

**Waste Isolation Pilot Plant**  
**Compliance Certification Application**  
**Reference 80**

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**New Mexico, WTSD-TME-3156, Albuquerque, NM, D'Appolonia Consulting**  
**Engineers.**

WTSD-TME-3156

# A Facsimile Report



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NATURAL RESOURCES STUDY  
Waste Isolation Pilot Plant (WIPP) Project  
Southeastern New Mexico

September 1982

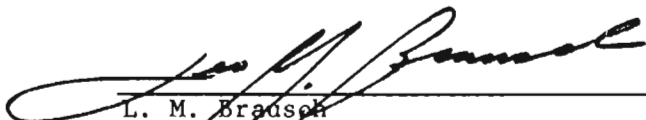
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U.S. Department of Energy  
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Albuquerque, New Mexico

Natural Resources Study  
Waste Isolation Pilot Plant (WIPP) Project  
Southeastern New Mexico

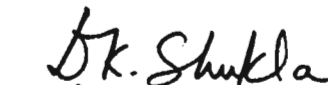
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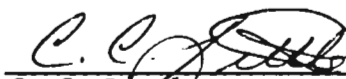
  
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## TABLE OF CONTENTS

	<u>PAGE</u>
LIST OF TABLES	iii
LIST OF FIGURES	iv
1.0 INTRODUCTION	1
1.1 THE WIPP SITE AND THE NATURAL RESOURCES PRESENT	1
1.1.1 Description of the WIPP Site	2
1.1.2 Mineral and Energy Resources	2
1.1.2.1 Potash	8
1.1.2.2 Hydrocarbons	11
1.2 PURPOSE OF THE NATURAL RESOURCES STUDY	13
1.3 STUDY METHODOLOGY	15
2.0 RESOURCE RECOVERY METHODS	17
2.1 POTASH	17
2.1.1 Exploration	19
2.1.2 Mining	19
2.1.2.1 Underground Mining	20
2.1.2.2 Solution Mining	23
2.1.3 Ore Processing	24
2.2 HYDROCARBONS	24
2.2.1 Exploration, Drilling, and Well Completion	25
2.2.2 Production Stimulation	27
2.2.2.1 Hydrofracing	27
2.2.2.2 Acidizing	29
2.2.2.3 Secondary and Tertiary Recovery	29
2.2.3 Production and Distribution	30
3.0 POTENTIAL EFFECTS ON THE WIPP FACILITY	31
3.1 UNDERGROUND MINING OF POTASH	31
3.1.1 Stress and Stress-Induced Creep	31
3.1.1.1 Empirical Relationships	31
3.1.1.2 Analytical Studies of Potash Mining	35
3.1.1.3 Analytical Studies of the WIPP Facility	38
3.1.1.4 Summary of Analyses	39

## TABLE OF CONTENTS

(Continued)

	<u>PAGE</u>
3.1.2 Stress-Induced Increases in Hydraulic Conductivity	40
3.1.3 Subsidence	43
3.2 SOLUTION MINING	45
3.2.1 Cavern Span and Stress Redistribution	46
3.2.2 Hydrofracing for Solution Mining	48
3.2.3 Summary of Analyses	48
3.3 HYDROCARBON DRILLING	49
3.4 HYDROCARBON PRODUCTION STIMULATION	49
3.4.1 Hydraulically Induced Fractures for Hydrocarbon Recovery	49
3.5 HYDROCARBON PRODUCTION	52
4.0 POSTULATED WASTE-RELEASE EVENTS	53
4.1 TIME OF ISOLATION	54
4.2 BREACHING EVENTS AND PATHWAYS	55
4.2.1 Drilling	55
4.2.1.1 Potash Exploration	55
4.2.1.2 Hydrocarbon Exploration	56
4.2.2 Underground Potash Mining	56
4.2.3 Hydrofracing	58
4.2.4 Hydrocarbon Production	61
4.3 DRIVING MECHANISMS	61
4.3.1 Hydrocarbon Production Stimulation Within the Bell Canyon Formation	62
4.3.2 Flooding Potash Mines with Waters from the Capitan Formation	62
5.0 SUMMARY AND CONCLUSIONS	64
REFERENCES	66

## LIST OF TABLES

<u>TABLE NO.</u>	<u>TITLE</u>	<u>PAGE</u>
1	Total Mineral and Energy Resources at the WIPP Site	7
2	Distribution of Resources and Reserves by WIPP Site Control Zone	9
3	USGS Grade Classification for Potash Ore	10
4	Summary, Extraction Technologies Applicable to WIPP Site Resources	18
5	Examples of Potash Mine Geometries in the Vicinity of the WIPP Site	22

## LIST OF FIGURES

<u>FIGURE NO.</u>	<u>DRAWING NO.</u>	<u>TITLE</u>	<u>PAGE</u>
1	NM78-648-A6	Site Location Map	3
2	NM78-648-B25	WIPP Site Control Zones	4
3	NM78-648-B28	WIPP Site Region	5
4	NM78-648-B26	Generalized Site Geologic Section	6
5	NM78-648-B27	Potash Deposits at the WIPP Site	12
6	NM78-648-A18	Study Flow Diagram	16
7	NM78-648-813-A1	Generalized Stress Distribution for Room-and-Pillar Mining	33
8	NM78-648-A24	Zone of Stress-Related Influence Around an Underground Opening	37
9	NM78-648-A20	Relationship of Salt Hydraulic Conductivity and Confining Stress	41
10	NM78-648-A19	Hydraulic Conductivity and Stress Distribution Around an Underground Opening in Salt	42
11	NM78-648-B30	Hydrofracing Analysis	51
12	NM78-648-A23	Schematic Representation, SAR Communication Event 1	57
13	NM78-648-B29	Schematic Representation, SAR Communication Event 2	59
14	NM78-648-A22	Schematic Representation, SAR Communication Event 3	60



## 1.0 INTRODUCTION

This report provides an account of the studies performed to evaluate the possible effects of recovering natural resources present at the Waste Isolation Pilot Plant (WIPP) site. Specifically, the potential mechanisms for breaching the WIPP facility by on-site potash mining or hydrocarbon recovery activities have been investigated. The results of this study serve as support for the DOE policy regarding resource recovery at the WIPP site. The conduct of this study was agreed upon by the DOE and the state of New Mexico in their stipulated agreement of July 1, 1981, to include detailed plans to control recovery of potash and hydrocarbons without disturbing the waste storage facility and the evaluation of the potential consequences of these plans. Exploration activities are an essential portion of resource recovery and as such are also included in the analyses.

Section 1.1 describes the WIPP project site and the natural resources present at that location. Section 1.2 discusses the purpose of the natural resources study, and Section 1.3 presents the methodology used in these evaluations. Chapter 2.0 describes the resource recovery potential at the WIPP site, including the extraction technologies available to recover these deposits. Chapter 3.0 addresses the disturbances in the geologic setting that result from the use of these extraction technologies. From these evaluations, Chapter 4.0 examines how such disturbances could cause or contribute to the release of radionuclides from the WIPP facility with subsequent radiation dose consequences. Chapter 5.0 presents the summary and conclusions of this study.

### 1.1 THE WIPP SITE AND THE NATURAL RESOURCES PRESENT

The WIPP project is to provide a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States. The WIPP project involves the disposal of transuranic (TRU) wastes in thick deposits of bedded salt located deep below the ground surface. Under the plans for the WIPP project, space for waste emplacement will be excavated in a

salt formation at a depth of approximately 2,150 feet. The site for this activity is located about 26 miles east of Carlsbad, New Mexico (Figure 1).

#### 1.1.1 Description of the WIPP Site

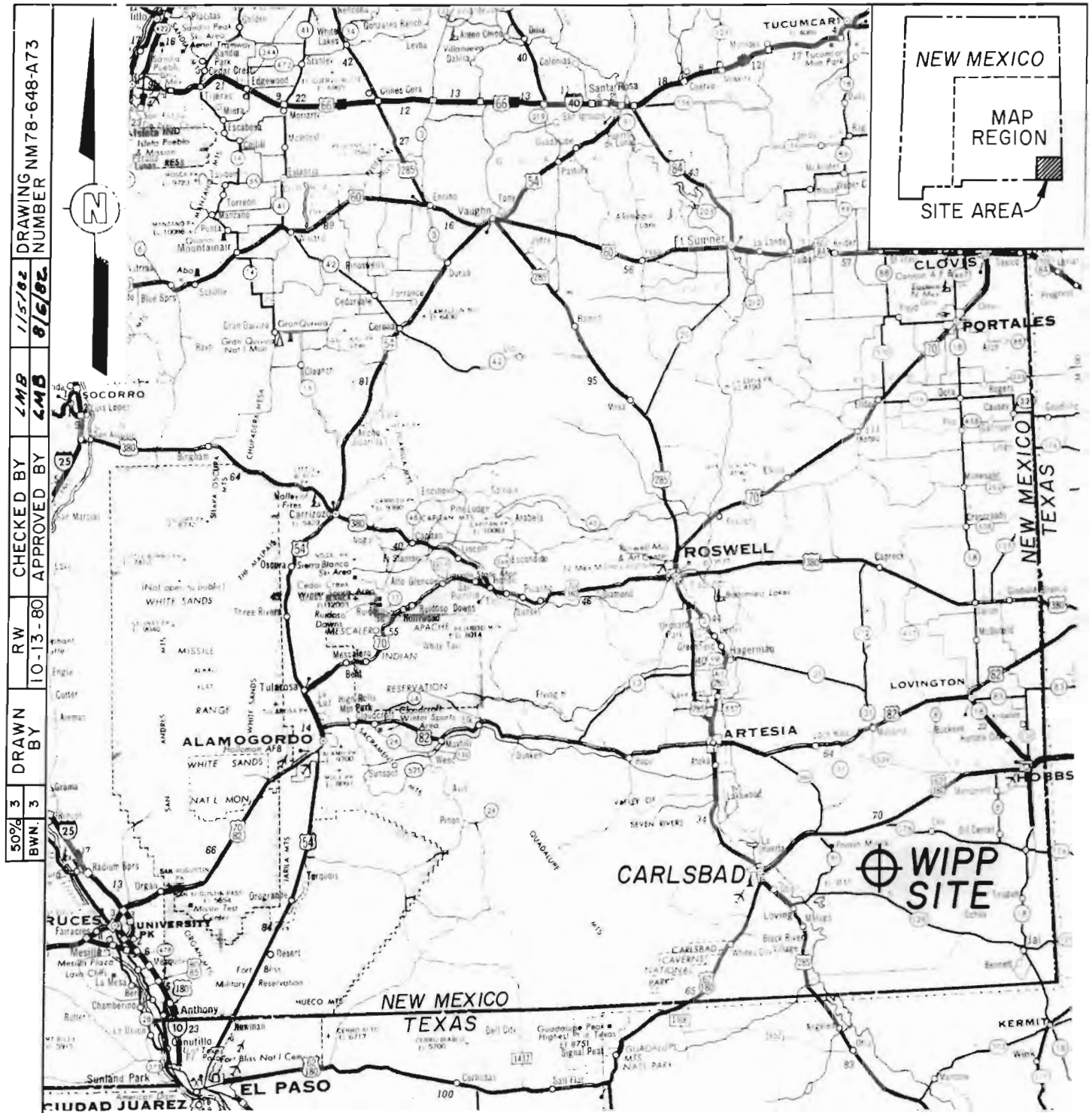
The land area presently being considered for the WIPP project is about 18,960 acres, an area approximately six miles in diameter, of which nearly 17,000 acres will be used to provide buffer zones around the underground facility. The site is divided into four control zones as follows (Figure 2):

