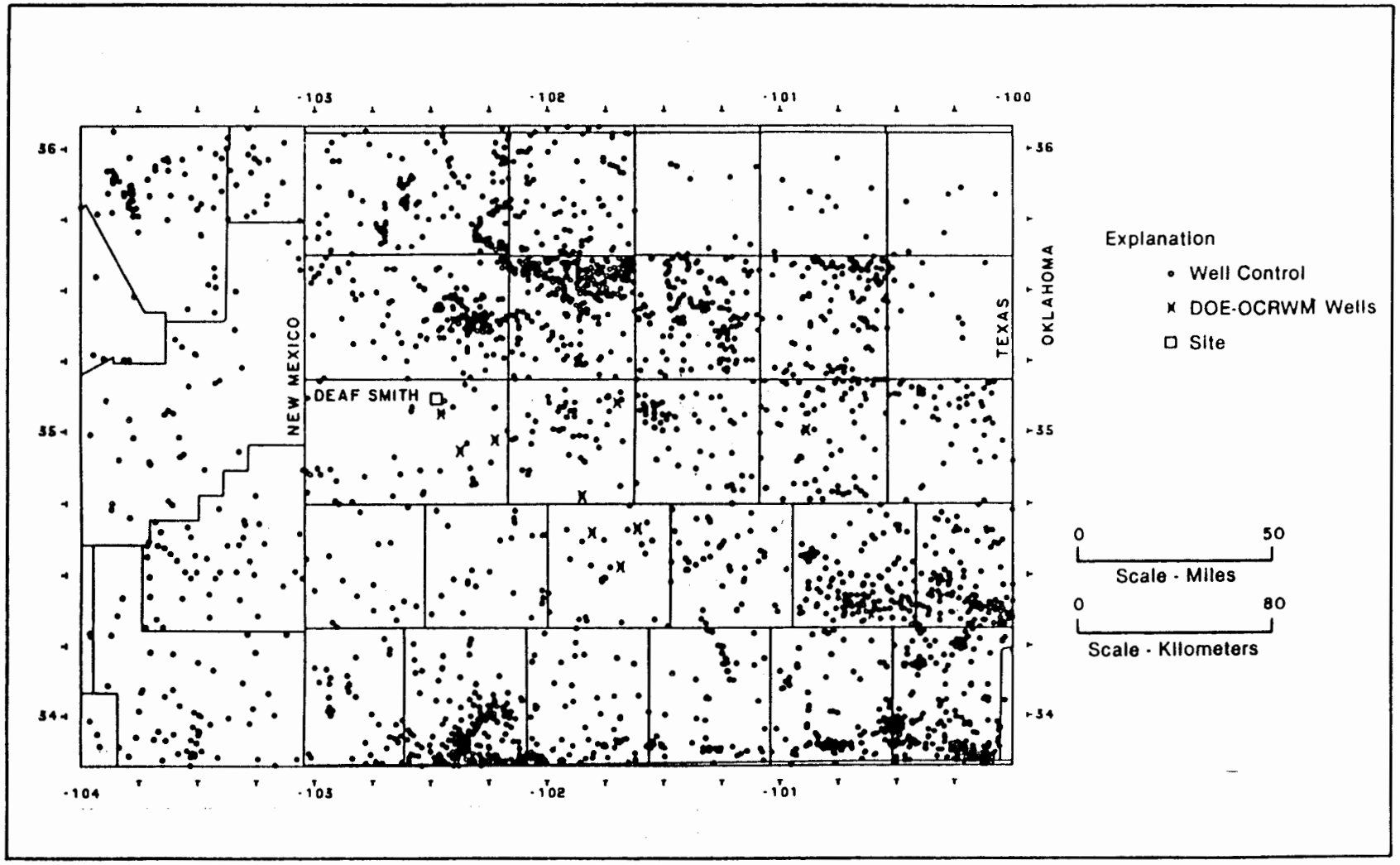


FIGURE 5-13: Wells Drilled for Oil and Gas. (Source: EA, Deaf Smith County Site, TX)

5.2.5.3 Limitations to the Characterization

Identification and characterization of artificial penetrations in areas that are extensively developed or penetrated may have some uncertainties involved. Areas that have fewer penetrations or more recent ones may be easier to characterize with respect to man-made subsurface features than those that have been extensively developed or have older wells. The quality of well records depends upon their age and varies from state to state. Seismic data may resolve large openings, but smaller-scale features may be obscured by background noise.

5.2.5.4 Presentation of Data

Location, type, and depth of man-made penetrations should be described and illustrated on geologic maps and cross-sections for the area. State-held and mining district records should be included, and the logistics for each type of penetration tabulated and discussed. Any field investigations on backfilling and sealing activities should be discussed and the area surveyed should be illustrated on a map. Any penetrations that are reported in State or district files that were not located at the site should be listed. Additionally, any penetrations at the site identified in the field survey for which no files exist, should also be included in the list. Results from geophysical tests should be discussed and raw data enclosed. Most importantly, any wells or other man-made borings that penetrate the repository rock formation should be listed and described separately with respect to potential adverse effects on repository performance.

5.3 Hydrology

The principal factors to be considered in the hydrologic characterization of the site include:

- Surface water
- Ground water.

Both of these subject areas are discussed in detail below with regard to (1) the type of information/data to be collected, (2) characterization methods, (3) limitations to the characterization, and (4) presentation of data. This information is summarized in Table 5-4.

Geologic factors described in Section 5.2 provide the geologic setting from which one may evaluate potential pathways for contaminant release to the environment. A hydrologic assessment should then determine whether fluids can enter the repository via these release points and render wastes mobile. Water sources, including surface water, ground water, and brine inclusions, should be identified, located, and their hydraulic and chemical characteristics fully described.

Water sources and inflow points will vary depending on the geologic setting and type of mine (e.g., existing room-and-pillar mine or solution-mined caverns). Many existing mines have water inflow from precipitation through the shaft or from ground water through fractures. Figure 5-14 shows various migratory pathways for water in a carbonate bedrock.

Mines in karstic terrain will experience water inflow from over-hanging sink holes. These existing mines generally have pumps and sumps installed at inflow points in the mine. Solution-mined caverns in salt domes may experience fluid breakthrough from (1) trapped solutions in cap-rock lost circulation zones that leak through or along the well casing stringers, or (2) trapped brine solutions within the salt stock that merge with the cavern as a result of salt dome growth and creep. Therefore, the hydrologic setting description to be included in the Part B permit application and no-migration petition will vary with the site and should focus upon potential water inflow sources in the area around the repository.

Hydrologic properties for surface water and ground water are discussed separately below. All repositories will need to have detailed surface water and ground water information fully characterized.

Property	Information Needs	Characterization Methods	Limitations to the Characterization	Presentation of Data
Surface Water	- Regional precipitation and E.T. Rates. - Location and size of all surface water bodies. - Water volume, flow rate and direction. - Drainage network. - Hydraulic connection between surface water and ground water. - Soil hydraulic properties. - General water chemistry and use.	- Field survey at site to determine characterize surface water and drainage networks. - Literature searches for soil, meteorological, and water quality data. - Soil boring and well logs can be used for water table elevation determination.	- Problems with determining area extent of field study.	- Information presented in text form plus: o surface topographic and hydrologic maps of 1:5000-1:12,000 o SCS soil maps o tabulated surface water flow, volume and quality data.
Groundwater	- Groundwater location. - Aquifer characteristics o General flow direction with respect to the repository o flow type o horizontal and vertical flow velocities o hydraulic interconnectivity points between aquifers o drawndown around wells in the area. - Groundwater chemistry o Salinity in total dissolved solids o Mineralization o Dissolved gases o Age dating o pH, Eh o Drinking water quality parameters o Microbiological activity o Temperature o Indicator chemicals.	- Geophysical surveys. - Field ground water testing and sampling o Piezometric head readings o General hydraulic testing methods - Laboratory analyses.	- Geophysical resolution of subsurface structures and groundwater. - Location of well boreholes and rock coring activities. - Inaccuracy of groundwater flow models.	- Hydrologic setting information o piezometric surface maps o flow nets. - Geophysical data should be provided. - Stratigraphic cross-section. - Tabulated chemical data. - Hydraulic conductivities and transmissivities specified.

TABLE 5– 4: Hydrologic Information for Repository Performance Analysis

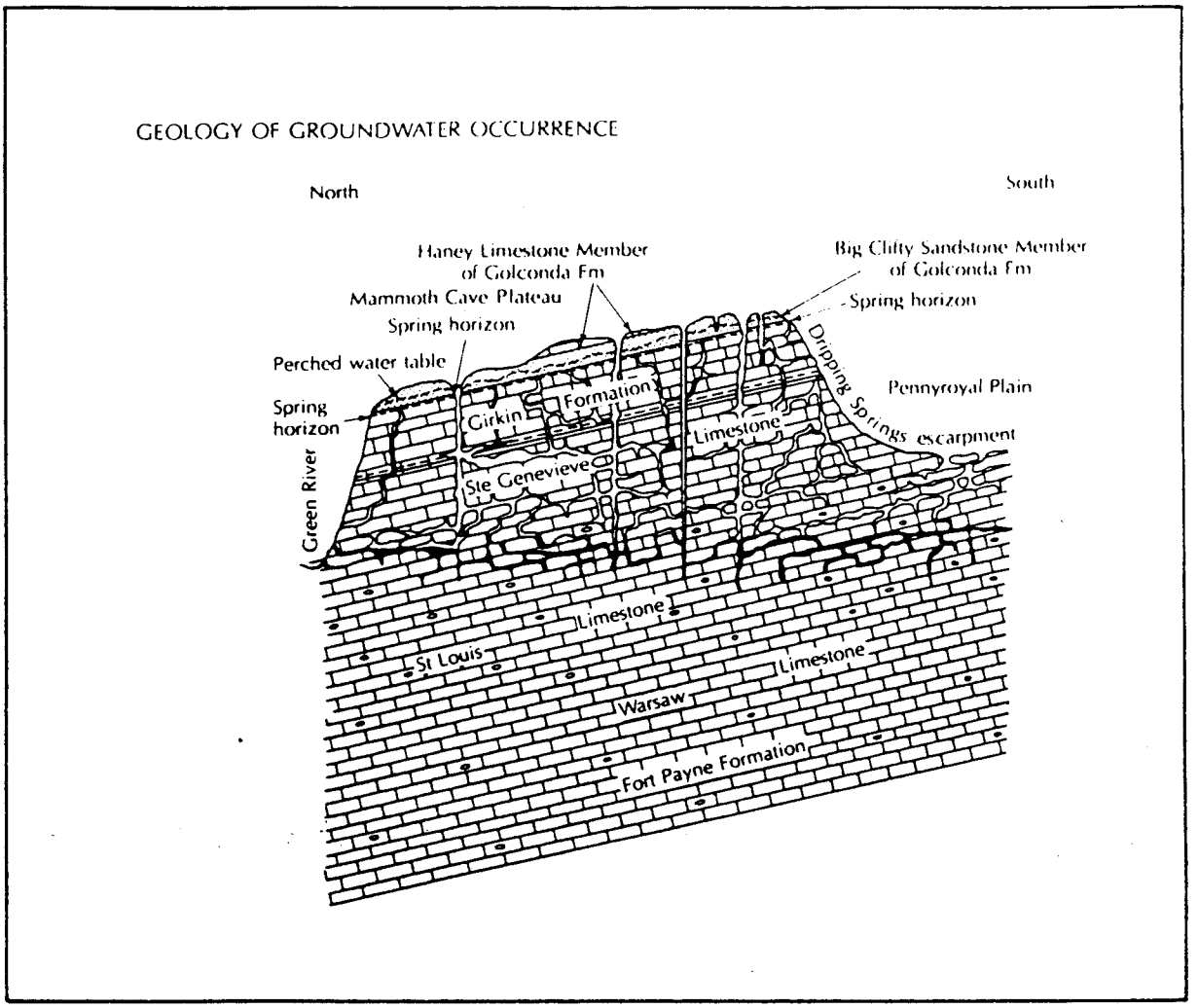


FIGURE 5–14: Ground–Water Flow in the Carbonate Aquifer of Mammoth Cave Plateau. (Source: Fetter, 1980)

5.3.1 Surface Water

5.3.1.1 Information Needs

Relevant factors in the surface hydrologic setting include the following:

- Regional precipitation and evapotranspiration rates
- Location and size of all surface water bodies
- Water volume, flow rate, and direction
- Drainage network
- Hydraulic connection between surface water and ground water
- Soil hydraulic properties (infiltration surface run-off rates)
- General water chemistry and use.

Meteorological information can be used to predict maximum shaft inflow rates during the reopening and operational phases of the repository, as well as a post-closure inflow rate in the event of seal or plug failure. This information should be applied when designing and installing sumps and pumps at the bottom of mine shafts and designing temporary and permanent plugs to seal off openings to the surface. Even those repositories sited in relatively dry regions may be subject to the effects of torrential rainfalls and/or mud slides at their portals. Therefore, maximum and average seasonal rainfall information should also be included in the discussion of the site meteorological conditions.