- o Control Zone I at the site center will contain nearly all of the surface facilities and occupy about 100 acres.
- o Control Zone II, an area of about 1,800 acres, overlies the area of maximum potential underground development.
- o Control Zone III occupies an area of about 6,200 acres. This zone provides a one-mile buffer strip around the area of maximum potential underground development.
- o Control Zone IV, a second one-mile-wide buffer zone, contains an area of about 11,000 acres.

The WIPP site is located in the north-central portion of the Delaware Basin, a region in which a shallow sea deposited more than 3,000 feet of evaporites during the Permian period (280 to 225 million years ago). The basin is bounded by a horseshoe-shaped (open to the south) massive limestone reef, the Capitan Formation (Figure 3). The facility horizon is to be developed in the bedded salts of the Salado Formation at a depth of about 2,150 feet, near the middle of the thick evaporite sequence (Figure 4). The Salado Formation is composed primarily of halite with lesser amounts of anhydrite, sylvite, and polyhalite.

#### 1.1.2 Mineral and Energy Resources

The mineral and energy resources that underlie the four control zones of the WIPP site are caliche, gypsum, salt, potash, and hydrocarbons (Table 1). Potash (sylvite and langbeinite), which occurs in strata



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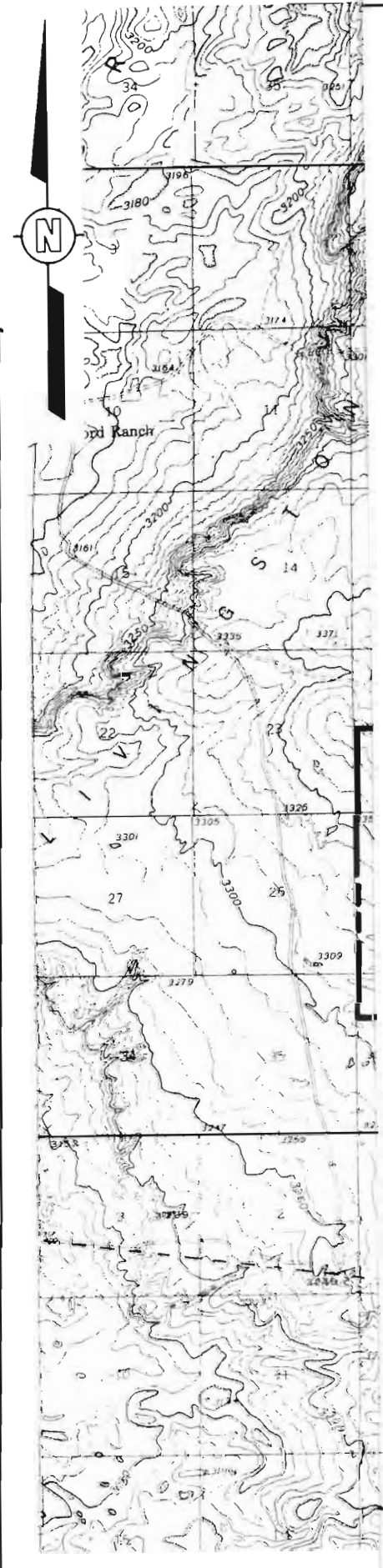
FIGURE 1

SITE LOCATION MAP

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REFERENCES:

1. USGS 15-MINUTE TOPOGRAPHIC QUADRANGLES: NASH DRAW, NEW MEXICO (1965) AND HAT MESA, NEW MEXICO (1972). SCALE 1:62500.
2. U.S. DEPARTMENT OF ENERGY (1981) ADAPTED FROM FIGURE 2.1-3.

CONTOUR INTERVAL = 10 FEET



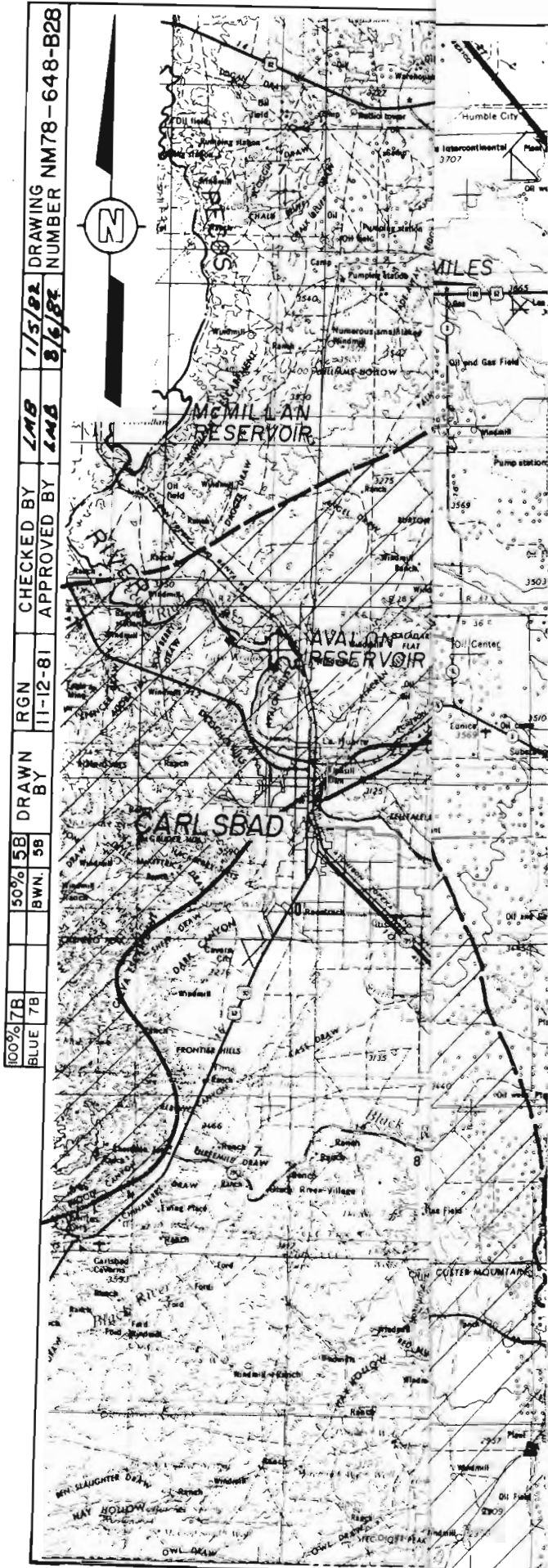
FIGURE 2

WIPP SITE CONTROL ZONES

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**LEGEND**

POSITION OF CAPITAN FORMATION:



**REFERENCES:**

1. U.S. ARMY TOPOGRAPHIC COMMAND, MAPS OF UNITED STATES: CARLSBAD, N.M.-TX., NI13-11 (REVISED 1972); AND HOBBS, N.M.-TX., NI13-12 (REVISED 1973) SCALE 1:250,000.
2. U.S. DEPARTMENT OF ENERGY (1981), FIGURE 2.1-3.

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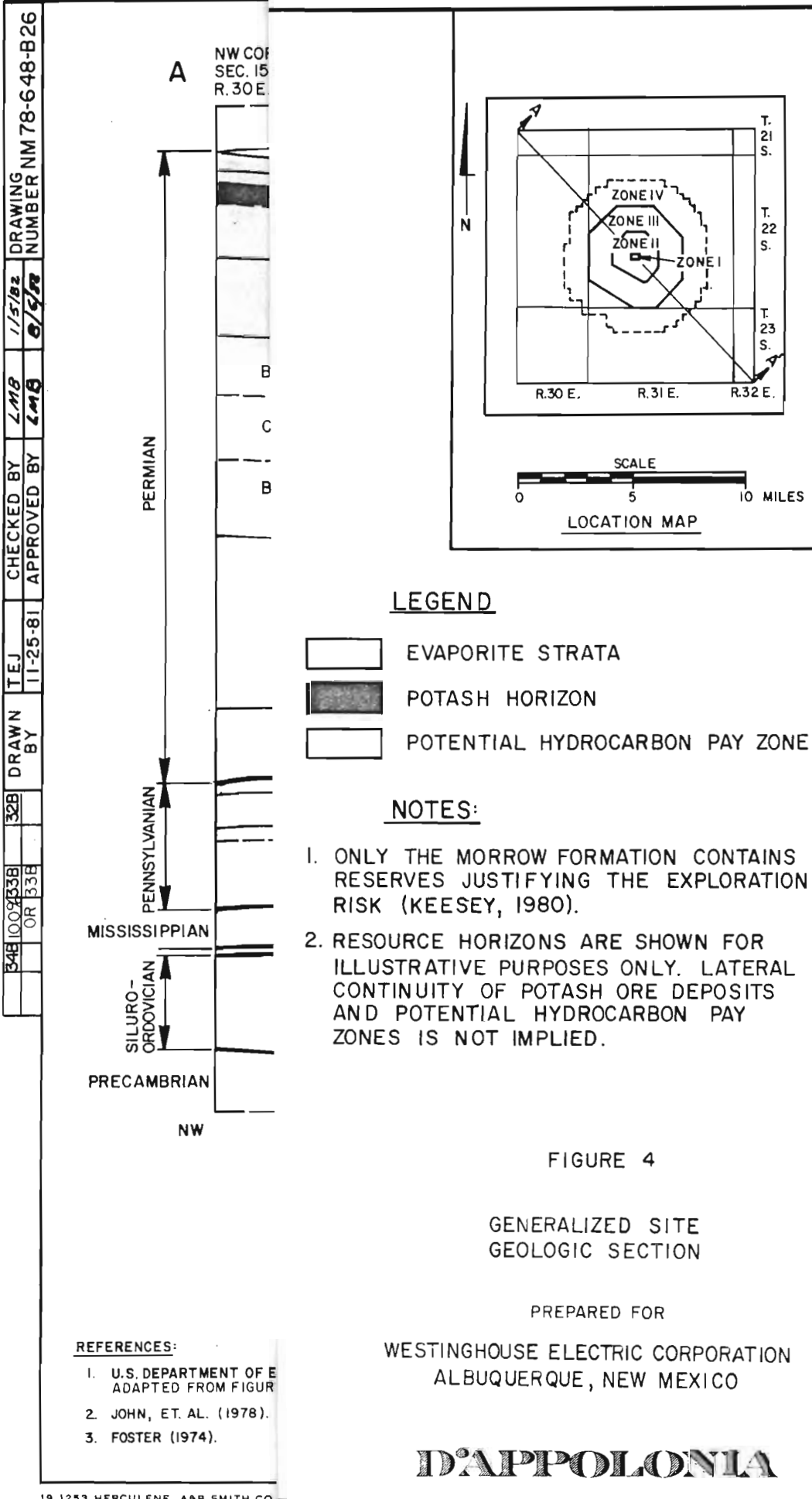


FIGURE 3

WIPP SITE REGION

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RESOURCE	COMMENTS
Caliche	Not considered an economic reserve. <sup>(3)</sup>
Gypsum	Not considered an economic reserve.
Salt	Not considered an economic reserve.
Potash:	
<ul style="list-style-type: none"> <li>● Sylvite Ore<sup>(2)</sup></li> </ul>	Reserves include 27.43 million tons at a richness of 13.33 percent K <sub>2</sub> O (U.S. Department of the Interior, 1977). <sup>(4)</sup>
<ul style="list-style-type: none"> <li>● Langbeinite Ore<sup>(2)</sup></li> </ul>	Reserves include 48.46 million tons at a richness of 9.11 percent K <sub>2</sub> O (U.S. Department of the Interior, 1977).
Hydrocarbons:	
<ul style="list-style-type: none"> <li>● Crude Oil</li> </ul>	Not considered an economic reserve.
<ul style="list-style-type: none"> <li>● Natural Gas</li> </ul>	Reserves are 44.62 billion cubic feet located at a depth of 14,000 feet (Keeseey, 1979).
<ul style="list-style-type: none"> <li>● Distillate</li> </ul>	Reserves are 0.12 million barrels located at a depth of 14,000 feet (Keeseey, 1979).

(1) Table adapted from

(2) Low-grade resource

(3) "Reserves," as described under present economic conditions.

(4) Sylvite reserves d

(5) One barrel equals

(6) The "degrees API" is.

above the waste storage horizon, and hydrocarbons (natural gas and distillate), which occur in strata below the waste storage horizon, are the only resources of practical significance (Table 2). The enormous deposits of caliche, gypsum, and salt elsewhere in the United States are more than adequate, and much more economically attractive, to meet requirements for these materials now and in the foreseeable future.

#### 1.1.2.1 Potash

The WIPP site is adjacent to the Carlsbad potash mining district where commercial quantities of potash are found in the McNutt Potash Member of the Salado Formation (Figure 4). A total of 11 ore zones or horizons has been identified in the McNutt Potash Member, numbered in ascending order from No. 1 near the base of the unit to No. 11 near its top. These zones contain varying quantities and qualities of potash ore in thicknesses to about eight feet.

Three studies have been performed to establish the extent and evaluate the quality of the potash resources at the WIPP site. The U.S. Department of the Interior, Geological Survey (USGS) performed a study to evaluate the available quantities and types of potash ore underlying the site. Studies conducted by the U.S. Department of the Interior, Bureau of Mines (USBM) and Agricultural and Industrial Minerals, Inc. (AIM) were economic evaluations whose purpose was to establish which portions of the identified resources qualify as reserves.

The USGS study identified the potash resources at the site and categorized these deposits by standard grades (Table 3); these grades relate to the purity of the ore discovered, expressed as the percent of potassium oxide ( $K_2O$ ) present. Generally, the higher the grade, the more economically valuable the ore. The USGS study used the results of an exploratory drilling program and associated laboratory analyses to accomplish the following objectives (John, et al., 1978):

- o Determination of the thickness and grade for each potash layer discovered in exploratory drilling.



DI	PERCENT OF TOTAL RECOVERABLE IN CONTROL ZONE IV
Potash: ● Sylv: ● Langl	71 65
Hydrocar: ● Crude: ● Natur: ● Dist:	57 57 57
Potash: ● Sylv(77) ● Lang(77)	100 73
Hydrocar: ● Natur: ● Dist:	53 75

(1) Table

(2) For

(3) Distie.

(4) Distr

(5) Sylv:

(6) All Zone IV (Keeseey, 1979).

TABLE 3  
 USGS GRADE CLASSIFICATION  
 FOR POTASH ORE<sup>(1)</sup>

GRADE <sup>(2)</sup>	ORE TYPE	POTASSIUM OXIDE (K <sub>2</sub> O) CONTENT <sup>(3)</sup> (percent)
Low	Langbeinite	3
	Sylvite	8
Lease	Langbeinite	4
	Sylvite	10
High	Langbeinite	8
	Sylvite	14

(1) Data from John, et al. (1978); table adapted from U.S. Department of Energy (1980), Table 7-6.

(2) Ore bed must have a minimum thickness of four feet for each grade class.

(3) The potassium oxide (K<sub>2</sub>O) content is the industry-accepted measure of quality, even though the potash salts do not in themselves contain K<sub>2</sub>O.

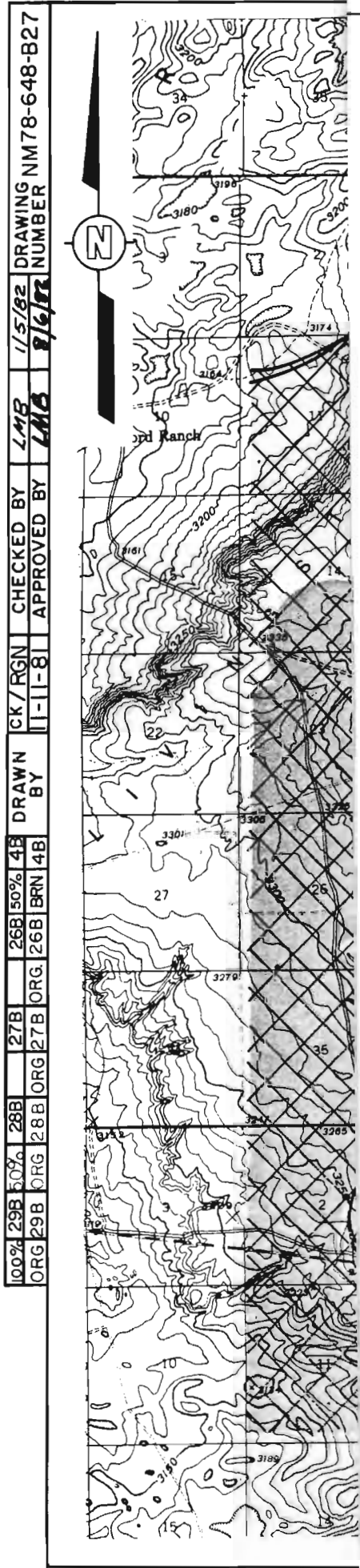
- o Assignment of mineralized layers to appropriate ore beds.
- o Determination of the probable continuity of ore beds.

As indicated in Table 2 and Figure 5, there are significant potash resources at the WIPP site with a minimum mining thickness of four feet. Roughly two-thirds of this ore is located within Control Zone IV of the site.