All surface water bodies that are present above and near the host repository formation should be identified and characterized. The areal coverage for identifying surface water bodies and drainage is site-specific but a minimum of a 4-mile radius should be characterized. Maximum volume of water and flow rates should be determined for all rivers, streams, creeks, ditches, lakes, sumps and ponds. Drainage in the surface area above the repository site and in the region should be described and seasonal variations in drainage characterized.

Any hydraulic connection of surface water with ground water should be identified. Points of groundwater recharge by precipitation or stream loss, as well as groundwater and discharge into surface water bodies should be located. Precipitation infiltration rates should be determined, based upon soil hydraulic properties such as permeability, percent saturation, and clay content. Such evaluations should be correlated with geologic and topographic maps.

General water quality and use of the major surface water bodies should be described. Other available drinking water sources should be discussed. Ranges in values for general water quality indicator parameters, such as Mg, Fe, Ca, Ni, BOD, COD, and pH, should be determined. The potential for host repository rock dissolution in water from surface water bodies should be assessed based on the surface water chemistry and known water-rock reaction kinetics.

5.3.1.2 Characterization Methods

A field survey of the surface area above the repository site should be conducted in order to locate and characterize surface water and drainage networks. Regional hydrologic maps may be used to determine regional drainage patterns. Soil information may be obtained from the Department of Agriculture, Soil Conservation Service (SCS) of state and/or county offices. Regional meteorological information may be obtained from the National Climatic Data Center in Ashville, NC (see Section 12.0). Water quality and use data can generally be obtained for large surface water bodies from the State Public Health or Environmental Protection Agencies. Water table elevations may be determined from existing soil boring and well logs in the area. If more information is necessary, geophysical surveys or boring activities should be conducted.

5.3.1.3 Limitations to the Characterization

Most of the information cited above can be obtained from field surveys and existing data with a fair degree of accuracy. Problems may arise when defining the areal extent of the field study required to identify all potential surface water inflow points. Mines can receive direct inflow from stream beds almost a mile upstream from the mine portal.

5.3.1.4 Presentation of Data

The information should be described in text form and illustrated on surface topographic and/or hydrologic maps of about 1:5000-1:24,000 scale. SCS soil survey maps should be included along with discussion of soil hydraulic parameters. Surface water flow, volume, and quality data can be tabulated for the different water bodies in the area. Water use and available resources should be discussed. Surface water features (such as Figure 5-15) should be presented in map form.

5.3.2 Ground Water

The hydrogeologic setting should be characterized to the fullest extent to all cases. In particular the repository site location within the host rock formation should be correlated to all sources of ground water, including aquifers, underground sources of drinking water (USDW), and other rock fluid inclusions. The repository itself must not be sited in a formation containing an aquifer.

5.3.2.1 Information Needs

Ground-water location, aquifer characteristics, and ground-water chemistry are the main areas to be addressed in siting any repository. Specific issues under these subject headings are discussed below as they relate to different repository designs and host rock characteristics.

All ground-water sources that may adversely impact, or be affected by, the repository must be identified and located within the local stratigraphic and structural setting. Perched groundwater may also be found in the repository formation in the form of dissolution pockets and a variety of geologically- anomalous zones. Particular care must be taken in the case of siting repositories in salt domes, salt beds, or limestone to identify these fluid inclusions. For aquifers, especially underground sources of drinking water (USDW) as defined in 40 CFR Part 144, the depth to water aquifer rock, formation(s), and lateral and vertical extent should be defined.

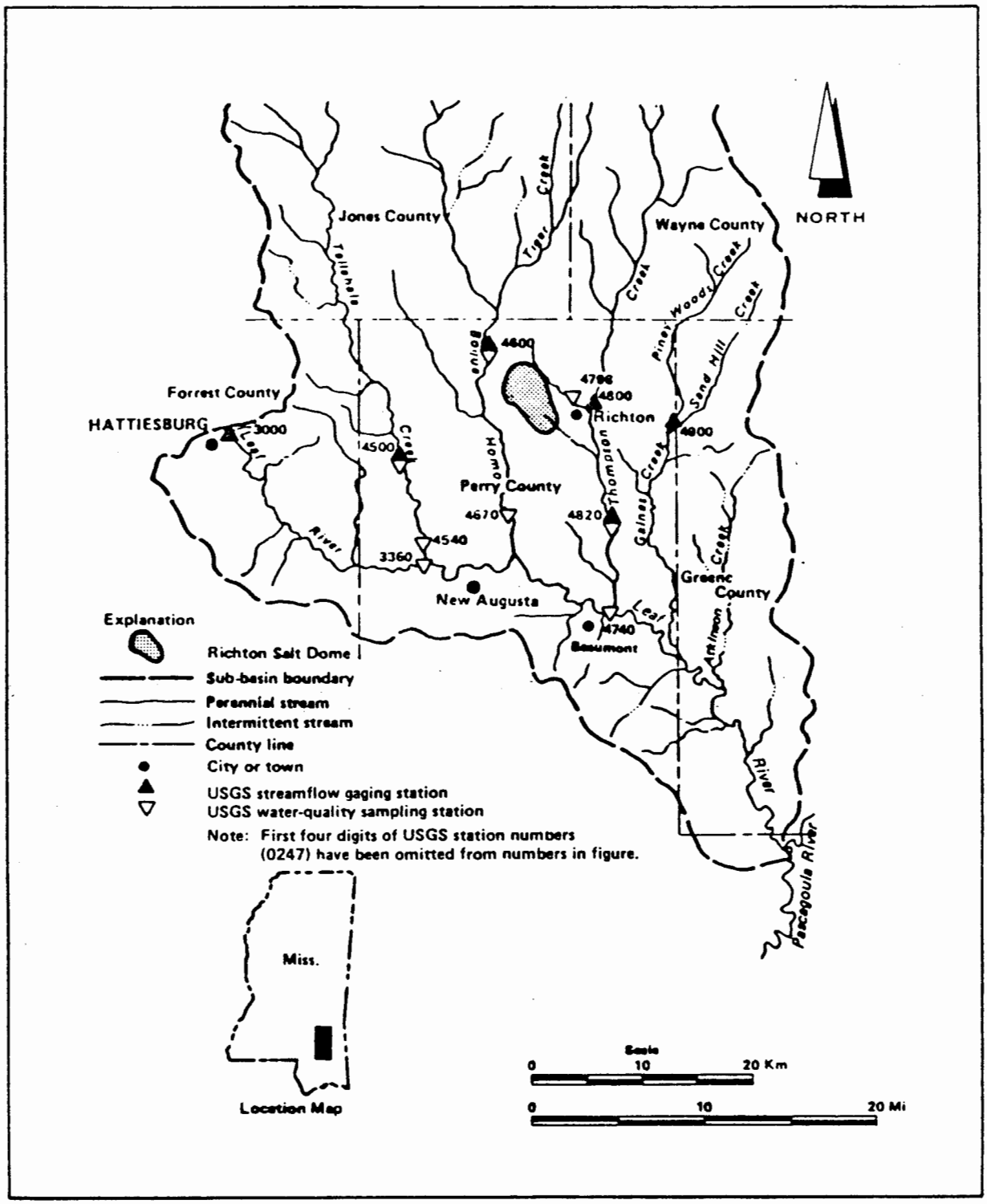


FIGURE 5-15: Surface Water Features in the Vicinity of Richton Dome. Source: EA, Richton Dome Site, MS)

Flow characteristics for all aquifers, including USDWs, should include the following parameters:

- General flow direction with respect to the repository (Figure 5-16)
- Flow type (i.e. fracture flow or flow through porous rock)
- Horizontal and vertical flow velocities
- Hydraulic interconnectivity points between aquifers
- Drawdown around wells in the area.

Velocities should be calculated, based on measured or assigned values, for rock permeabilities (or hydraulic conductivity), transmissivity, and storage coefficients for the vertical and horizontal components of flow. Potentiometric surfaces should be defined for confined aquifers. Recharge and discharge zones should be defined. These in-situ parameters should be incorporated into a 2-dimensional transient solute transport model along with external factors, such as drawdown around wells in the area.

Flow parameters are difficult to evaluate in the case of ground water flowing in fractured rock. Detailed knowledge of orientations and apertures is required in order to calculate equivalent porous media properties, such as hydraulic conductivities and transmissivities. Such detailed knowledge is rarely possible to obtain. Thus, there will be large uncertainties in the characterization of ground water flow through fractured media.

General chemical properties to be defined for ground water in each aquifer include the following:

- Salinity in total dissolved solids
- Mineralization
- Dissolved gases
- Radiogenic content
- Age determination
- pH, Eh

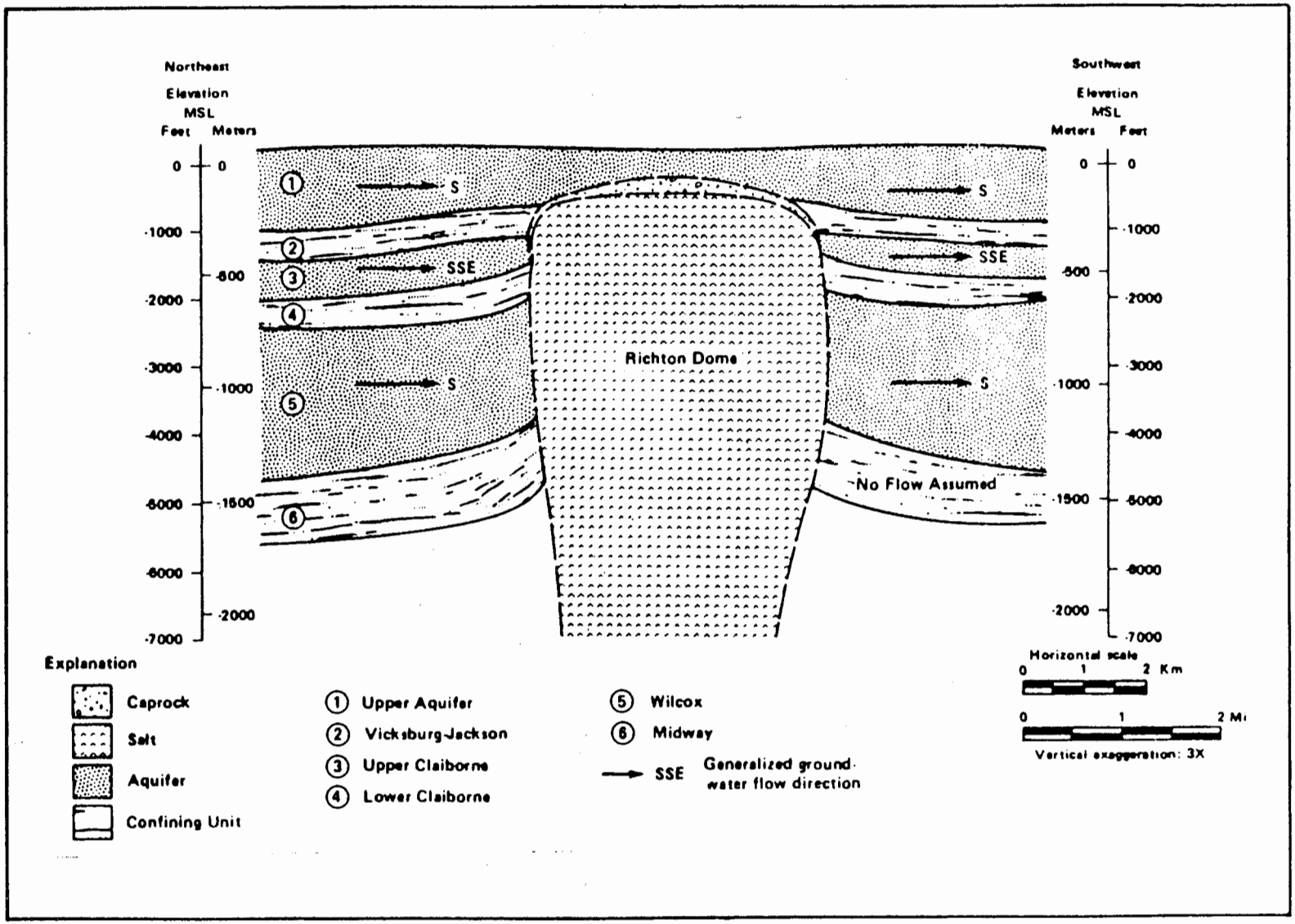


FIGURE 5-16: Generalized Ground-Water Flow Directions near Richton Dome. (Source: EA, Richton Dome Site, MS)

- Drinking water quality parameters
- Microbiological activity
- Temperature
- Indicator chemicals.

Salinity determines the aquifer's potential to be used as a drinking water source and is the basis for identifying USDWs. It is also critical when defining dissolution rates of water soluble repository formations. Mineralization, dissolved gases, and radiogenic content define the influence of rock and in-situ gases (e.g., methane, carbon dioxide, and radon) upon the aqueous chemistry. The age of ground water is derived from the stable isotope chemistry (i.e., ratio of 0 18 to 0 16) and is useful in determining the amount of movement of water and contact with surface precipitation waters. The pH and redox potential (Eh) are critical parameters for aquifers which may have contact with the repository formation and engineered hydraulic barriers (e.g, casing lining, plug, and sealant materials in shafts and openings). Drinking water quality parameters may be used to define the existing levels of specific chemicals and any contamination of the ground water. Identifying microbiological organisms may be useful in ground water fate and transport modeling when defining degradation rates and resulting attenuation of waste constituents. The temperature of the water is important when defining water rock reaction kinetics and the geothermal gradient at the site.