The two separate studies of the economic potential of the potash resources at the WIPP site (U.S. Department of the Interior, 1977; Agricultural and Industrial Minerals, Inc., 1979) used varying approaches and report different results describing the economic attractiveness of the potash resources. Each of these evaluations involved segmenting the ore deposits into distinct blocks of ore and identifying which areas could economically be developed by mining operations. Both studies agree, however, that no economically attractive deposits (i.e., reserves) of sylvite exist within the inner three control zones at the WIPP site and that the majority of the langbeinite reserves are located outside the inner zones (Table 2). The most attractive langbeinite deposits, and the only "reserves" under current market conditions (USBM Mining Unit B-1), are located north-northeast of the site center in Control Zones III and IV (Figure 5).

#### 1.1.2.2 Hydrocarbons

The New Mexico Bureau of Mines and Mineral Resources (NMBM&MR) conducted a hydrocarbon resource study in southeastern New Mexico for an area that included the WIPP site (Foster, 1974). The resource evaluation was based both on the known reserves of crude oil and natural gas in the region and on the probability of finding new reservoirs in areas where past unsuccessful exploratory drilling was either too widely spread or too shallow to have allowed discovery. The fundamental assumption in this study was that the WIPP site has the same potential for containing hydrocarbons as the much larger region in which the study was conducted and for which exploration data were available. Table 1 indicates the



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- LOW STANDARD RESOURCES
- LEASE STANDARD RESOURCES
- HIGH STANDARD RESOURCES
- ECONOMIC LANGBEINITE MINERALIZATION (RESERVES)

**REFERENCES:**

1. USGS 15-MINUTE TOPOGRAPHIC QUADRANGLES: NASH DRAW, NEW MEXICO (1965) AND HAT MESA, NEW MEXICO (1972). SCALE 1:62500.
2. U.S. DEPARTMENT OF INTERIOR (1977,1979).
3. JOHN, et al. (1979).

CONTOUR INTERVAL = 10 FEET



FIGURE 5

POTASH DEPOSITS  
AT THE WIPP SITE

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results of this study that show large quantities of natural gas and lesser deposits of crude oil and distillate are statistically probable at the WIPP site.

The study of resources by NMBM&MR indicated that there could be as many as 15 potential productive horizons (pay zones) within the rocks that underlie the evaporite deposits (Figure 4). The Ramsey sand near the top of the Bell Canyon Formation in the Delaware Mountain Group is the rock unit stratigraphically closest to the WIPP facility that may contain hydrocarbon resources. Economic analysis (Keeseey, 1976; 1979; 1980) has revealed that only a single zone, the Morrow Formation of Pennsylvanian age, is worthy of exploration risk. Gas production from the Atoka Formation is not large enough to justify exploration of this unit, although some production ancillary to Morrow production may be possible. The Morrow Formation is a consistent natural gas producer over much of the area surrounding the WIPP site. The results of the evaluation of reserves are shown in Table 2. The crude oil resources are not considered reasonably extractable, but significant quantities of natural gas are likely to be present at the site.

#### 1.2 PURPOSE OF THE NATURAL RESOURCES STUDY

In the development of the WIPP project, the primary concern of the DOE is protecting the public health and safety. As a conservative feature in the DOE design to maintain the integrity of the WIPP site and ensure that the emplaced wastes are isolated from the environment, the DOE has delineated buffer zones around the underground development in which resource recovery will be strictly controlled or prohibited. The DOE recognizes that the state of New Mexico is concerned primarily with protecting the public health and safety but does rely upon the royalties generated from resource recovery as a significant source of revenue and that other adverse economic and social impacts could result if access to the resources at the WIPP site is permanently denied. The two possibly conflicting goals of maintaining integrity of the waste storage area and maximizing the opportunity for resource recovery at the site must be examined in terms of the potential consequences if resource recovery is allowed.

The conduct of the natural resources study was agreed upon by the state of New Mexico and the DOE in the stipulated agreement of July 1, 1981. It is intended to resolve questions presented by the New Mexico Environmental Evaluation Group (EEG) and other groups within the state of New Mexico that raised questions concerning resource recovery in their review of WIPP project documents (U.S. Department of Energy, 1980; 1981b), the WIPP Final Environmental Impact Statement (FEIS), and the WIPP Safety Analysis Report (SAR). The results of this study are also intended to serve as the basis for the DOE interim policy regarding natural resource recovery at the WIPP site (U.S. Department of Energy, 1981a). As such, the potential effects of resource recovery on isolation of emplaced waste, as discussed in this report, are considered only during the period in which institutional controls are preserved; after controls are lost, the DOE policy will no longer be germane.

The study is specifically aimed at the potential consequences of developing the resources in Control Zone IV, and using directional drilling from within Zone IV to recover the hydrocarbons underlying Zones I, II, and III. Nearly 75 percent of the attractive potash deposits underlie this outer buffer zone and all of the natural gas and distillate reserves can be accessed by existing drilling techniques (either vertical or directional) from within Control Zone IV (Keeseey, 1979). Accordingly, allowing resource recovery from within Zone IV substantially mitigates any adverse economic and social impacts of permanent resource denial. Permanent prohibitions in the inner two zones are necessary to preserve site integrity and to prevent interference with WIPP operations. Similar restrictions for Control Zone III are indicative of the DOE's conservative design to protect the integrity of the WIPP waste emplacement horizon. In addition to resource recovery of potash and hydrocarbons, the impact of solution mining for other evaporite minerals or excavation of an underground storage cavern was evaluated, although this activity is considered technically unattractive and/or not feasible near the WIPP site.

### 1.3 STUDY METHODOLOGY

Assessing the potential consequences of allowing resource recovery within Control Zone IV at the WIPP site involves the evaluation of extraction technologies used to access the natural resources in this area to determine which specific resource recovery activities are feasible (Figure 6). The natural resources study assessed the potential effects of recovery operations within Zone IV on the integrity of the geologic containment of the emplaced radioactive wastes. Feasible resource recovery activities were examined to determine whether these activities would: affect the time of isolation before a breaching event could be assumed to occur; cause fracturing or dissolution of the waste emplacement host rock; or introduce a driving mechanism that would tend to force wastes out of the storage facility.

Considering the events by which radionuclides could reach the environment, specific resource recovery activities were evaluated, resulting communication events were postulated, and these events were compared to the breach mechanisms evaluated in the WIPP SAR.

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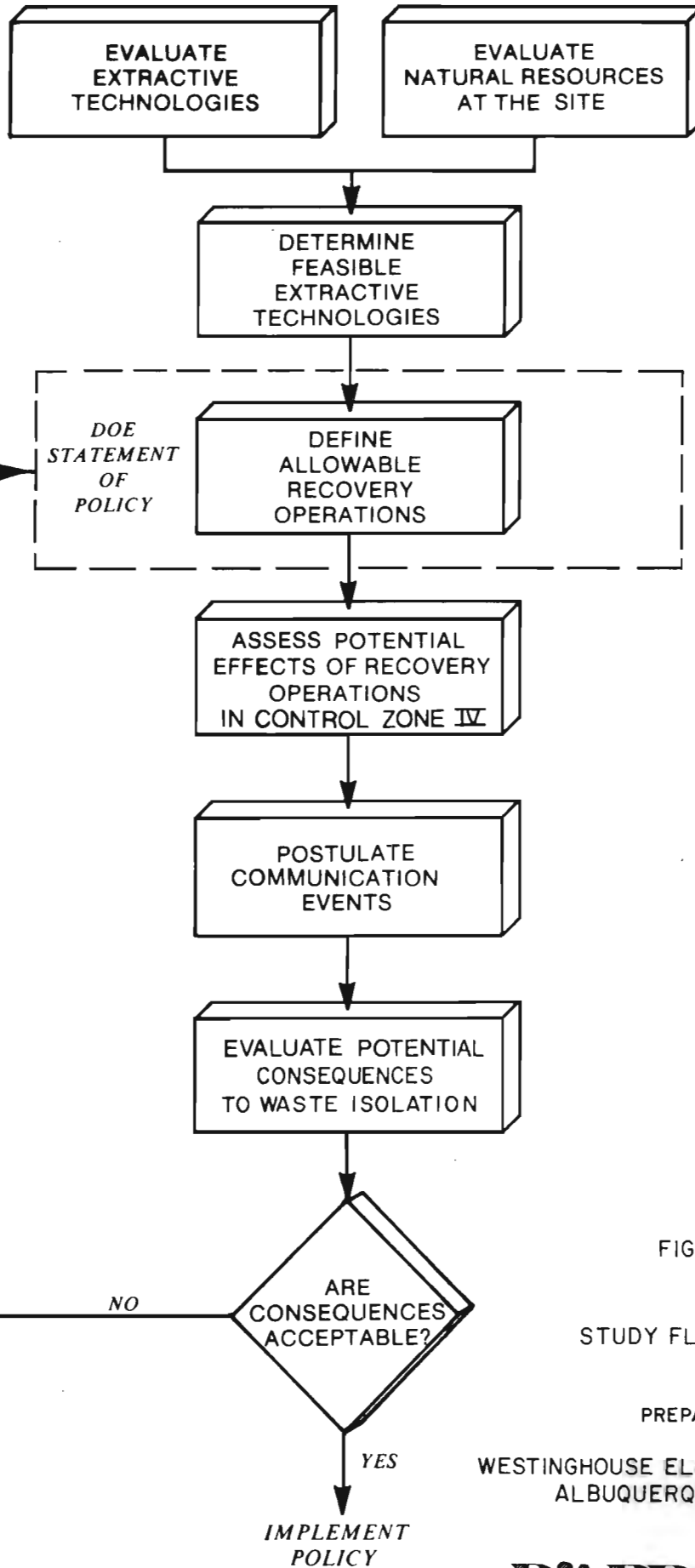


FIGURE 6

STUDY FLOW DIAGRAM

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## 2.0 RESOURCE RECOVERY METHODS

This chapter describes the feasible extraction technologies for recovering the natural resources underlying the WIPP site. The methods used in mining potash and producing hydrocarbons determine what disturbances could reasonably be expected. Using geomechanical and hydrogeologic analyses, the potential disturbances induced by the various extraction activities are examined (Chapter 3.0).

The evaluations of what techniques could be employed to recover the resources from within Control Zone IV at the WIPP site (Table 4) were performed in consideration of the following:

- o The methodology is appropriate for the specific geologic and hydrogeologic conditions at the WIPP site.
- o The extraction technologies are currently considered feasible (i.e., extrapolation of what may constitute future technologies was not made).
- o Extraction methods are technically feasible, although not necessarily economically attractive (i.e., the assessment was made independent of the current market price of the resources).

The information presented herein resulted from interviews with potash mining companies operating in the Delaware Basin, review of the USGS, USBM, and NMBM&MR data, and analyses by engineers and geologists specializing in mining and hydrocarbon recovery.

### 2.1 POTASH

Developing potash resources involves three generally sequential steps, as follows:

- o Exploration
- o Mining
- o Ore processing

The following paragraphs describe technologies that can be used to accomplish each of these phases of potash recovery. Specific attention is given to those aspects of these activities that could potentially

TABLE 4  
SUMMARY  
EXTRACTION TECHNOLOGIES  
APPLICABLE TO WIPP SITE RESOURCES<sup>(1)</sup>

TECHNOLOGY	DEPOSIT				
	POTASH		HYDROCARBONS		
	SYLVITE	LANGBEINITE	CRUDE OIL	NATURAL GAS	DISTILLATE
<u>Potash Mining</u>					
● Underground Mining					
- Conventional	X	X			
- "High Recovery" <sup>(2)</sup>	X	X			
● Solution Mining					
- Single Well					
- Multiple Well	X				
<u>Hydrocarbon Recovery</u>					
● Drilling					
- Vertical Drilling in Zone IV			X	X	X
- Deviated Drilling from Zone IV			X	X	X
● Production Stimulation					
- Hydrofracing			X	X	X
- Acidizing			X	X	X
● Secondary and Tertiary Recovery					
- Flooding			X		
- Steam or Carbon Dioxide Injection			X		

(1) Methods that could technically be employed to recover resources.

(2) Includes longwall mining, shortwall mining, etc.

lead to conditions or contribute to circumstances which result in breaching the WIPP facility. Although this section specifically identifies potash as the recoverable resource of interest, the techniques used for exploration and mining of potash would be applicable to exploitation of other evaporite minerals or the development of underground storage caverns.

#### 2.1.1 Exploration

Exploration for potash deposits includes drilling small-diameter (e.g., four to six inches in diameter) boreholes to locate ore zones and obtain core for testing. The core is analyzed to determine the ore grade and other properties that affect minability and processing efficiency, such as the percentage of insoluble materials. In addition to the ore zone itself, the rocks immediately overlying and underlying this horizon are studied so that the behavior of the prospective mine floor and roof can be evaluated. The material properties of a possible mine floor are of concern typically to a depth of less than about 20 feet below the ore zone. Accordingly, exploratory boreholes for potash deposits would not be expected to penetrate more than a few tens of feet below the McNutt Potash Member. Since the vertical location of the lower limits of the McNutt Potash Member is approximately 400 feet above the storage facility, at no time would such a borehole be expected to be drilled within about 350 to 400 feet vertically of the WIPP emplacement horizon.

The accuracy of downhole surveying techniques and other controls on drilling operations is such that the location of the bottom of a 1,000-foot-deep borehole can be determined within about five feet vertically and ten feet horizontally. An errant borehole could not feasibly connect with emplaced waste in the WIPP facility or the shafts connecting this facility to the surface.

#### 2.1.2 Mining

Methods used in potash mining depend on the specific mineral (i.e., sylvite or langbeinite) present in the deposit. Sylvite is a relatively

soft, soluble mineral and can be mined by a variety of underground techniques or by solution mining. Langbeinite is a harder material for which the options available for underground mining are more limited. Langbeinite is also less soluble than the evaporite materials that typically surround it so that solution mining is not feasible.

#### 2.1.2.1 Underground Mining

Underground mining for potash in the Delaware Basin typically involves constructing vertical shafts to the elevation of the ore zone and then extracting the minerals in an underground excavation that follows the trend of the ore body. The mining methods that are normally employed are similar in many respects to those available for underground coal mining.

The shafts are generally constructed by conventional (drill-and-blast), raise boring, or blind boring techniques. The shafts typically range from 10 to 20 feet in diameter and commonly are lined with concrete down to the top of the salt formation. Because there is generally so little water present in the overburden rock strata in the area, special provisions for collecting and removing groundwater are not typical, even though some shafts have encountered groundwater in sufficient quantities to require dewatering or sealing. Where water-bearing zones are encountered, they are typically sealed by injecting grout into the formation.

Underground mining proceeds by developing entries from the shafts to the areas where the ore will be extracted. In the Delaware Basin potash mines, the shaft pillar radius (i.e., the area of low extraction around the shaft for maintaining its long-term stability) is generally equivalent to the depth of the shaft. High-extraction room-and-pillar or modified longwall or shortwall techniques are most commonly employed in production panels. More novel techniques, such as the yield pillar concept, have been attempted but were unsuccessful due to the geologic conditions specific to the Carlsbad area.

The size of entries, extraction ratios in production areas, and other factors of the mine design are controlled by aspects of the local stratigraphy, such as the location of clay seams, the thickness and lateral extent of ore beds, and other localized features that occur within the McNutt Potash Member. Consequently, for the mines in the Carlsbad potash mining district, mine planning rationale is established primarily through previous mining experience on the particular property. Table 5 presents data for several of the potash mines in the vicinity of the WIPP site. Development strategies in all of these mines are similar, but local conditions result in some variations. The mine geometries are established to maximize ore recovery and minimize stability problems.

Roof bolting is used only as a precaution or to minimize slabbing (local falls) of the roof. Floor heave has been reported in some of the local mines. One mine in the Delaware Basin extracts potash from two ore zones separated in some places by as little as 50 feet of intervening evaporite rock. It is interesting to note that where multiple ore zones are being mined, techniques to minimize the potential adverse effects (e.g., "stacking pillars") are not generally used. Nevertheless, only minor floor problems have been observed and such problems have not been found to interfere with normal production activities. Faulting through the overlying openings has not resulted from the subsidence caused by mining the lower unit.

Conventional drilling and blasting is commonly used to develop entries as well as for production panels, especially when mining langbeinite. One mine uses a modified shortwall mining technique and longwall mining has also been attempted. The most common technique for mining sylvite involves the use of continuous miners. The use of continuous miners in langbeinite ore zones is extremely limited due to the hardness of the ore and consequent high rate of bit wear.

Most of the mining companies use retreat mining methods (removing all or portions of support pillars) to increase extraction ratios. Use of these methods sometimes leads to subsidence and surface manifestations

TABLE 5  
 EXAMPLES OF POTASH MINE GEOMETRIES  
 IN THE VICINITY OF THE WIPP SITE<sup>(1)</sup>

PARAMETER	MINE (OWNER)			
	NATIONAL POTASH COMPANY	POTASH COMPANY OF AMERICA	INTERNATIONAL MINERALS AND CHEMICALS CORPORATION	KERR-McGEE CHEMICAL CORPORATION
<u>Depth (feet)</u>				
● Range	1,600 to 1,700	750 to 1,400	800 to 900	800 to 2,300
● Average	-(2)	1,000	-	-
<u>Main Entries</u>				
● Number	5	-	-	-
● Height (feet)	11	-	-	-
● Width (feet)	30	35	-	25
● Spacing (feet)	120	-	-	-
<u>Production Areas</u>				
● Height of Opening (feet)	4 to 8	5	6.5 to 8	-
● Panel Width (feet)	-	-	32	-
● Pillar Size (feet)	90 x 90	75 x 75	30 x 40 or 30 x 50	-

(1) Information from interviews with mine operators conducted by D'Appolonia personnel in September 1981.

(2) "-" indicates information not available.

of this subsidence have been identified in the Delaware Basin; however, despite such subsidence, the integrity of the overlying salt is indicated by the absence of water inflow to the mines from overlying aquifers.

Experience in the Carlsbad potash mining district has indicated that, from a practical point of view, there is little need for concern relative to the effects of one mining operation on adjacent mines. Contrary to most underground coal mining procedures, large barrier pillars are not being left at property boundaries and several operators may be mining to within 50 feet of their property lines.

#### 2.1.2.2 Solution Mining

In the solution mining of potash, fresh water is injected to dissolve the ore body and the resulting brine containing the ore is then extracted for processing. The types of solution mining techniques suited to potash extraction are the following:

- o Single-well systems in which one well with at least two layers of casing is used for injecting water and extracting the potash. This technique results in a "teardrop" shaped cavity or a vertical cylinder.
- o Multiple-well systems in which the injection and extraction wells are separate so that a horizontal seam is dissolved. Communication between the wells is initiated by hydraulic fracturing.

Because the sylvite in the Carlsbad potash mining district tends to be thinly bedded, the multiple-well system appears to be the more appropriate solution mining system. Davis and Shock (1970) reported the results of the experimental use of the multiple-well method for the solution mining of sylvite in the Delaware Basin. Because langbeinite is less soluble than the surrounding rock (e.g., sylvite and halite), it is not amenable to solution mining.

The Potash Company of America and Continental Potash have tried unsuccessfully to solution mine potash in the Carlsbad potash mining district. These failures have been attributed to the following:

- o The low grade of ore
- o The thinness of the ore beds
- o Problems with pumping and heating (to increase salt solubility) the injection water

The unavailability of fresh water in the Carlsbad area would be a further problem associated with any future attempts to solution mine potash in commercially significant quantities.