5.3.2.2 Characterization Methods

A combination of geophysical surveys, field ground water testing and sampling, and laboratory analyses are needed to characterize the hydrogeologic setting around the repository.

Surface geophysical techniques (e.g., electrical resistivity) should be employed to locate ground water in large fluid inclusions and aquifers. The results should provide the basis for developing a monitoring and test well program around the repository site.

Ground-water flow direction and rates can be determined from piezometric head readings and hydraulic testing methods in wells drilled into the aquifers around the repository. Effective porosity, transmissivity, permeabilities and storage coefficients can be calculated from the hydraulic test results and/or known or carefully assumed rock properties.

Deriving flow parameters in fractured aquifer formations requires additional and intensive geophysical investigations and rock coring to locate and characterize the fractures in the rock. Fracture densities and orientations may be used to estimate the vertical and horizontal flow rates and flow direction.

Laboratory chemical studies should follow EPA-approved methods for drinking water parameters (salinity, dissolved gases, pH, Eh). For the other parameters, generally accepted procedures should be employed. Sample container, preservation, and holding times should follow EPA recommendations. Chain-of-custody procedures should be observed from sample collection through sample analysis and disposal. Quality control/quality assurance is necessary during field operations and laboratory analysis. Information on ground water sampling and analysis and quality control/quality assurance measures is readily available in other EPA guidance and technical resource documents (See Section 12.0) and will not be discussed in this document.

5.3.2.3 Limitations to the Characterization

The major limitations in characterizing the hydrogeological setting include the following factors:

- geophysical resolution of subsurface structures and ground water
- location of boreholes and monitoring wells.

Geophysical methods will resolve the major structures and ground water regions to a certain depth below the surface. Uncertainties will remain in relation to fracture flow characterization. The state-of-art modeling of groundwater flow through fractured

rock has not yet achieved acceptable accuracy in most cases. These factors represent the greatest uncertainty in siting geologic repositories.

5.3.2.4 Presentation of Data

Tables, figures and maps are quite useful in illustrating the hydrogeologic setting. Raw data from geophysical surveys may be included, along with a cross section correlating the structure and stratigraphy with the location of aquifers and solution pockets relative to the repository site (Figure 5-17). Piezometric surface maps may be included for the identified aquifers showing location of monitoring, test and existing wells. Flow nets and piezometric surface maps should be provided for each aquifer. Hydraulic conductivities and transmissivities should be specified along with equations and methods used to derive them. Chemical data should be tabulated and detailed discussions of well installation, testing, sampling, and chemical analysis procedures provided.

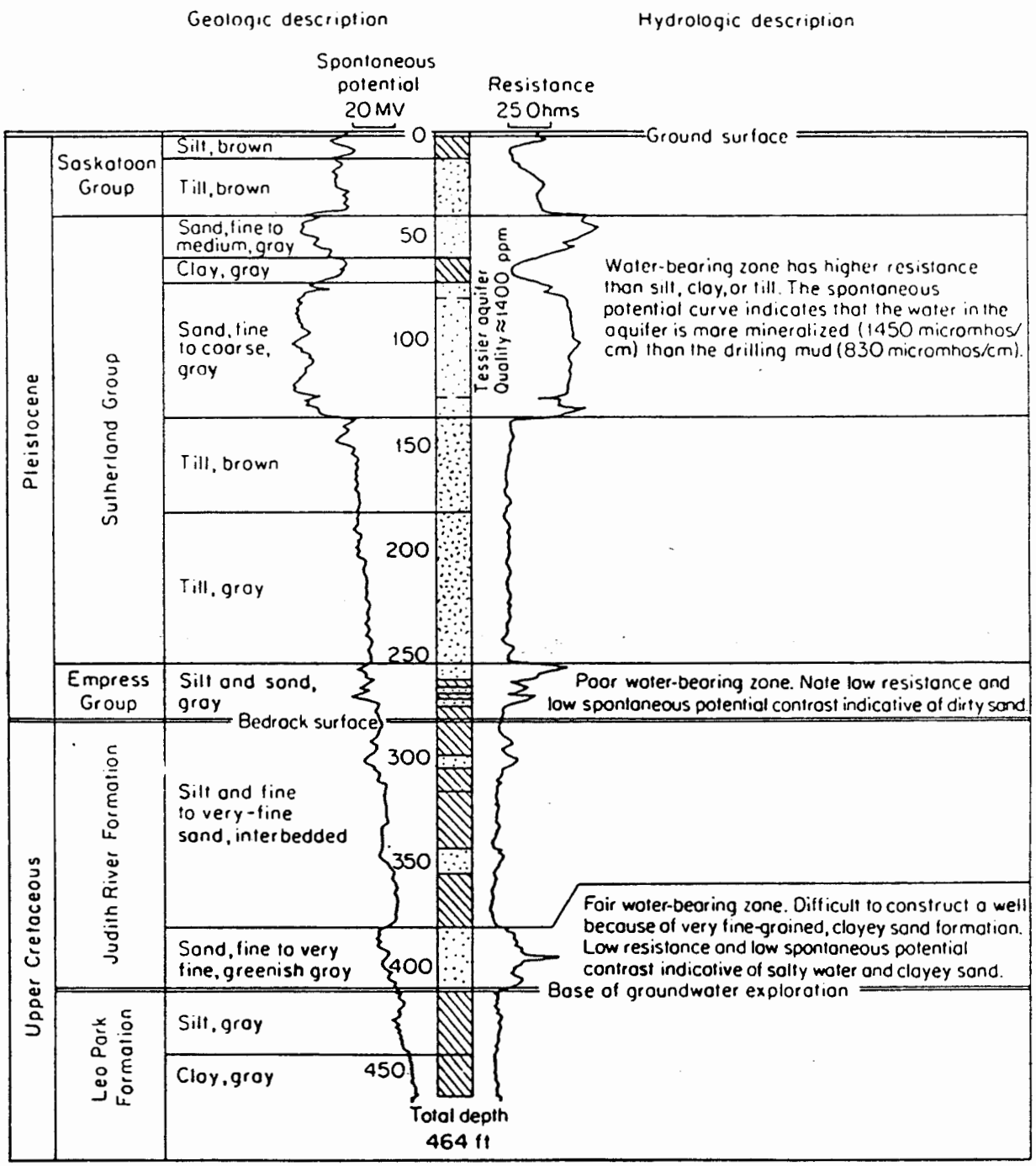


FIGURE 5–17: Geologic Log, Electric Logs, Geologic Description, and Hydrologic Descriptions of a Test Hole in Saskatchewan. (After Christianson, et al., 1971). (Source: Freeze and Cherry, 1979)

EXHIBIT 5-1

APPENDIX OF GEOLOGIC TERMS

Breccia: Fragmental rock whose components are angular and therefore, as distinguished from conglomerates, are not waterworn.

Compression: A system of forces or stresses that tends to decrease the volume or shorten a substance, or the change of volume produced by such a system of forces.

Dip: The angle at which a stratum or any planar feature is inclined from the horizontal. The dip is at a right angle to the strike.

Geochemistry: Geochemistry may be defined very broadly to include all parts of geology that involve chemical changes, or may be focused more narrowly on the distribution of the elements.

Histogram: Multiple-bar diagram showing relative abundances of specimens, materials, or other quantitative determinations divided into a number of regularly arranged classes.

Mineralogy: The science of the study of naturally formed chemical elements or compounds having a definite range in chemical composition, and usually a characteristic crystal form (minerals).

Orogeny: The process of forming mountains, particularly by folding and thrusting.

Orientation: The assignment or imposition of a definite direction in space.

Piezometric: An imaginary surface that everywhere coincides with the static level of the water in the aquifer.

Rose diagram: Circular or semi-circular diagram for plotting strikes (or dips) of planar features, such as joints, dikes, etc.

Slickenside: Polished and striated (scratched) surface that results from friction along a fault plane.

Stereo net: A coordinate system used to plot a two-dimensional array of points, each representing the orientation of a single plane in three dimensions.

Strain: Deformation resulting from applied force; within elastic limits strain is proportional to stress.

EXHIBIT 5-1

APPENDIX OF GEOLOGIC TERMS (CONTINUED)

Stratigraphy: That branch of geology which treats the formation, composition, sequence, and correlation of the stratified rocks as part of the earth's crust.

Stress: The intensity at a point in a body of the internal forces or components of force which act on a given plane through the plane.

Strike: The course or bearing of an outcrop of an inclined bed or structure on a level surface.

Structural geology: Study of the structural (as opposed to the compositional) features of rocks; of the geographic distribution of the features and their causes.

Tectonic: Of, pertaining to, or designating the rock structure and external forms resulting from the deformation of the earth's crust.

Tension: Stress caused by pulling. Opposed to compression, and distinguished from torsion.

Source: Dictionary of Geological Terms, American Geological Institute

SECTION 6.0

REPOSITORY DESIGN AND OPERATION

This section presents repository design and operation considerations that should be described in the Part B permit application to demonstrate compliance with the performance standards in 40 CFR 264.601. The focus of this discussion is on standards applicable to subsurface portions of facilities during the active life of the repository. Additional design considerations applicable to closure and post-closure care period are discussed in Section 10.0. Other guidance manuals are available describing the design and operating requirements applicable to surface facilities used to manage hazardous wastes such as tanks and waste piles (refer to Section 12 for a listing of those information sources).

The Subpart X regulations do not provide specific design or operating requirements. However, they do contain environmental performance standards that require repositories to be located, designed, constructed, operated, maintained, and closed in a manner that will ensure protection of human health and the environment (40 CFR 264.601). Permit applications should contain descriptions of repository design and operation sufficient to demonstrate compliance with the performance standards.

Geologic repositories may involve a broad range of design and operating practices. For example, solution-mined caverns in salt domes may be designed to accept waste through a relatively narrow shaft, with no human activity required inside the mine, while room- and pillar mines may require workers and heavy equipment inside the mined space. To the extent that repository designs and operating procedures differ, the information presented in their respective permit applications will differ. However,

the Part B application for any repository will generally need to address at least the following four factors critical to demonstrating proper facility design and operation:

- Structural Stability
- Hydrologic Isolation
- Waste Emplacement Methods
- Worker Safety and Health.

The additional demonstrations required relative to repository design and operation for obtaining a no-migration variance will typically entail longer-term projections of stability and isolation characteristics than for facilities not seeking variances. The latter facilities must demonstrate suitable stability and isolation for their active life and the post-closure care period, whereas facilities requesting a variance must provide demonstrations that will be valid for as long as the wastes in the repository remain hazardous. Facilities from which all wastes and waste residues will be removed at closure (i.e., storage repositories) need only demonstrate suitable performance during their active life.

6.1 Structural Stability

The geologic repository, including shafts, drifts, and caverns associated with disposal operations should be designed to ensure the structural integrity of the unit. Stability of the repository and overlying rocks is dependent mainly upon the strength of the host rock materials. Therefore, the strength and stress-strain relationships of the host rock and any engineered support materials that comprise walls, ceilings, or floors of any underground opening must be determined. The required mechanical properties of host rocks were discussed in Section 5.2. Repositories should not be sited in formations or portions of formations that contain weak or highly fractured rock; however, reliance on engineered materials, such as concrete and steel, may be required in openings that penetrate weaker rock formations overlying the repository formation. The host rock mechanical properties must also be considered when determining repository depth. A sufficient distance from other artificial penetrations

(e.g., abandoned wells or mine areas) and sufficient depth should be maintained to ensure repository structural stability.

Mining methods used to open or reopen the mined space are dependent upon host rock strength characteristics and must be selected to minimize structural damage and the potential for cave-in or blow out. These issues are discussed further below with respect to conventional mines and solution-mined caverns.

The structural stability of the repository must be assured in the permit application and should be routinely verified throughout its operating life. The permit application should contain the descriptions, methods, and results of the initial structural stability studies as well as descriptions of the frequencies and methods of inspections that will be formed during the repository construction and operating life. This will assure that adequate structural stability is maintained throughout the repository operating life.

6.1.1 Strength of Natural and Engineered Materials

Information and analyses of mechanical properties of man-made materials can be obtained from various science publications. Such literature should be reviewed and presented in the Part B permit application for all materials involved in the support of underground openings. The mine openings and caverns should be designated to remain intact with minimum maintenance during the active life of the repository. Additional mine space or openings not used in repository operations should be properly backfilled and sealed to prevent collapse and/or water inflow to the repository. As described in Section 10 of this manual, closure of the repository will require proper sealing and/or backfilling to maintain the structural integrity of the repository and the overlying strata.

In the case of repositories in salt domes, the rock characteristics and stability of the cap rock must be assessed. The cap rock may contain complex mineralogical assemblages and cavernous spaces with fluid and gas inclusions. Shafts and well

casings in these rocks may require additional supports (e.g., stainless steel stringers) that can provide structural integrity during uplift, domal growth, and creep closure of the salt dome and changing mineralogical conditions in the cap rock (Figure 6-1).

6.1.2 Location Within the Formation

Location of the geologic repository and associated structures within a formation is an important factor when evaluating the structural stability of the repository design. The depth of the opening and the distance from other openings within the formation and the formation boundaries must be considered with respect to the host rock strength characteristics and size of the opening. Given host rock strength and required spacing of the openings, a suitable depth within the formation and thickness of walls (or pillars), ceilings, and floors must be demonstrated.

For solution-mined caverns in salt domes, empirical design parameters are generally used. Figure 6-2 illustrates these parameters, including thickness of pure salt stock above the cavern, the thickness of salt between the cavern and the margin of the dome, the ratio of the thickness of salt (web) between caverns and the diameter of the caverns, and the ratio of the height of the cavern to the diameter of the cavern. A lower cavern depth limit of 5,000 to 7,000 feet below the ground surface is a generally-accepted standard based on projected creep rates for salt at these depths. While mathematical models and techniques are available that predict cavern stability, their accuracy is questionable and generally not acceptable unless verified with empirical design parameters (Seni, et al, 1985).

Varying standards and criteria for design of conventionally-mined openings have been adopted by the District Manages of the sixteen MSHA mining districts. Design standards in districts may be based on engineering calculations and/or experience. Plans for reopening or developing mines in the different districts should be reviewed for structural integrity following generally accepted approaches in the mining district where the repository is sited.

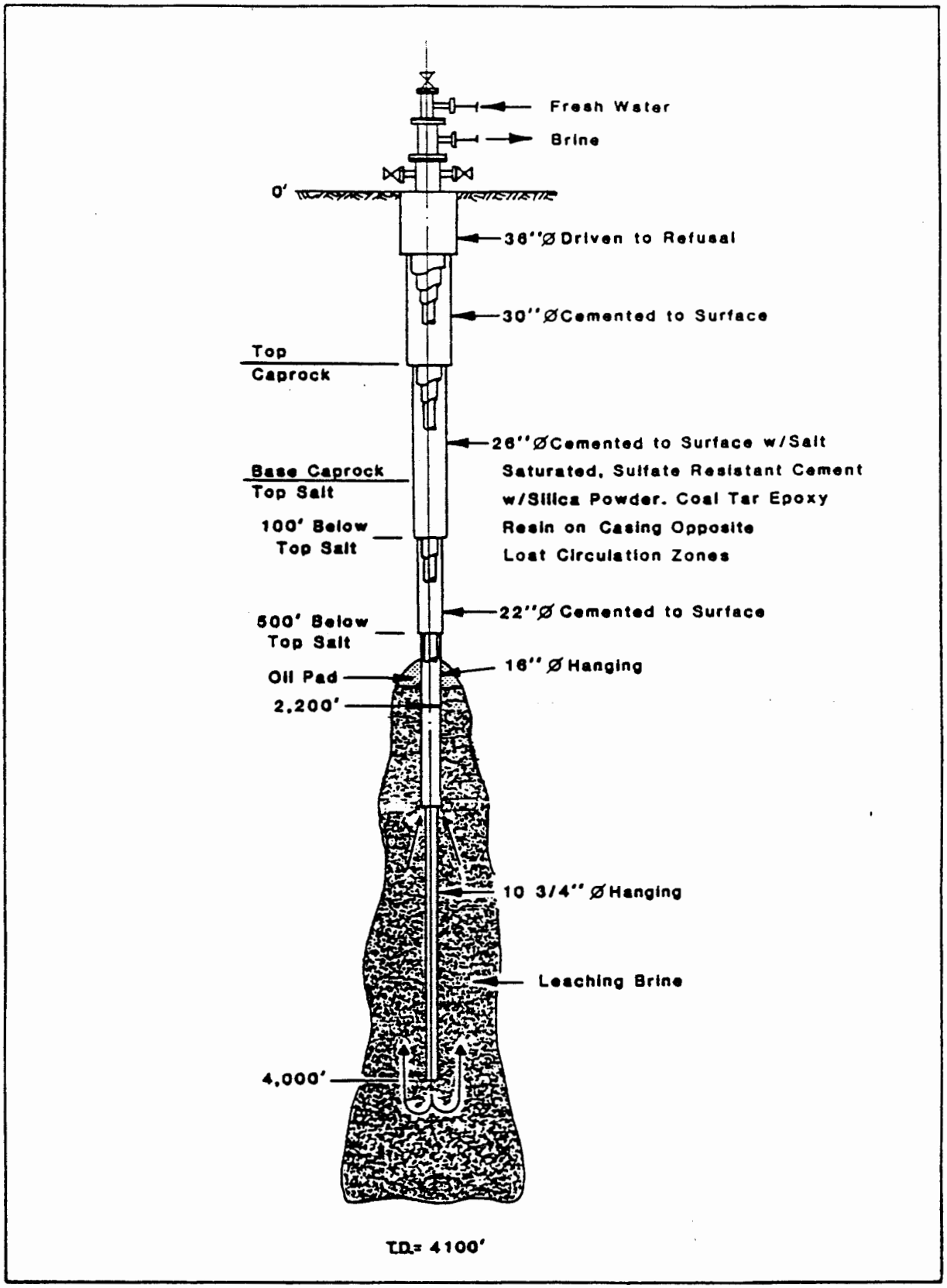


FIGURE 6-1: Solution-mined cavern construction in a salt dome. (Source: URM, 1986).

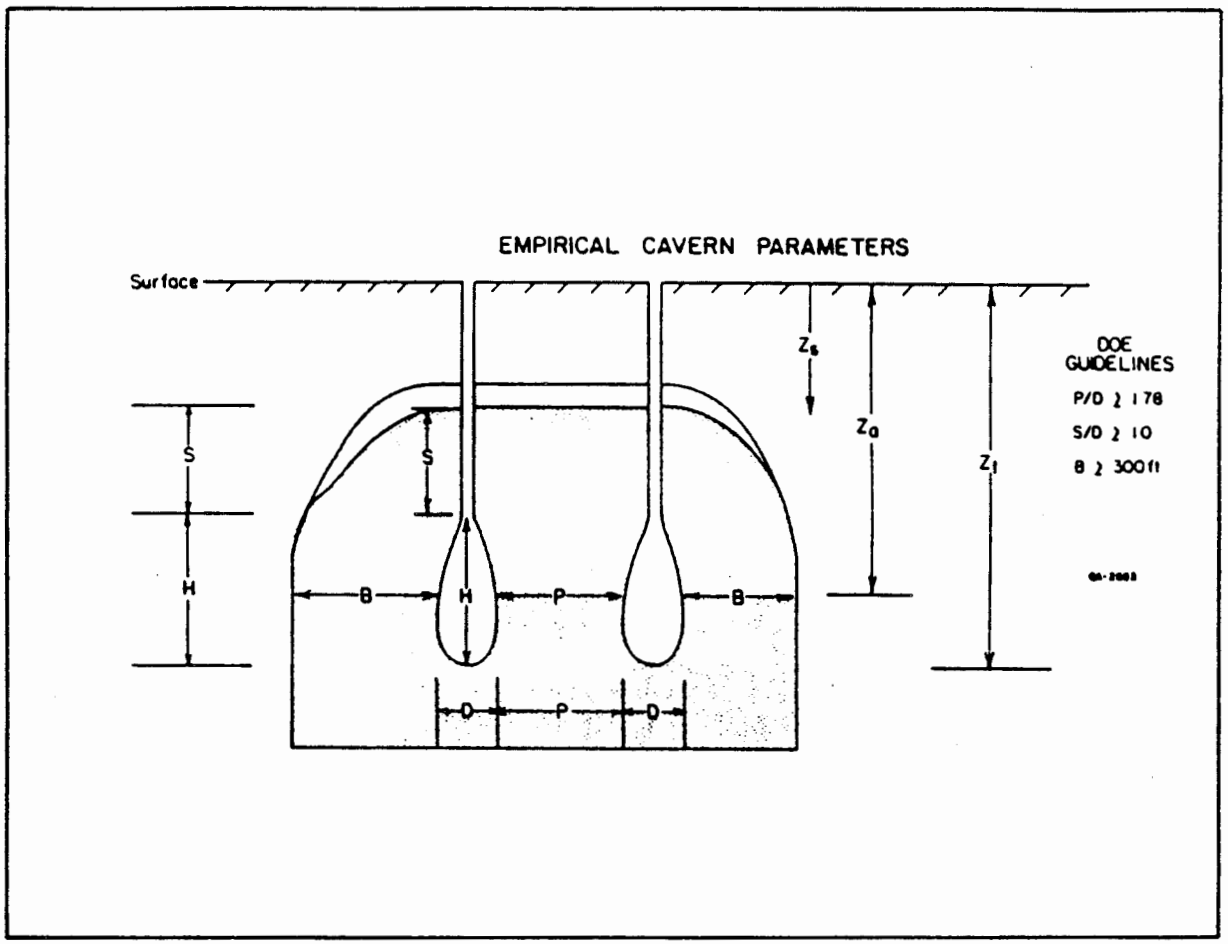


FIGURE 6–2: Cross–section Showing Empirical Spacing Relationships for SPR Caverns. (Source: Seni, et al., 1985)

6.1.3 Summary of Structural Stability Concerns

Designing, constructing, and operating mined openings for disposal of hazardous waste must take into account mechanical properties of the wall and host rock material. Rock strength characteristics determine whether additional structural support systems are required (e.g., shotcreting, mesh and bolts, timber or steel sets). These characteristics provide guidelines for locating the mined- space within the formation and selecting appropriate mining methods. Mining methods requiring artificial support generally appear unsuitable, as they typically indicate poor structural stability or waste isolation characteristics of the host rock. Room-and-pillar and solution mining appear the most suitable mining techniques for repository formations when used in rocks having sufficient strength to support the overburden and waste loads without significant need for engineered support and maintenance.

The permit application should identify the mechanical properties of the host and wall rock formations; specify depths and thicknesses of ceilings, walls, and floors; and provide dimensions of the mined space. Strength characteristics should be presented in the permit application for the expected pressure, temperature, and in-situ stress conditions, and the depth and size of the opening. The application must include design plans and discussions of the rationale for those design specifications.

Design specifications may be derived empirically or mathematically, as appropriate. Engineering analyses and plans for providing certification of the structural stability of the mined space by a qualified mining or geological engineer should be submitted along with the design plans. The plans should allow the areal extent of the repository and associated workings, as well as cross-sectional views. Detailed descriptions of support structures, hydraulic barriers, and holding and disposal areas should be included in the drawings.

If engineered structures are required in the repository, design plans should illustrate where they are needed. A discussion of the structural integrity and performance of the engineered and natural support systems at these locations must

included. Schedules and procedures for conducting repairs, maintenance, and inspections of these areas should also be included.

6.2 Hydrogeologic Isolation

Structural issues discussed in section 6.1 also affect the hydrologic isolation capabilities of the repository. The need for additional design and operation considerations specific to hydrologic isolation should be addressed in the Part B application, including shaft liners and shaft seals.

In theory, all mined openings leading to the ground surface have a potential for water entry, either from surface precipitation or from ground water situated in overlying or surrounding formations. The potential for surface and/or ground-water penetration into the repository must be assessed and, where the potential exists for mobilization of hazardous constituents of the wastes from such entry, engineered systems must be designed and operated to minimize leakage into the repository.

In cases where the repository host formation is situated below aquifer formations, lining or casing of the aquifer penetrations with cement or other relatively impermeable, strong materials is recommended to prevent ground water from entering the mine. Solution-mined caverns should generally have shafts with two or more casings and strings that provide structural support as well as a barrier to ground water penetration. The casing or lining material must be compatible with ground water to ensure long-term waste isolation. The ground waters' pH and redox potential must be determined in order to assess shaft material suitability. In cases of conventional mines with large openings to the surface, pumps and sumps may be installed at the bottom of the shaft to collect and remove any surface rainwater infiltration during periods of worker activity in the mines. In these instances, the repository area should be located away from these openings to reduce the potential for waste-water interaction. Repository areas sealed with temporary plugs should be monitored to determine conditions behind the plugs before the plugs are removed.

Depending on surface and subsurface conditions, unused openings to the repository may require sealing to prevent precipitation and ground water from entering the cavern. Seal design and performance requirements are addressed in Section 10 of this manual.

The permit application should identify the location of all underground structures relative to ground water and identify all potential pathways for water leakage into and out of the repository. Descriptions of the planned design, construction, and maintenance of all ground-water barriers should be provided, including shaft seals and penetration linings and casings. The long-term effectiveness of these hydrologic barriers and their structural stability and corrosion resistance should be demonstrated based on empirical data, laboratory tests, field test, and accepted theoretical performance models.

The permit application should also contain descriptions of the inspection procedures and frequencies that will be employed to insure that sufficient hydrogeologic isolation is achieved during construction and operation. Consideration should be given in the inspection plans to assessing the nature, source, and impacts of any water found to be entering the repository.

6.3 Waste Emplacement

Waste handling and storage methods utilized in geologic repositories should promote the long-term isolation and stability of the waste within the repository and ensure worker safety and health. This section discusses different waste emplacement methods and appropriate application content. Inspection procedures and schedules that will insure continued satisfactory functioning of waste emplacement devices and structures should also be included in the application.