These experiences and the lack of suitable water supplies suggest that the potential for application of currently available solution mining technology for the extraction of sylvite at the WIPP site is remote. There appears to be little or no incentive to mine in this fashion, as compared to underground methods.

### 2.1.3 Ore Processing

The primary method for separating potash minerals from other evaporite minerals is by heavy-media separation. Through this technique, the potassic minerals are separated by relying on the differences in specific gravities between these minerals and those of other evaporites. Sylvite and langbeinite are typically processed separately except by the International Minerals and Chemical Corporation, which holds a patent on a method to process low-grade ore that is a combination of sylvite and langbeinite.

## 2.2 HYDROCARBONS

Hydrocarbon development in the vicinity of the WIPP site is primarily concerned with natural gas, but limited amounts of distillate and crude oil can be found. Exploiting these resources requires the following sequential steps:

- o Exploration, drilling, and well completion
- o Production stimulation (not always necessary)
- o Production and distribution



The following paragraphs address these aspects of hydrocarbon development and the methods employed at each step.

### 2.2.1 Exploration, Drilling, and Well Completion

Exploration for hydrocarbons typically involves a two-step process, performed in stages to minimize the potential for spending large sums of money on a nonproductive hole. The first step utilizes remote methods that provide indirect evidence of an oil or gas horizon. The most frequently utilized method is seismic reflection, which is performed at the surface and does not involve disturbance of the natural, in-place rock. The second step involves drilling exploration boreholes through expected pay zones. Downhole geophysical measurements are usually taken as the drilling proceeds to update available data.

An important factor in understanding oil and gas exploration is that, if sufficient quantities of oil or gas are encountered, the exploration hole becomes the production well. These dual roles dictate how boreholes are developed; the methods are quite unlike those for mineral exploration or other geologic investigations. A basic tenet in drilling for oil and/or gas is that the hole must be kept open. If the hole closes, a very expensive drill stem and other tools may be lost and, in the worst case, the hole may become unusable.

Oil and gas holes are normally drilled to a relatively large diameter (e.g., 15 to 30 inches) through the shallow unconsolidated materials. A steel surface casing is set and cemented in the hole to prevent closure. The drill hole is then advanced at a lesser diameter, generally at least, to the top of the salt in the Delaware Basin and steel casing is cemented in place. Drilling then continues, possibly with additional reductions or "step-downs" in well diameter and additional casing emplacement (through upper portions of the hole), until the potential pay zone horizon is penetrated. High-integrity cement bonding between the casing and formation strata is achieved and verified using downhole geophysical logging techniques. After the pay zone has been intersected and some evidence of hydrocarbons noted, small-diameter (e.g., four- to

six-inch) steel "production tubing" is inserted into the hole and the lower 100 to 500 feet cemented into place.

The portion of this tubing in the production zone is then perforated by shooting small steel projectiles through it by means of directional charges. Any formation water associated with the hydrocarbon-producing horizon is drained and testing is performed to determine the reservoir characteristics and feasibility of using the well for hydrocarbon production.

Drilling for oil and gas can proceed vertically or it can deviate from the vertical beginning at any given depth. The sequence of placing casing and inserting production tubing does not change, although some of the procedures are altered when directional drilling techniques are employed. The location of the bottom of boreholes is determined by downhole surveying techniques. Directional surveying proceeds as the hole is drilled producing downhole location data accurate enough that litigation may be based on them. For vertical drilling, these techniques can determine the location of the bottom of a 14,000-foot-deep borehole within about 100 feet horizontally and 20 feet vertically. These error bands are approximately doubled in the case of directional drilling.

If, as a result of testing, the well is believed to have a good potential for production, further operations may be conducted in the well to optimize production. Most of these production-optimizing operations are designed to increase the hydraulic conductivity of hydrocarbon host rock, allowing oil and/or gas to flow more easily into the wellbore, and thus stimulating production from an otherwise substantially porous, but low hydraulic conductivity, formation.

If testing results indicate that production of hydrocarbons from the drill hole is unlikely, the production tubing is severed near the bottom (just above the cement bond) by small explosive charges and removed. The drill hole is then plugged by emplacement of cement grout at

selected intervals, separated by intervals of drilling fluid. The actual plugging plan for hydrocarbon exploration wells varies from well to well, but in all cases is mandated by applicable state and federal regulations.

### 2.2.2 Production Stimulation

Stimulation of a gas- or oil-producing well involves a process to increase its yield. Methods are commonly classified as follows:

- o Primary stimulation - increase the hydraulic conductivity of the reservoir rocks.
- o Secondary stimulation - increase the driving force by water flooding or other methods.
- o Tertiary stimulation - decrease the viscosity of the hydrocarbons.

Primary production stimulation is applicable to all hydrocarbon recovery operations and can be performed in many ways. The most common primary production stimulation technique is hydraulic fracturing ("hydrofracing").

#### 2.2.2.1 Hydrofracing

Hydrofracing involves injecting fluid and pressurizing it until the tensile stress induced in the host rock is sufficient to crack it. These cracks then connect the pores in the rock and greatly increase the hydraulic conductivity of the reservoir formation. The fracturing is initiated at the desired depth within the drill hole by pressurizing through the perforated portions of the production tubing.

Hydrofracing typically involves several steps as follows:

- o Injecting fluid into the production tubing.
- o Increasing the fluid pressure until it exceeds the in situ tensile strength of the reservoir rock.
- o Observing pressure levels to assure that fracturing of the reservoir rock has occurred (marked by rapid pressure decline).

Once a tensile fracture is initiated, it is penetrated by liquid from the borehole and fracture propagation under continuous hydraulic action takes place. The fracturing fluid carries a propping agent to ensure a highly permeable flow channel is maintained after pressure release. The hydrofracing fluid is then removed from the hole and the hole is flushed with nitrogen or other inert materials.

Two fundamental factors define the geometry of the induced fractures and limit their extent:

- o The elastic behavior of the strata being fractured is governed by the rock material properties and the external loading.
- o The resistance to flow due to the fluid viscosity reduces the pressure exerted by the fracturing fluid as it moves through the narrow openings away from the borehole.

Hydrofracing a reservoir horizon requires a design to account for these factors prior to its execution in the field. Such designs specify the pressure to be used to overcome the lithostatic pressure and the tensile strength of the rock and consider the following types of conditions for the specific well and formation to be fractured:

- o Confining pressure (lithostatic, pore fluids)
- o Lithology and strength characteristics of the rock to be fractured
- o Orientation of bedding planes, fissures, and other planes of weakness

The design of the hydrofrac must also specify the characteristics of the fracturing fluid and the schedule by which it is injected to establish how the initiated fractures are propagated. The fluid viscosity and efficiency in propagating fractures (expressed as a fluid-loss coefficient) are the fluid properties that must be determined. The pumping rate and pumping time are also key variables in designing the fracture geometry.

The size and extent of the induced fracturing is directly controlled by the amount of energy placed into the system. By selecting appropriate fluids and pumping schedules, the well developer has a good deal of control over the extent of fracturing. One important consideration is that the effort is made to limit the vertical extent of fractures so that other permeable, but barren, zones are not interconnected with the pay zone. The degree of such control is increased when the formation to be fractured is homogeneous and isotropic. As the rock characteristic becomes more complex, the control over the fracturing decreases.

#### 2.2.2.2 Acidizing

Acidizing is another method to increase the hydraulic conductivity of hydrocarbon-producing rocks. Acidizing involves injecting an acid into the producing horizon to break down materials chemically so that the pores in the rock become interconnected. Acidizing is especially applicable to calcareous rocks or sandstones cemented with calcareous materials. The acid reacts with the calcium carbonate to break down the cementation of the rock.

Acidizing a formation involves many of the same steps as hydrofracing. The primary concern is injecting the acid into a formation having low hydraulic conductivity and dispersing it away from the injection point in appropriate concentrations. Accordingly, the borehole is pressurized at the desired level to initiate small fractures and the acid solution is then injected under pressure to flow into and propagate the small openings.

#### 2.2.2.3 Secondary and Tertiary Recovery

Secondary and tertiary production techniques are used to provide an artificial driving force to push oil into a well and to reduce the viscosity of heavy crude oils, thereby increasing the effective hydraulic conductivity. Water, brine, steam, carbon dioxide, surfactants, or other materials are injected into the formation to provide driving force, reduce surface tension, heat the material, or chemically react with it to cause the crude oil to flow more readily into the well.

Secondary recovery methods are commonly employed in portions of the Delaware Basin that contain practical quantities of crude oil. Such production methods are not evaluated in detail in this report, however, because of the minimal amount of crude oil likely to exist within the WIPP site. This technology could possibly, in the future, be advanced and adapted to enhance the recovery of natural gas.

### 2.2.3 Production and Distribution

Natural gas flows from wells because of the lithostatic pressure head under which it has formed and accumulated; no pumping of natural gas is required. The gas from wells is most commonly pure enough for direct market use with little refinement necessary. At a producing well site, the gas is either stored in tanks for distribution or compressed directly and sent into transmission pipelines.

Crude oil is pumped from the reservoir using positive displacement pumps. It is collected in storage tanks at the well pad and later sent to processing facilities for refining.

### 3.0 POTENTIAL EFFECTS ON THE WIPP FACILITY

The purpose of this chapter is to delineate those aspects of the described extraction activities that could result in disturbances affecting the waste emplaced in the WIPP facility. This analysis provides information on the extent of influence of disturbances and forms the basis for the assessment of the potential effects of developing the natural resources in Control Zone IV of the WIPP site.