6.3.1 Manual Emplacement of Waste

The permit application must provide a complete description of the equipment and procedures for conveying wastes from the surface to disposal areas in the repository. If elevators are used to lower wastes into the repository, engineering and operating

details should be provided for each elevator, including capacity, dimensions, safety features, loading/off-loading procedures, and inspection frequency and procedures. If waste drop chutes are employed, the application should provide a drawing showing dimensions and location of the chutes as well as charging and discharging/collection procedures. Where bulk wastes are dropped into a repository, dust control methods must be clearly described.

The numbers, types, and capacities of equipment used to move wastes within the repository should be identified in the application. If containerized waste is placed in the repository, the container stacking method(s) must also be described. The safety of the proposed stacking method(s) and maximum safe stacking height should be demonstrated. The need to provide internal cavern support and hydrologic isolation by backfilling voids during waste placement should be addressed. If backfilling is indicated, the proposed method should be described, including the materials to be used and the long-term settlement/subsidence potential of the wastes as placed.

Waste movement routes within the repository should be clearly identified in the application. Appropriate traffic controls and operating procedures to be utilized in underground portions of the facility must be described in the application.

The application must describe the potential for contamination of areas of the repository not designated for waste emplacement. Waste loading, transport, unloading and emplacement activities should be conducted to minimize such contamination. As necessary, methods for equipment and repository decontamination that will protect workers and prevent the uncontrolled spread of hazardous wastes and waste constituents should be developed and described in the application.

6.3.2 Remote Emplacement of Waste

Certain repositories, such as solution-mined caverns in salt domes, may be designed to allow remote waste emplacement with no worker presence required underground. The effectiveness of dust control methods should be described and the

degree of compaction achieved within the repository (i.e., ultimate void space) identified. The long-term subsidence potential of the waste mass and potential impacts of subsidence on repository stability should be determined.

The shaft through which wastes are charged must be adequately sized to prevent jamming and appropriate supporting demonstrations provided in the application, considering the physical form of the wastes, waste charging rates and the geometry of the drop chute. Methods for periodically assessing the level of wastes within the cavern to verify projected compaction should be provided. Drop-charging of containerized wastes should not be conducted unless it is positively demonstrated that no risk of explosion, fire, or repository damage exists and that long-term settlement of wastes due to container decomposition will not impair the repository's structural integrity or isolation capabilities.

6.4 Occupational Safety and Health

Standards promulgated by MSHA for mining operations may be appropriate in certain cases involving development or modification of existing mined spaces. Nevertheless, OSHA standards must be applied at all repositories during the operation phases. Standards promulgated by OSHA in 29 CFR 1910 regulate several aspects of worker safety and health at hazardous waste repositories. The OSHA standards applicable to repositories include requirements for:

- Safety and health risk analysis
- Employee training
- Personnel protective equipment
- Medical surveillance
- Decontamination procedures
- Standard operating procedures for waste management
- Contingency planning
- Confined space entry procedures.

Applicants should consult OSHA for guidance concerning these standards; additional guidance concerning compliance with OSHA standards is not addressed in this manual. However, many aspects of facility operation governed by OSHA affect the content of RCRA Part B permit applications. For example, employee training requirements under OSHA contain specific provisions not included in RCRA training requirements. To avoid inefficiencies, the training program outlined in the Part B should incorporate all applicable OSHA requirements.

Additional design and operating measures appropriate to protecting worker safety and health are recommended by EPA for repositories requiring an underground worker presence. These measures include provision of adequate ventilation, designs to allow timely evacuation of workers from underground areas, and fire protection measures.

6.4.1 Repository Ventilation

The application should contain a written ventilation plan for the repository. The plan should demonstrate that adequate fresh air will be supplied to all areas of the repository where worker presence may be required. Adequate ventilation will typically require a system of main and booster fans and associated dampers, vents, and control equipment. Changes to the repository, such as the opening or closing of rooms or shafts, or changes in equipment use, should be preceded by a revision in the ventilation plan. Main and booster fans installed and used to ventilate active areas of the repository should be operated continuously when workers are underground. In the event of a ventilation system failure, all workers underground in the affected areas should be withdrawn, except those working on the fan. Ventilation should be restored and air quality in the affected areas tested to assure it is safe to breathe prior to allowing workers to reenter the repository.

The ventilation plan should contain, where applicable, the following:

Schematic. A map or schematic of the repository on a scale not smaller than 1:24,000 showing:

- Direction and quantity of principal air flows
- Locations of seals to be used to isolate closed or unused areas of the repository. Seals should be provided with a means for checking air quality behind the seal and a means to prevent a water head from developing behind the seal, unless the seal is designed to impound water
- Locations of areas withdrawn from the ventilation system
- Locations of overcasts, undercasts, and other airway crossover devices designed to allow return and intake air to cross without mixing
- Locations of known oil, gas, or water wells, to a radius of 2 miles
- Locations of permanent underground shops (facilities intended to exist for one year or more), oil fuel storage depots, hoist rooms, compressor, and battery charging stations
- Significant changes in the ventilation system projected for the future.

Fan Data. Repository fan data for all main and booster fans to be used including manufacturer's name, type, size, fan speed, blade setting, approximate pressure at operating point, and motor brake horsepower rating. All underground main fans should have controls placed at a protected location remote from the fan and preferably on the surface.

Operating Descriptions. Diagrams, descriptions, or sketches showing how ventilation is to be accomplished in each working place including the approximate quantity of air provided, and size and type of auxiliary fans used. When auxiliary fan systems are used, the systems should minimize recirculation and be maintained to provide ventilation air that effectively sweeps active areas of the repository. Ventilation doors should be substantially constructed, covered with fire-retardant material (if constructed of wood), equipped with audible or visual warning devices (if

mechanically operated), and should be kept closed as much as possible to maintain normal ventilation in active areas of the repository.

Air Contaminant Sources. The number and type of internal combustion engine units to be used underground, including make and model of unit, type of engine, make and model of engine, and brake horsepower rating of engine.

Dust Control Systems. Diagrams and operating capabilities of any equipment to be used to remove and collect dusts from the repository.

Inspection Plans. Inspection procedures and frequencies for critical components of the ventilation system. Inspection plans should identify the equipment that will be inspected and the types of potential problems for which the equipment will be inspected.

6.4.2 Evacuation Precautions

Repositories requiring underground worker presence must be designed and maintained to facilitate timely evacuation in the event of emergencies or ventilation system failures. It is recommended that at least two access shafts to the surface be equipped to allow human agress. The evacuation methods used in these escape routes should not depend on an interuptable power supply that could fail in the event of an emergency. It is recommended that evacuation shafts provide a fail-safe non-powered means of escape, such as ladders or hand-powered hoists, as a backup to any powered means of evacuation. The permit application should identify the design features of the repository that allow for timely evacuation from any underground area where workers may be present.

6.4.3 Fire Protection

Repositories requiring worker presence underground must be designed and maintained to prevent fires and, in the event of a fire, maximize worker protection during

evacuation. Specific design measures recommended include control doors at surface access points and fire-proofing measures for ventilation fans.

Control doors should be located at or near shaft stations of intake shafts and any shaft designated as an escapeway or at other locations that provide equivalent protection. It is recommended that the doors be constructed and maintained to meet MSHA requirements specified in 30 CFR 57.4760. Provisions for remote closure of the doors should be made at landings of timbered intake shafts unless a person specifically designated to close each door in a fire can reach the door within three minutes. Doors should only close or open according to predetermined conditions and procedures. The doors should not reopen due to differential in air pressure. One person should be able to manually open the doors from either side and the doors should not be obstructed.

In lieu of control doors, mechanical ventilation reversal with a fan should be used to provide at least the same amount of protection as doors. Ventilation should be accomplished by a main fan. If the main fan is located underground, several specifications should be met:

- The cable or conductors supplying power to the fan should be routed through areas free of fire hazards.
- The main fan should be equipped with a second, independent power cable or set of conductors from the surface; the power cable or conductors should be located so that an underground fire disrupting power in one cable or set of conductors will not affect the other.
- A second fan capable of accomplishing ventilation reversal should be available for use in the event of a main fan failure. The ventilation system should provide rapid air reversal that allows workers time to exit to fresh air by a second escapeway or find a place of refuge according to predetermined conditions and procedures.

Fan installations should be made of noncombustible materials. Areas within 25 feet of fans should be free of combustible materials, except installed wiring, ground and track support, headframes, and direct-fired heaters. Other timber should be coated with one inch of shotcrete, one-half inch of gunite, or other noncombustible materials.

Abandoned electric circuits should be deenergized and isolated so they cannot be inadvertently energized. During operations in shafts or vertical or inclined passageways involving the use of open for electric arcs (such as welding or soldering), or when falling sparks or hot metal from work performed in a shaft or passageway could pose a fire hazard, special fire prevention measures should be taken. A multipurpose, dry-chemical fire extinguisher should be at the worksite to supplement other fire extinguishing equipment. The affected area should be inspected during the first hour after the operation is completed. Additional inspections should be made or other fire prevention measures should be taken if a fire hazard continues to exist. In addition, one of the following fire prevention measures should be taken:

- Wet down the area before and after the operation, taking precautions against electrical shock
- Isolate any combustible material with noncombustible material
- Shield the activity so that hot metal and sparks cannot cause a fire
- Provide a second person to watch for and extinguish any fire
- Cover or bulkhead the opening immediately below and adjacent to the activity with noncombustible material to prevent sparks or hot metal from falling down the shaft or passageway.

Firefighting equipment should be inspected according to the following schedule:

- Visually once a month to determine that the equipment is fully charged and operable
- Annually for mechanical operation and integrity, the amount and condition of extinguishing agent and expellant
- According to the manufacturer's schedule to determine the hydrostatic integrity of extinguishing agent vessels
- Every three months for water pipes, valves, outlets, hydrants, and hoses to identify damage or deterioration
- Annually for fire suppression system and according to the manufacturer's schedule.

The inspector should certify that the inspection or test has been completed and record the date and results of the inspection.

The permit application should describe the fire protection afforded by the repository design and specify the inspection and maintenance procedures to be employed to assure continued proper operation of those systems.

SECTION 7.0

WASTE CHARACTERIZATION

Facility owners and operators must, at a minimum, obtain a detailed chemical and physical analysis of each waste managed that contains all the information that must be known to treat, store, or dispose of the wastes in accordance with applicable 40 CFR 264.13. This section identifies general waste analysis requirements applicable to all disposal facilities and suggests several parameters appropriate for wastes to be placed in geologic repositories.

Extensive guidance is available describing the development and implementation of waste analysis plans. Three EPA publications that should be consulted in the development of waste analysis plans are:

- Waste Analysis Plans--A Guidance Manual
- A Method for Determining the Compatibility of Hazardous Wastes
- Test Methods for Evaluating Solid Wastes--Physical/Chemical Methods (SW-846)

The latter document provides detailed sampling and analysis procedures that can be used in characterizing hazardous wastes.

The Part B application for a geologic repository must contain a listing of the pertinent physical and chemical properties of every waste type to be received for treatment and/or disposal, as well as a plan for verifying the content of wastes as they are received for treatment/disposal or are generated. The actual wastes placed in the repository may not necessarily correspond to the initial wastes characterized in the Part B permit application, but the owners or operators should, however, identify the physical and chemical properties of the wastes to be placed in the repository and any limits on waste types appropriate to assuring safe operation of the repository. Of

particular concern are those waste properties that could impact waste mobility or repository stability, such as volatility, reactivity, corrosivity, solubility in water and susceptibility to phase or species transformation. Summary data, such as total organic chemicals, is insufficient to meet the requirements for wastestream analysis.

7.1 Suggested Characterizations and Waste Limitations

Certain waste characteristics may produce undesirable results in the repository environment, either during the facility's active life or after closure. The limitations relevant to the repository must be identified and the wastes analyzed to assure that tolerance levels are not exceeded. The decision of suitable waste characteristics should be based on unit design and operating life as well as host-rock compatibility.

7.1.1 Reactivity

No waste that are explosive or shock sensitive should be placed in repositories. Wastes that could react to produce toxic gases (such as cyanide- or sulfide-bearing wastes) should also be excluded. Other waste reactivity characteristics should be assessed on a case-by-case basis to determine if the reaction products (e.g., heat or innocuous gases) could present a worker safety threat or compromise the repository's structural integrity or isolation characteristics. Gas generation is a significant concern after closure of the repository if the potential exists to produce back-pressures that could rupture seals or induce rock-mass fractures.

7.1.2 Ignitability

It is recommended that ignitable wastes (i.e., wastes with a measured flashpoint less than 140°F using EPA approved test methods) not be placed in underground repository areas owing to the potential risk associated with fires in such confined areas.

7.1.3 Volatility

Volatile wastes (i.e., those with high vapor pressures) should not be placed in underground repositories unless it can be demonstrated that worker health will not be compromised and that volatile emissions will be adequately controlled or will not present a threat to the environment or human health.

7.1.4 Waste Compatibility and Corrosivity

Wastes that contain materials that are incompatible with repository rock, engineered materials, formation gases, and other waste components or are corrosive to repository materials should not be placed in the repository without prior stabilization treatment. Empirical waste-waste compatibility data have been correlated and are described in "A Method for Determining the Compatibility of Hazardous Wastes." For gas-waste compatibility, the expected formation gases may be introduced to a vessel containing waste leachate and any reaction between the two media monitored over time.

Specific guidance on testing methods for other compatibility studies (such as waste-rock compatibility) have not been issued by EPA. However, a suggested approach for addressing the waste-rock or waste-seal compatibility involves immersing samples of rock and seal material in a vessel containing waste leachate maintained at the environmental conditions in the repository. Any gas or heat evolution or specimen dissolution can be measured over time to determine compatibility of the waste with the solid material. Limited work has been performed on waste-rock compatibilities. However, an EPA study identified some potential incompatibilities of wastes stored with selected rock types, including metal oxides, lead oxides, and fluoride compounds. These wastes were found to be incompatible for storage with rock salt because an unfavorable reaction occurred (Fenix and Scisson, 1975).

7.2 Waste Analysis Plan

The application must include a copy of the waste analysis plan indicating how the facility will ensure that analyses of hazardous waste received are accurate and up-to-date. The plan should include: (1) a description of how the waste analyses will

be performed; (2) a list of the parameters chosen for analysis and an explanation of the rationale for their selection; and (3) the test methods to be used to test for the chosen parameters. In addition, the plan should specify the sampling methods to be used to obtain a representative sample of each waste and a description of the frequency at which the analyses will be repeated. For wastes generated offsite, the procedures used to inspect and/or analyze incoming waste shipment should be described (including procedures to determine their identify and the sampling methods used to obtain statistically representative samples for analysis).

SECTION 8.0

PERFORMANCE MONITORING REQUIREMENTS

This section provides guidance on the permit application requirements related to performance monitoring at geologic repositories. Owners or operators of hazardous waste treatment, storage, or disposal facilities are required to monitor, test, and inspect the facilities to ensure that releases that may have adverse effects on ground water, surface water, or air due to migration of waste constituents from the facility do not occur.

The permit conditions specifying performance monitoring requirements for hazardous waste repositories will be formulated on a case-by-case basis. The requirements will largely depend on the repository setting and the nature of the wastes managed and must comply with 40 CFR 268.6(d)(2), (e), (f), and (1). Guidelines for ground-water, surface water, and air monitoring, and the requirement for leak/leachate detection and other repository monitoring systems are presented below.

8.1 Ground-Water Monitoring

The determination of the need for ground-water monitoring will be based on consideration of the following site-specific criteria:

- The degree of hydrologic isolation of the proposed repository site
- The nature of the wastes to be placed in the repository
- The presence of leak/leachate detection, collection, and removal systems.

Ground-water monitoring is required unless the permit applicant can successfully demonstrate it is not necessary. A successful demonstration must show:

- There is no potential for the movement of liquids from the repository to the accessible environment

- There is no potential for generation of hazardous leachate in the repository.

To demonstrate that there is no potential for the movement of liquids from the repository, the permit application must consider natural geologic discontinuities of the host rock, the location of aquifers, and the potential for flooding. Demonstrations of no potential for leaks or generation of leachate in the repository must consider the characteristics of the waste and the chemical composition of ground water in the repository area.

If ground-water monitoring is to be provided, the permit application must include a complete description of the monitoring well locations, depths, ability to detect releases, sampling and analysis procedures, and reporting procedures. These elements are described in detail in the 1986 draft RCRA Ground-water Monitoring Technical Enforcement Guidance Document. Also, the plan should include the constituents to be monitored, monitoring interval, duration of monitoring, and monitoring techniques.

Repository ground-water monitoring may differ considerably from typical ground-water monitoring. Notably, for a repository, the uppermost aquifer will typically not need to be monitored. Rather, the aquifer most likely to be affected by releases from the repository will be monitored. This may require wells that are several hundred feet deep. Special well construction and sampling provisions may be necessary. Factors that should be considered include:

- Corrosion-resistant well construction materials such as stainless steel casing and screening may be necessary to resist corrosion in sulfide rich environments often found in mines located in mineral districts

- Wells drilled through salt water aquifers may require grouting with cement containing additives to minimize corrosion of the cement

- It may be desirable to use in-site samplers that do not expose samples to the atmosphere (e.g., a syringe that places samples in an evacuated container) to sample deep wells. It may also be desirable to partition off the lower section of the well with a diaphragm or bladder to minimize the volume of water that must be pumped from the well before sampling.

If ground-water monitoring is required, monitoring well construction and placement, ground-water sampling and analysis procedures, data evaluation, and response to detected releases must comply with 40 CFR 264.97.

8.2 Surface Water Monitoring

The need for surface water monitoring will be determined on a case-by-case basis according to the potential for releases from the repository. Potential sources of discharges to surface water may include water infiltrating the repository that is collected and pumped to the surface for discharge to surface water. It may be necessary to monitor the collected liquids for contaminants present in the wastes placed in the repository to ensure hazardous wastes or hazardous waste constituents are not discharged to the environment. Any discharge to surface waters may require a NPDES permit and the discharge may require monitoring in accordance with NPDES requirements specified in 40 CFR 122.48.

If discharges to surface waters are to be monitored, the application must describe the monitoring equipment and placement, the constituents to be monitored, the monitoring interval, the monitoring techniques and reporting requirements. It is suggested that the monitoring program meet monitoring program standards for NPDES permits as described in 40 CFR 122.48.

Leachate collected from portions of the repository containing wastes may also be a hazardous waste. It may be characteristically hazardous as described in 40 CFR 261 Subpart C, or it may be a listed hazardous waste as described in 40 CFR 261 Subpart D. If the leachate is generated from portions of the repository containing listed hazardous wastes, it must be managed as a hazardous waste unless it is delisted. Guidelines for delisting hazardous wastes are provided in the EPA document Petitions to Delist Hazardous Wastes: A Guidance Manual. If the leachate is collected from areas of the repository managing only characteristically hazardous waste, it must be tested to verify that it is not characteristically hazardous or managed as a hazardous waste.

8.3 Air Monitoring

If the ventilation system at a repository could carry hazardous constituents from the repository to the atmosphere, air monitoring may be required. The potential for releasing dusts or volatile fumes containing hazardous constituents from the repository must be described in the permit application.

If air monitoring is required, the permit application should include a description of the air monitoring program. The program should include provisions for monitoring at locations where emissions to the atmosphere may potentially occur (in addition to monitoring for potential releases to the atmosphere, it may be necessary to monitor areas within the repository to assure worker safety; refer to OSHA requirements in 29 CFR 1910 for guidance on monitoring within repositories to assure worker safety). The air monitoring equipment and placement, the constituents to be monitored, the monitoring interval, the monitoring techniques, procedures to alert operators and/or workers to unacceptable emissions (e.g., alarms), and reporting requirements should be described in the application.

8.4 Leak/Leachate Detection

Leak/leachate detection systems should be employed if the nature of wastes to be placed in the repository and/or the degree of hydrologic isolation could lead to an accumulation of liquids containing hazardous wastes or hazardous constituents in the repository. Leak/leachate detection will not be required if the permit application successfully demonstrates there is no potential for migration of the wastes or waste constituents into the accessible environment during the active life of the repository and during the post-closure care period.

If a leak/leachate detection system is required at a repository, the permit application must describe the system design, operation, and maintenance. A discussion of how the system will detect leaks and leachate generated anywhere in the repository, and how the leachate will be collected and managed should be included in the permit application.

8.5 Repository Monitoring

Additional monitoring of repository conditions (such as temperatures and pressures) may be necessary. The need for such monitoring should be determined based on assessments of potential conditions that could compromise the repository's structural integrity or hydrologic isolation. For example, remote emplacement of wastes in a cavern through an access pipe (as may be proposed for solution-mined salt domes) could result in waste releases to the environment or excessive water intrusion if the access pipe is ruptured by differential movement of surrounding strata. It is suggested that repositories employing such designs utilize access shafts with an outer, pressurized, fluid-filled casing. By monitoring the pressure in the casing, ruptures allowing a release of the casing fluids can be immediately detected and corrective measures undertaken in a timely fashion.

Pressure and/or temperature monitoring may also be appropriate in closed portions of repositories where excessive temperatures or pressures could create undesirable waste reactions, lead to seal damage, or induce fractures of host rock. Moisture monitors, such as neutron probes, may also be advisable in many active and closed repository environments to detect the presence of infiltrating water.

The repository permit application must address the need for such repository monitors. Assessments of potential conditions that could lead to repository failures should be provided and, unless the potential for such occurrences is demonstrated to be insignificant, appropriate monitoring systems must be provided.

SECTION 9.0

CONTINGENCY PLANS

This section provides guidance on the permit application information requirements related to contingency plans at geologic repositories. Subpart D of 40 CFR 264 requires the owners or operators of hazardous waste geologic repositories to develop contingency plans and emergency procedures. The Contingency Plan is a stand-alone document that must be included in the Part B application. Its purpose is to minimize hazards to human health or the environmental from fires, explosions, or any unplanned sudden or nonsudden release of hazardous waste or hazardous waste constituents to air, soil, or surface water (40 CFR 264.51). The plan should also address hazards unique to mines, such as cave- ins. The Contingency Plan must describe emergency procedures to be followed by facility personnel in response to such events.

A single Contingency Plan must be prepared that covers both the surface and subsurface activities at the site. However, facilities where workers are not required to enter the subsurface workings, such as solution-mined repositories using remote emplacement of wastes, need not address worker safety in the underground environment. Generally, obtaining a no-migration variance will not affect the contents of the contingency plan.

9.1 General Information

The Contingency Plan must provide the facility name and location, identify the facility operator(s), and provide an overall description of facility operations and wastes managed. Site plans showing all surface structures, access roads, subsurface workings, and permanent equipment must be included in the plan. All access and ventilation shafts within the repository as well as drifts, rooms, and other passageways should be clearly diagrammed. The facility locations designated for waste unloading, storage, processing, and emplacement should also be shown on the plans.

9.2 Emergency Coordinators

The Contingency Plan must identify, by name, a primary emergency coordinator for the facility and at least one alternate. The plan must include the facility telephone numbers at which the coordinators can be reached as well as their home telephone numbers and addresses.

The emergency coordinator is an employee either on the facility premises or on call with the responsibility for coordinating all emergency response measures. The coordinator must be familiar with all aspects of the Contingency Plan, all operations and activities at the facility, the location and characteristics of waste handled, the location of all records within the facility, and the facility layout. In addition, the coordinator must have the authority to commit the resources needed to carry out the contingency plan.

9.3 Plan Implementation

The plan should clearly describe the steps to be taken by the emergency coordinator and other facility employees in determining when the Contingency Plan is to be implemented and the steps to be taken to protect human health and the environment in the event of an emergency. These descriptions should include the following elements:

- Procedures for alerting the primary and/or alternate emergency coordinators in the event of an occurrence that may require activation of the plan
- Procedures for assessing the nature and extent of the emergency, including the identification of the character, source, and amount of involved wastes
- Criteria for implementation of the Contingency Plan (e.g., imminent threat to worker safety or high potential for environmental releases)
- Procedures for communicating the emergency conditions to facility employees (e.g., alarms or intercoms)
- Procedures for notification of local authorities and the National Response Center and requesting outside assistance
- Procedures to contain, control, and correct emergency situations

- Procedures to prevent the recurrence of emergencies
- Procedures to assure that all emergency equipment is cleaned and fit for its intended use before operations are resumed
- Procedures for notification of the EPA Regional Administrator and other appropriate authorities of the incident, the responses taken, and the capability of the facility to resume operations.

9.4 Emergency Equipment

The Contingency Plan should describe the locations, specifications, and capabilities of all emergency equipment at the facility. It is recommended that repositories requiring human presence underground include the following emergency equipment at the facility:

- On-site fire fighting equipment that is strategically located to allow fire fighting in all underground areas
- Fire extinguishers on all self-propelled underground equipment, except compressed air-powered equipment without inherent fire hazards
- Appropriate fire protection systems for underground transformer stations, combustible liquid storage and dispensing areas, pump rooms, compressor rooms, and hoist rooms
- Fire suppression systems other than fire extinguishers and water hoses at mine entrances, unless all combustible materials are covered with shotcrete, gunite, or other fire-retardant coatings with equivalent protection characteristics
- Emergency communication equipment, such as alarms and intercom systems, strategically located in all underground areas
- First aid equipment near all working areas.

Additional emergency equipment typical of that required at other RCRA facilities should also be maintained at the facility. This equipment generally includes:

- External communication equipment (e.g., telephones)
- Spill containment and cleanup equipment

- Personnel protective equipment (e.g., gloves, boots, respirators)
- Eyewashes, emergency showers, and fire blankets
- Decontamination equipment.

It is also suggested that self-rescue equipment be stored at strategic locations in the repository. Self-rescue equipment would include items of use to workers trapped by a cave-in, such as shovels, picks, and compressed air supplies.

9.5 Coordination Agreements

The Part B must include documentation showing that local emergency response authorities who may be requested to provide assistance in the event of a facility emergency (e.g., fire, police and rescue squads, and local hospitals) have received copies of the Contingency Plan. Coordination agreements with such organizations should be instituted. If any organizations refuse to enter into coordination agreements, that refusal should be documented in the Part B.

Where more than one police and fire department might respond to an emergency, the coordination agreements should designate primary fire emergency authority to a specific police and a specific fire department. Arrangements to familiarize local hospitals with the properties of hazardous waste handled at the facility and the types of injuries or illnesses that could result from fires, explosions, or releases at the facility should be made and documented in the Part B.