#### 3.1 UNDERGROUND MINING OF POTASH

The opening of entries for underground potash mining causes a redistribution of stresses within the surrounding rock that can lead to opening of fissures, alterations of rock fabric, and/or increase the hydraulic conductivity of the surrounding rock. Mining can also lead to surface subsidence and subsidence-induced fracturing above the mined level. Evaluation of the extent of such disturbances can draw upon both empirical data and solutions of simplified governing equations.

##### 3.1.1 Stress and Stress-Induced Creep

The effects of stress redistribution and stress-induced creep related to potash mine development in the WIPP site area were evaluated using both available empirical data and the results of analytical studies. The evaluations are described in the following sections. More sophisticated methods, such as geomechanical modeling using finite element techniques, could be applied to give a more precise evaluation. However, the results of first approximations and very conservative preliminary analytical studies demonstrate the adequacy of Control Zone III as a buffer between potash mines developed within Control Zone IV and the WIPP facility (even using very conservative assumptions), and more exact analyses are not necessary.

##### 3.1.1.1 Empirical Relationships

Empirical relationships derived from mining experience in potash, coal, and other bedded formations provide valuable means of estimating ground behavior based on actual observations. Although parameters such as

lithology, stratigraphic thickness, rock strength, and mine geometry vary widely from mine to mine, fundamental relationships generally applicable to all bedded geologic settings have been derived from data collected from throughout the world. Adler and Sun (1976) performed a review of data from worldwide mining experience in many bedded geology settings, from which they condensed the most commonly accepted concepts and theories of ground behavior and control. Among these is the pressure-arch theory for estimating the distribution of stresses due to underground mining. Abel (1979) prepared a review of WIPP design considerations in which he presented a method of estimating the distance of load transfer in WIPP pillars due to drift excavation. His calculational method was based on pressure-arch theory and was derived from an extensive collection of empirical data.

When a mine entry is driven, the sag of the immediate roof results in load transfer to the solid ribs, creating a "pressure-arch" above the opening in this distressed zone (Figure 7). Field observations have shown that the maximum width of the pressure-arch increases with depth, is strongly affected by the local stratigraphy and associated rock mass properties, and becomes interactive with subsidence phenomena at shallow mining depths. Empirical relationships have been developed to describe the size of the pressure-arch around an underground opening. The following equation (Adler and Sun, 1976) is a typical example:

$$W_{\max} = 0.15H + 60 \quad (1)$$

where:

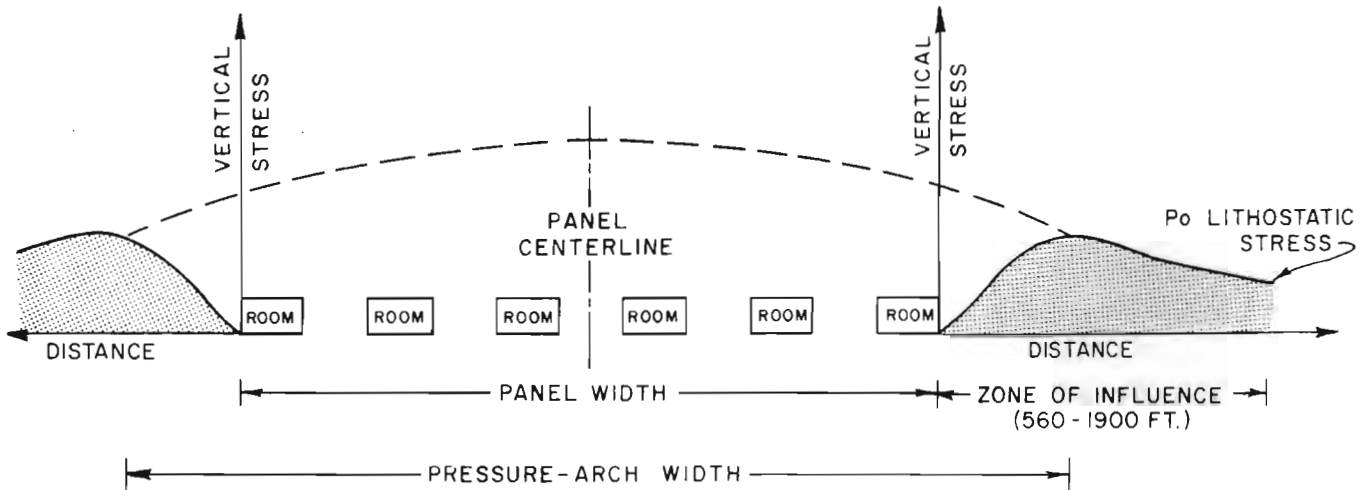
H = depth of the mine, feet

$W_{\max}$  = width of the maximum pressure-arch, feet.

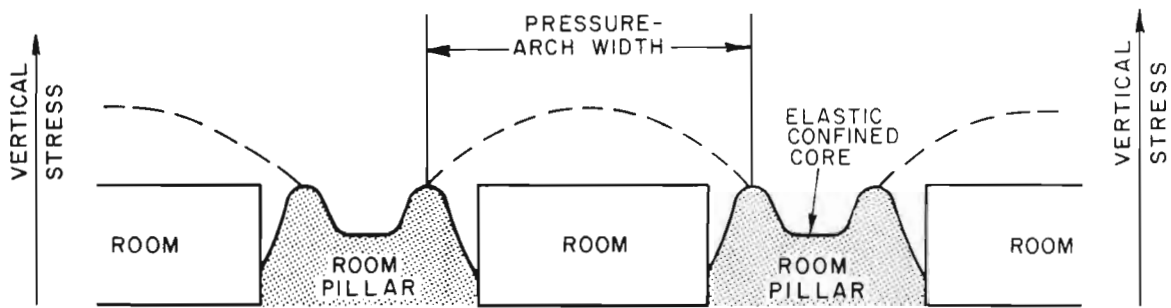
Most references (e.g., Stefanko, 1978; Adler and Sun, 1976) recommend a panel width of  $0.75W_{\max}$  for design purposes, based on operator experience. In theory, if  $W_{\max}$  is exceeded, the panel is too wide and excessive loads will be shed directly on the pillars, thereby creating potential instabilities in the roof, floor, or the pillar itself (Figure 7).



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FAR FIELD STRESS EFFECTS OF POTASH MINING



STABLE PILLAR CONFIGURATION WITH NO ROOM INTERACTION

VERTICAL STRESS DISTRIBUTION  
 LINE OF MAXIMUM COMPRESSION

NOTE  
 DRAWINGS NOT TO SCALE

FIGURE 7

GENERALIZED STRESS DISTRIBUTION  
FOR ROOM-AND-PILLAR MINING

PREPARED FOR

WESTINGHOUSE ELECTRIC CORPORATION  
ALBUQUERQUE, NEW MEXICO

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According to the pressure-arch theory, the maximum load occurs near the abutments and, beyond this point, the load is gradually dissipated over some distance. Considering only the side abutments, several approaches can be examined to estimate the zone of influence, which is the distance from the edge of the opening to the point at which the undisturbed in situ stress is once again reestablished. Within the zones of influence, changes in the stress or deformation levels would be detectable; outside of the zone, no measurable change in the undisturbed in situ conditions would be expected.

British experience (Whittaker, 1975) suggests that the influenced zones within the side abutments extend to a maximum distance of one-quarter to one-third of the thickness of the rock overlying the mine (i.e., mine depth), decreasing exponentially from the ribside. According to studies by Abel (1979) using data from a number of underground mines, the load transfer distance can be calculated at a 95% confidence level by the formula:

$$\text{Load Transfer Distance} = -45.0 + 0.373H - 0.0000820H^2 \quad (2)$$

where:

H = depth of the mine, feet  
 Load Transfer = distance away from the opening at which  
 undisturbed in situ stress is reestablished

Applying the above information from Whittaker (1975) to the WIPP site area, the calculated zone of influence for the potash mine would be 660 feet, based on using a factor of 0.33 (influence extends horizontally a distance of one-third of the mine depth) and a depth of 2,000 feet. Although the lower beds in the potash zone at the WIPP site are at a depth of about 1,700 feet, a depth of 2,000 feet was selected for conservatism. The calculated zone of influence for the WIPP facility would be approximately 700 feet using a similar factor of 0.33 or 538 feet using a factor of 0.25, and a depth of 2,150 feet. Applying Abel's equation (2) to the WIPP facility, the load would be transferred over a distance of 378 feet.

Local mining experience also indicates a relatively small zone of disturbed rock around a mine opening. Cognizant personnel at the International Minerals and Chemicals Corporation mine about ten miles west of the WIPP site (where the potash zone is considerably shallower than at WIPP) expressed that, on a practical basis, the effects of potash mine openings extend away from the mined area a distance of about four times the height of the room. This local rule of thumb would suggest a small separation would be required (on the order of 100 feet) to eliminate any noticeable impact of mining at the WIPP facility due to the proximity of potash mines.

In summary, the results of the empirical relationships suggest that the combined zones of influence from potash mining and WIPP excavations is about 1,400 feet (660 feet due to potash mine; 700 feet due to WIPP facility). These empirical relationships, as well as local mining experience, indicate that a buffer zone of 1,400 feet width will separate the effects of a potential potash mining operation and the WIPP facility.

### 3.1.1.2 Analytical Studies of Potash Mining

An analytical model was used to evaluate the potential effects of mining potash in Control Zone IV of the WIPP site. The model was applied to a simplified case of 100 percent extraction of a cylindrical panel 300 feet in diameter. This model would represent a conservative upper bound to a 500- to 800-foot-wide panel at 60 percent areal extraction. This is because the far-field stress effects from extraction are controlled by the extraction ratio, and the model assumes an extraction volume which is an order of magnitude larger than the volume for a 800-foot-wide panel.