9.6 Evacuation Plans

The Contingency Plan must describe the signal(s) that would be used to alert employees to evacuate the facility, including subsurface portions of the repository. Site plans should be included in the Contingency Plan showing the primary and alternate evacuation routes from every location in the subsurface environment that workers may be required to enter, as well as surface structures.

It is recommended that facilities institute subsurface evacuation plans that can be executed so as to remove all workers from potentially hazardous areas to the surface or to designated central evacuation points within 10 minutes of an alarm signal. Alternately, the subsurface workings should be equipped with a ventilation system that will reverse air flow in sufficient time to allow workers adequate time to safely exit the underground workings or reach a safe refuge area in the event of a fire or the release of toxic or asphyxiating fumes.

SECTION 10.0

REPOSITORY CLOSURE AND POST-CLOSURE CARE

This section describes the manner in which geologic repositories must be closed and, in the case of disposal repositories, cared for after closure (the post-closure care period). Included are descriptions of the types of information required in closure and post-closure plans submitted with the Part B permit application that are unique to geologic repositories. Although this section describes many of the standards applicable to hazardous waste repositories, it is not a comprehensive review of all closure and post-closure requirements. Additional detailed guidance for closure and post-closure plan preparation can be obtained from EPA's RCRA Guidance Manual For Subpart G Closure and Post-Closure Care Standards and Subpart H Cost Estimating Requirements.

If all wastes and waste residues are to be removed from the repository at the time of closure, the facility is considered a storage repository and is not required to prepare a post-closure care plan. No significant differences are anticipated between closure and post-closure plans for repositories located in conventional mined space (e.g., room-and-pillar mines) and those in solution mines using remote waste emplacement techniques. However, closure plans for facilities desiring no-migration variances may vary significantly from those for which a variance is not sought. Facilities requesting no-migration variances must demonstrate that adequate waste isolation will be achieved for as long as the wastes remain hazardous, with verification provided by performance projections based on accepted theoretical, empirical, and practical analyses. In some cases, this period may be longer than the minimum 30-year post-closure care period. Facilities that do not request a variance must only demonstrate adequate containment capabilities through the post-closure care period.

10.1 General Requirements

The Part B application must include separate closure and post-closure plans that address all surface and subsurface hazardous waste management units. Both plans must also be kept at the facility during its active life and updated to correspond to any changes in relevant factors, as appropriate. The repository must be closed at the end of its active life in a manner that minimizes the need for further maintenance and assures compliance with the repository performance standards in 40 CFR 264.601 throughout the post-closure care period. Partial closure, such as the sealing of cells or rooms within the repository, may be desirable during the active life of the facility. However, all partial and final closure activities must be completed within 180 days after receiving the final volume of hazardous waste at the repository, unless additional time can be demonstrated to be necessary to complete closure as described in 40 CFR 264.113(b)(1).

The closure plan must identify the steps necessary for complete or partial closure of the facility at any point during its intended operating life. The plan must describe how the facility will be closed in a manner that minimizes the need for further maintenance and controls; minimizes or eliminates threats to human health and the environment; and avoids post-closure escape of hazardous waste, hazardous waste constituents, leachate, or waste decomposition products to ground water, surface water, the surface environment, or to the atmosphere. The closure plan must also include a schedule for all partial closure activities and final closure, including the expected year of closure. If closure will require more than 180 days after the date of receipt of the last volume of hazardous waste, an extension must be requested and justified in the plan.

The post-closure plan must also describe the monitoring and maintenance activities to be conducted after closure of the repository and the frequency of these activities.

10.2 Closure Design

Proper closure of geologic repositories will necessitate thorough sealing of all access shafts into the repository cavern if the nature of the wastes placed in the repository are such that hazardous leachate or gases could be generated within the repository after closure. This will require the construction of bulkheads or seals that will be effective at preventing the migration of water into areas where wastes are present and preventing the migration of hazardous waste, waste leachate and gases from the repository that could have adverse impacts on human health or the environment. Repository seals must be designed to withstand the forces expected to be present due to rock creep, hydraulic pressure, and probable collapses within the repository. In addition, seal materials must be demonstrated to be chemically compatible with the host rock and any wastes and waste leachate that may come into contact with the seals.

10.2.1 Seal Location

It is important that seals be located in areas of shafts, drifts, and other openings where surrounding rock mass will prevent leakage around the seal and provide adequate shear strength to support the plug. Geologic discontinuities and fracture plans from high stresses induced by mining operations and the presence of the mine openings themselves should be avoided. In addition, the effects of confined seals subjected to end pressures on rock stress and the potential for creating stress fractures through seal placement should be considered in selecting seal location. The presence of weak rock beds of shale, siltstone, sandstone, or conglomerate will increase leakage potential and reduce seal/rock interface shearing resistance and should be avoided. The closure plan should demonstrate that the proposed seal location will provide adequate leakage protection and shear support considering the factors described above.

10.2.2 Seal Design

The closure plan must demonstrate that the design of the seal is sufficient to assure its long term performance given the expected static and dynamic forces to which it will be subjected and the potential for water leakage through surrounding rock.

Protection against leakage will generally dictate an elongated seal, as shown in Figure 10-1, shapes c through f. Seal designs requiring excavation into the surrounding strata, as shown in shapes a, b, and c, may induce fractures during keyway excavation that would create leakage pathways and should generally be avoided unless keyways can be excavated in a manner that will not produce unacceptable fracturing. In general, parallel rough-sided excavations can provide adequate seal retention under heavy loads, provided the seal is sufficiently long. It is recommended that main shaft seals provide redundant protection (i.e., two independent seals) with pressure and/or moisture monitors between the seals.

In calculating the design load for a shaft seal, it should be assumed that the seal will be subject to a load equivalent to a head of water from the level of the seal to the ground surface, unless it can be clearly shown that subsurface conditions would result in lower heads that cannot under any circumstances be exceeded.

Potential long-term effects of pore water pressure and groundwater chemistry on the seal should be described in the closure plan. In particular, the potential for spalling of the free face of the seal should be considered.

To compensate for the set shrinkage expected in concrete seals cast directly against rock, it is recommended that the seal/rock contact zone be grouted to prevent leakage through any shrinkage gaps. The suggested method for accomplishing the grouting is to provide one or more narrow chases completely surrounding the seal cross-section into which grout is then injected and pressurized to achieve a tight ring seal.

For seals to be placed in salt deposits or other formations that exhibit plastic creep, it should be demonstrated that the forces exerted by the creeping action would not compromise seal integrity.

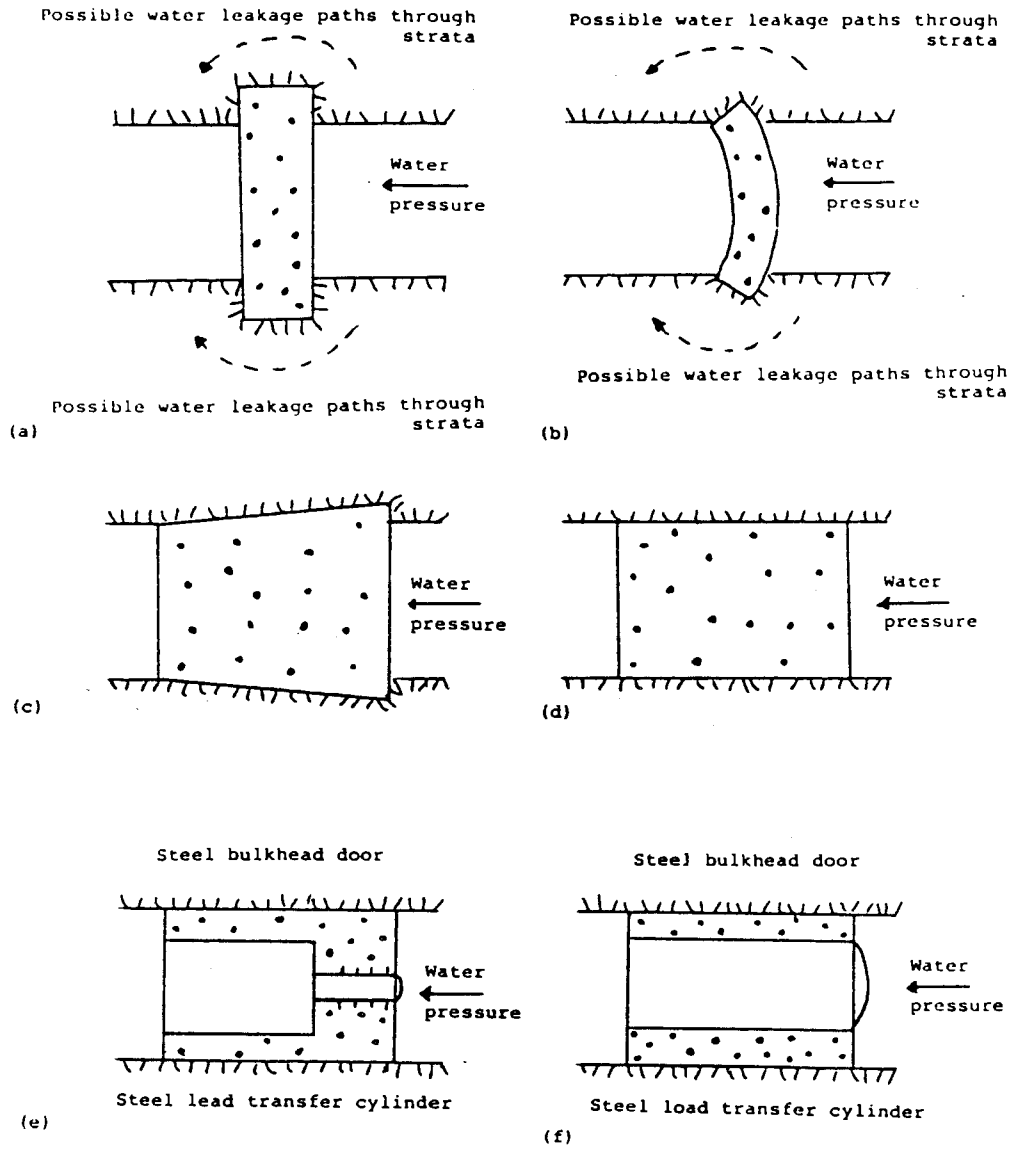


FIGURE 10–1: Plug Shapes. (a) reinforced concrete slab in rectangular opening (adequate strength but insufficient leakage resistance) (b) unreinforced concrete arch in rectangular opening (adequate strength but insufficient leakage resistance) (c) unreinforced concrete tapered plug in rectangular opening (adequate strength and leakage resistance but uneconomical) (d) unreinforced concrete parallel plug in rectangular opening (economical with adequate strength and leakage resistance) (e) unreinforced concrete cylindrical parallel plug, with man access, in circular opening (f) unreinforced concrete cylindrical parallel plug with roadway access, in circular opening. (Source: International Journal of Mining Engineering, 1983, 1, 189–228).

10.2.3 Seal Materials

Seal materials should be selected to achieve the desired design strength and sealing characteristics at construction and retain those characteristics in the long-term. Effects of shrinkage, thermal changes and ground pressures during concrete curing should be considered in computing the as-installed seal strength. Internal build-up of heat within the concrete seal mass due to the hydration process can induce high thermal stresses that result in thermal cracking when the seal cools. Where appropriate, it is suggested that cement seals utilize replacement materials to minimize the heat of hydration gain.

The long-term ability of the seal materials to withstand corrosion should be demonstrated in the closure plan. For example, seals in salt domes may be exposed to saline and sulfate-bearing fluids in the dome cap rock that could aggressively attack many materials. Laboratory corrosion studies that simulate the expected seal environment should be conducted to determine seal material corrosion rates.

Seal materials should also be able to withstand cracking over time due to in-situ or overburden stresses. This criteria especially applies to repository seals in salt domes or salt beds where salt creep can cause seals to fracture or crack. In these cases, plastic materials, such as salt, should be used to seal the repository openings.

10.2.4 Repository Venting

The potential for gas generation within the repository after closure should be determined and, if appropriate, a system for gas venting provided. Venting should be provided whenever the potential pressures generated from gas buildup could induce fractures in the host rock or seal materials that may compromise the isolation afforded by the repository. The design and operation of any required venting system should be included in the closure plan. The design of such gas venting systems should not create pathways for waste or waste leachate migration from the repository or, where the nature of the wastes is such that contact with water could generate hazardous leachate, create pathways for water migration into the repository.

Procedures and equipment for monitoring repository vent emissions during the post-closure care period should be specified in the application. Systems for alerting personnel to unacceptable vent emission levels, such as alarms, should also be described.

10.2.5 Waste Retrievability

Although not required, repositories may be designed to facilitate waste retrieval at a later date if a hazardous condition is detected or changing economic conditions warrant resource recovery from emplaced wastes. If the repository closure design will allow for future waste retrieval, the pertinent characteristics and designs of the repository's retrievability features should be described in the closure plan. Seal designs similar to those shown in Figure 10-1, shapes e and f, are recommended for repositories in which retrievability is desired. These designs provide bulkhead doors through which the repository could potentially be accessed at a future date.

10.3 Post-Closure Care

Unless all waste and waste residues are removed during closure, post-closure care and a post-closure permit will be required (40 CFR 270.1(c)). If the nature of the wastes in the repository and the repository characteristics are such that leaks, leachate, or gases may be generated that could migrate from the repository, appropriate leachate and/or gas detection, collection, and removal systems must be operated and maintained throughout the post-closure care period. Post-closure care must be provided for a period of at least 30 years after completion of the authorized final closure of the repository. If ground-water monitoring systems are utilized during the repository active life, they must also be operated and maintained throughout the post-closure care period.

The post-closure plan must describe each of the planned post-closure activities and the frequency with which they will be performed to ensure 1) the integrity of the seal and containment system and 2) the proper functioning of the monitoring equipment (40 CFR 264.118). Security or access control should be provided around the mine

entrance and any gas vents, particularly if pumps or machinery to handle toxic leachate will be present.

Access to the repository, including accidental penetration by other mining or drilling operations, must be prevented after the repository is closed. This may require permanent control of mineral and/or water rights in the proximity of the repository. The potential for future activities that could compromise repository structural stability or isolation characteristics must be assessed and appropriate controls instituted after closure that will prevent such occurrences.

SECTION 11.0

EXPOSURE INFORMATION

Section 3019 of RCRA, as amended by HSWA of 1984, requires owners or operators of landfills or surface impoundments to submit exposure information for their facilities. This information would supplement existing information and data in the Part B permit application. Furthermore, the report would assess the potential for the public to be exposed to hazardous waste constituents through releases from the disposal unit. an EPA guidance manual, the Permit Applicants' Guidance Manual for Exposure Information Under RCRA 3019, describes the content and format of Exposure Information Reports (EIRs) for these facilities.

Similar information requirements are contained in the Subpart X regulations. Specifically, 40 CFR 264.601 and 270.23 require that owners and operators consider and provide information related to the potential for human and animal exposure via the air, surface water, soils and groundwater.

An exposure assessment involves an assessment of the following factors:

- Potential for releases of hazardous waste constituents from failures and from routine operations
- Potential human and animal receptors
- Potential health risks and natural resource damage from exposure
- Other sources of environmental contamination in the area.

In the case of geologic repositories, the exposure assessment must consider potential releases from surface activities (e.g., treatment and storage units) as well as from the subsurface areas (e.g., repository disposal area and shaft openings). Guidance on characterizing releases and resulting exposure potential from surface

activities and facilities is provided in the EPA guidance manual on exposure information cited above. This section discusses the additional information on releases and exposure potential from the subsurface areas. In most cases, the release pathways from geologic repositories will be air, surface water, and ground water; hence the focus of the following discussion will be on these media.

11.1 Potential for Releases

The potential for release of hazardous waste constituents is dependent on (1) physical-chemical properties of the wastes, (2) the design and operation of the facility, and (3) characteristics of the release pathway. Potential for releases of hazardous constituents via a particular pathway (e.g., air or ground water) is very small if the physical-chemical properties (e.g., volatility, solubility) of the waste constituents are such that the constituents will not enter into the media. Similarly, if the transport media, for example ground water, is not available at the repository or associated openings, the potential for release via that pathway is very small or negligible. However, in most cases, waste constituents have some volatility or water solubility and the location of ground water is such that the potential for release is not negligible. In these cases, design and operating factors should be discussed and release potentials assessed quantitatively or semi-quantitatively based on modeling or predictive efforts. These assessments require the identification of potential repository failure modes and evaluation of the nature and extent of releases that may occur from each potential failure.

11.1.1 Physical-Chemical Properties of the Wastes

Physical-chemical information provided in the Part B permit application should be cited in the EIR as it relates to the potential for transport via the particular pathway. For air, volatility and air-water partitioning constants (e.g., Henry's Law constant) should be determined for liquids projected to be emplaced in the repository. Any potential waste reactions resulting in gas evolution should be identified, although chemically unstable wastes should not be placed in the repository without prior stabilization.

When addressing surface water and ground-water pathways, waste constituent solubility and the hydrolysis rate constant should be discussed with respect to the ground-water chemistry (e.g., salinity, pH, Eh) at the site. This analysis can be based on known molecular reactions or laboratory studies with ground-water samples collected at the site.

11.1.2 Design and Operations

Design and operating factors, such as hydraulic barriers in the mine and waste emplacement methods, should be discussed as they affect the potential for release to the air, surface water, or ground water. Rock, casing, lining, and sealing materials should be described with respect to any adverse chemical reactions with waste and ground water. Effects of in-situ rock stresses on any engineered structural support materials should be assessed and the period of performance evaluated. Closure and post-closure plans for sealing and backfilling should be discussed with respect to the effectiveness of proposed measures for mitigating collapse of the repository openings and penetration by surface water or ground water. Waste emplacement methods should be described with respect to reducing the potential for accidental spills and fires.

11.1.3 Release Pathways

Release pathways should be characterized and potential release scenarios modeled for each applicable pathway, based on physical-chemical properties of the waste and the proposed design and operating procedures of the repository. Modeling of worst-case failure scenarios may include, but are not limited to, the following:

- Sudden flooding events
- Engineered hydraulic and/or structural support system failure
- Earthquake or other earth movements
- Electrical fire or accidental spill conditions
- Failure of closure or temporary seals and structures
- Mining and underground injection.

SECTION 12.0

OTHER SOURCES OF INFORMATION

This section provides references, in addition to the guidance provided in earlier sections, to give a complete picture of design, operation, closure, and post-closure information which the applicant may need to include in the geologic repository permit application. A list of pertinent publications is presented in Table 12-1. These publications are available from:

- American Society for Testing and Materials
  1916 Race Street
  Philadelphia, PA 19103
  215-299-5400

- Government Printing Office
  Publications Department
  Washington, D.C. 20402-9325
  301-783-3238

- National Technical Information Service
  Commerce Department
  Springfield, VA 22161
  703-487-4650

Table 12-2 lists organizations that can supply additional information. Finally, the RCRA hotline and EPA regional offices (listed in Table 12-3) can supply additional assistance and guidance in acquiring relevant publications.

Table 12-1

Other Sources of Information

Document Title	Description	Available From
A Guide for Estimating for Incompatibility of Selected Hazardous Waste Based on Binary Chemical Mixtures	Provides systematic methods for determining the compatibility of most binary combinations of hazardous wastes; also lists and classifies compounds known or expected to be in hazardous wastes	*ASTM (P-168)
A Method for Determining the Compatibility of Hazardous Wastes	Provides methods for determining the compatibility of binary combination of hazardous wastes	**EPA (600/2-80-076)
Alternate Concentration Limit Guidance Based on 264.94(b) Criteria Part I	Information required in alternate concentration limit demonstrations	EPA headquarters
Closure and Post-Closure Interim Status Standards (Subpart G)	Explains requirements for closure and post-closure	EPA (EPA SW-912)
Design and Development of a Hazardous Waste Reactivity Testing Protocol	Test scheme including field test kit and flow diagrams to determine gross chemical composition of waste material into reactivity groups and predict compatibility	**NTIS (PB 84-158-807)
Environmental Assessment (Deaf Smith County Site, Texas)	Provides specific information on this site to evaluate it as a potential disposal unit of spent nuclear fuel and high-level radioactive waste.	**NTIS

Table 12-1 (Continued)

Other Sources of Information

Document Title	Description	Available From
Environmental Assessment (Richton Dome Site, Mississippi)	Provides specific information on this site to evaluate it as a potential disposal unit of spent nuclear fuel and high-level radioactive waste.	**NTIS
Financial Assurance for Closure and Post-Closure Care: Guidance Manual	For permit applicants and writers; main sourcebook on Subpart H requirements	**NTIS (PB 82-237-595)
Financial Requirement - Cost Estimates Interim Status Standards (Subpart H)	Provides guidance on estimating costs	EPA (SW-913)
(Draft) Guidance Document for Research, Development, and Demonstration Permits under 40 CFR 270.65	Recommends information to consider in preparing permit applications and in drafting permit conditions; provides general framework for evaluating proposals and issuing RD&D permits	EPA headquarters
Guide to the Disposal of Chemically Stabilized and Solidified Waste	Guidance on disposing of stabilized and solidified wastes	***GPO (005-000-00226-6)
Hydraulic Simulation on Solid Waste Disposal Sites	Guidance on hydro-geologic modeling for hazardous waste sites	***GPO (005-000-00225-8)

Table 12-1 (Continued)

Other Sources of Information

Document Title	Description	Available From
Interim National Criteria for a Quality Hazardous Waste Management Program under RCRA	Sets basic criteria and performance standards for implementing the RCRA program for Regions and States	EPA (530-SW-84-006)
Liability Coverage: A Guidance Manual (Subpart H)	Information for permit applicants and writers on liability coverage for TSDs	**NTIS (PB 83-144-675)
Management of Hazardous Waste Leachate	Guidance for managing hazardous waste leachate	***GPO (055-000-00224-0)
Method for the Storage and Retrieval of RCRA Ground-Water Monitoring Data on STORET	Guidance on use of STORET for ground-water monitoring	EPA headquarters
Permit Applicants' Guidance Manual for Exposure Information Requirements under RCRA Section 3019	Provides guidance to owners and operators of landfills and surface impoundments for submitting information on potential for public exposure to hazardous waste as required by RCRA Section 3019	EPA headquarters and regions
Permit Applicants' Guidance manual for the General Facility Standards	Provides guidance on meeting the general information requirements of 270.14(b) (1-12, 19) and the 264 standards referenced by those requirements	EPA (SW-968)

Table 12-1 (Continued)

Other Sources of Information

Document Title	Description	Available From
Permit Applicant's Guidance Manual for Hazardous Waste Land Treatment, Storage and Disposal Facilities	Guidance for completing Part B permit applications	***GPO (055-000-00240-1)
Petitions to Delist Hazardous Waste: A Guidance Manual	Addresses information required to submit delisting petitions by persons who generate or manage listed wastes	**NTIS (PB 85-194-488)
(Draft) Permit Writers Guidance Manual for Hazardous Waste Land Storage and Disposal, Phase I, Criteria for Location Acceptability and Existing Applicable Regulations		EPA headquarters (OSW)
RCRA Ground-Water Monitoring Technical Enforcement Guidance Document	Technical enforcement guidance regarding appropriate design and implementation of ground-water monitoring at RCRA interim status facilities	***GPO (055-000-00260-6)
(Draft) RCRA Guidance Manual for Personnel Training	Provides guidance to owners and operators of hazardous waste management facilities and their personnel	RCRA hotline
(Draft) RCRA Guidance Manual for Subpart G Closure and Post-Closure Care Standards and Subpart H Cost Estimating Requirements	Provides guidance on closure and post-closure planning	EPA headquarters

Table 12-1 (Continued)

Other Sources of Information

Document Title	Description	Available From
RCRA Permit Quality Protocol	Provides guidance for evaluating the quality of RCRA permits issued by States or Regions	EPA headquarters
Soil Properties, Classification, and Hydraulic Conductivity Testing	Guidance on soils testing	EPA
Solid Waste Leaching Procedure Manual	Guidance on obtaining leachates from solid wastes	EPA (SW-924)
Statutory Interpretive Guidance - Treatment of Bulk Hazardous Liquid Wastes	Treatment methods acceptable to comply with the 5/8/85 statutory prohibition	EPA headquarters
Test Methods for Evaluating Solid Waste, 2nd Edition	Technical information on testing of hazardous wastes for all applications	**NTIS (PB 85-103-026)
Waste Analysis Plan Guidance Manual	Details specific guidance on how to prepare and evaluate Waste Analysis Plans; Required as part of the Part B permit application	***GPO (055-000-00244-4)

* ASTM - American Society for Testing Materials
** NTIS - National Technical Information Service
*** GPO - Government Printing Office

Table 12-2

Organizations Supplying Additional Information

Organization:	Available Information	Organization Address
Bureau of Mines	Mine design, safety, and operation standards	Bureau of Mines Public Inquiries 2401 E. St. NW Washington, D.C. 20241
Bureau of Economic Geology	Natural resources associated with salt domes	Bureau of Economic Geology The Univeristy of Texas of Austin University Station P. O. Box X Austin, TX 78713-7508
Department of Agriculture	Meteorological and agricultural data	Department of Agriculture 14th and Independence Avenue, SW Washington, D.C. 20250
Federal Insurance Administration	Flood maps	Federal Insurance Administration 10101 Senate Drive Lanham, MD 20706
National Climatic Center	Windroses and climatic information	National Climatic Center Department of Commerce Federal Building Ashville, NC 28801

Table 12-2 (Continued)

Organizations Supplying Additional Information

Organization:	Available Information	Organization Address
National Oceanic and Atmospheric Administration (NOAA)	Meteorological data	NOAA Public Affairs Room 5808, Herber Hoover Bldg. 14th and Constitution Avenue, NW Washington, D.C. 20230
Occupational Safety and Health Commission	Worker safety and health issues	Occupational Safety and Health Commission 1825 K Street, NW Washington, D.C. 20006
Soil Conservation Service	Soils surveys, land use information, and aerial photographs	Soil Conservation Service USDA - SCS P. O. Box 6567 Fort Worth, TX 76115
U.S. Geological Survey	Geologic and topographic maps	U.S. Geological Survey Public Inquiries Office 503 National Center Room 1-C-402 12201 Sunrise Valley Drive Reston, VA 22092