The closed-form solution based on a secondary creep law is given in Chabannes (1982) as follows:

$$\sigma_e = \frac{3^{1/2} a^{2/n} (P_o - P_i)}{nr^{2/n}} \quad (3)$$

where:

- $\sigma_e$  = von Mises effective stress change, pounds per square inch
- $a$  = radius of circular panel, feet ( $a = 150$  feet for potash mines)
- $r$  = radius to point of interest, feet
- $n$  = stress exponent, dimensionless ( $n = 4.9$  for Salado salt at the WIPP site [Hermann, et al., 1980])
- $P_o$  = far-field confining stress, pounds per square inch
- $P_i$  = internal pressure, pounds per square inch.

The following assumptions were made in the analysis:

- o The opening is in the shape of an infinitely long cylinder in a homogeneous, isotropic medium. This assumption allows for a convenient closed-form solution.
- o The excavation stays open. This assumption adds conservatism to the results in that, as closure occurs, the opening will eventually collapse resulting in establishment of a new stress field with lower abutment pressures.
- o No internal pressure is applied, i.e., it is assumed that the opening is self-supporting ( $P_i = 0$ ).
- o The closed-form solution used is based on a secondary creep law, implying the following:
  - The stress distribution applies at a time when steady-state conditions have been established.
  - Transient creep phenomena, which occur prior to establishing steady-state conditions, cannot be studied.

In the closed-form solution, the radius of stress-induced influence was related to the radius of the underground opening based on the von Mises effective stress (Figure 8). This stress is the driving force that causes creep closure of underground openings. The zone of influence was determined by selecting the minimum value of the von Mises effective stress for which an "effect" could be assumed and calculating the distance out from the opening where this stress level would be reached. A "cutoff" stress level of 250 pounds per square inch was selected. The limit of the zone of influence occurs when the von Mises effective

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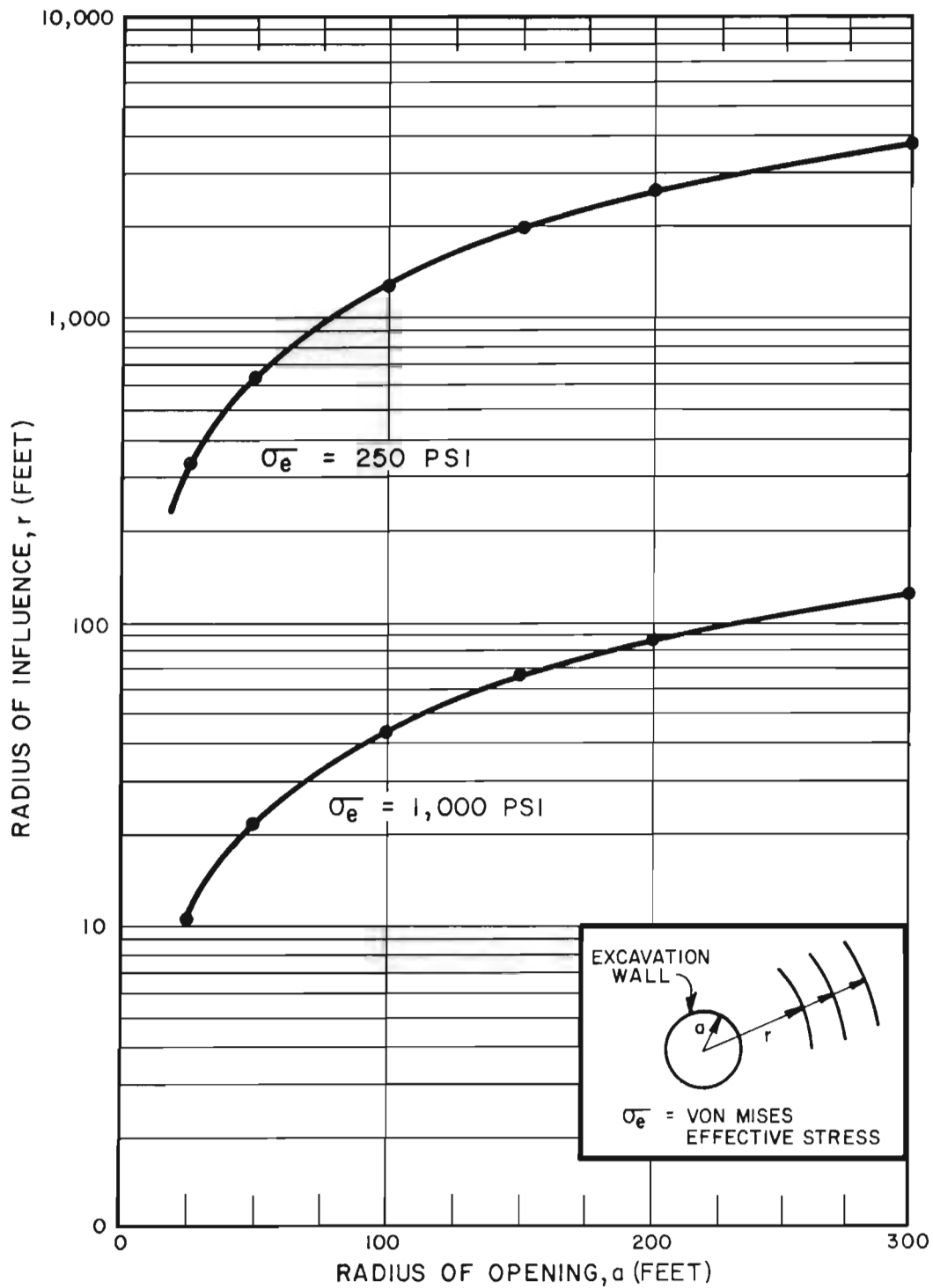


FIGURE 8

NOTES:

- ANALYSES ARE FOR AN UNDISTURBED LITHOSTATIC STRESS OF 2,000 PSI. THIS STRESS CORRESPONDS TO A DEPTH OF ABOUT 2,000 FEET.
- ANALYSES ARE SPECIFIC TO THE SALADO SALT AT THE WIPP SITE.

ZONE OF STRESS-RELATED INFLUENCE  
AROUND AN UNDERGROUND OPENING

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stress induced by the mining is decreased to 250 pounds per square inch. This value is conservative relative to the lithostatic conditions near the WIPP horizon and is near the lower detection limit for such stress levels measured in the laboratory (Bakhtar, 1979). The analysis was performed assuming the far-field confining stress ( $P_0$ ) is 2,000 pounds per square inch, which corresponds to a depth of approximately 2,000 feet.

Using these very conservative assumptions, Equation (3) indicates that the effect of a potash mine excavation could extend out to a distance of about 1,900 feet in the same horizontal plane as the mining (Figure 8).

### 3.1.1.3 Analytical Studies of the WIPP Facility

Current WIPP design calls for 100-foot-wide pillars with rooms 33 feet wide, producing a low (<30%) extraction ratio in contrast to conventional mining practice. An assessment of the extent of the abutment zone around a typical WIPP storage room was made using the Wilson's Hypothesis or the confined core method of pillar design (Wilson and Ashwin, 1972). The pillar is assumed to fail around its periphery. The stress is redistributed from this failed zone to the center of the pillar where rock is under triaxial confinement. The equation for the distance to peak abutment stress is given by (Wilson and Ashwin, 1972):

$$y = \frac{m}{\tan B (\tan B - 1)} \ln \left( \frac{\sigma_v}{\sigma_o} \right) \quad (4)$$

where:

- y = distance to peak abutment stress
- m = seam extraction height
- $\sigma_v$  = peak vertical abutment stress
- $\sigma_o$  = unconfined strength of broken rock
- $\tan B$  = triaxial stress factor

Based on Equation (4), the distance from the room edge to peak abutment stress is estimated at 13 feet. The width of the abutment zone is estimated as 22 feet on each side of the pillar such that the width of

the confined elastic core is 56 feet. This analysis predicts that each room acts independently of the other.

The above analysis is also consistent with that presented by Adler and Sun (1979). They show that for a pillar-to-opening width ratio of 3:1, stresses are concentrated in the outer quarters of the pillar, and the central one-half of the pillar has a negligible increase in stress.

These data indicate that the pressure arches over individual drifts are isolated, and only the outside drift need be considered in the calculation of far-field stress effects. Therefore, by applying Equation (3) to the WIPP facility conditions, the effect of the WIPP excavation would be estimated to extend to a distance of 210 feet in the same horizontal plane as the facility horizon. To account for some small effects from adjacent drifts or crosscuts, this figure may be arbitrarily doubled to about 400 feet.

#### 3.1.1.4 Summary of Analyses

The conservative analyses in previous sections indicate there should be no superposition of stress effects from the mining of potash upon the local stress distribution around the underground WIPP facility if the separation distance is at least 2,300 feet (1,900 feet due to the potash mine; 400 feet due to the WIPP facility). The conservative, simplified analysis suggests a wider buffer zone (2,300 feet) required around the WIPP facility than that obtained by applying empirical data (1,400 feet). In either case, the 5,200-foot-wide Zone III provides considerably more than the necessary separation. Both the analytical and empirical studies, as well as past mining experience in the area, indicate that underground potash mining can be conducted within Control Zone IV without influencing the in situ conditions surrounding the WIPP facility or creating a mechanism for breaching the WIPP facility.

Another factor to be considered is the location of the ore zone which is about 400 feet above the WIPP underground facility horizon. For the analyses, the potash mine and the WIPP facility were assumed to be at a

depth of 2,000 feet and 2,150 feet, respectively. Due to this additional difference in elevation or depth, the undisturbed zone separating a developed potash mine and the WIPP facility would be larger than assuming the mine and WIPP facility are on nearly the same horizontal plane.

### 3.1.2 Stress-Induced Increases in Hydraulic Conductivity

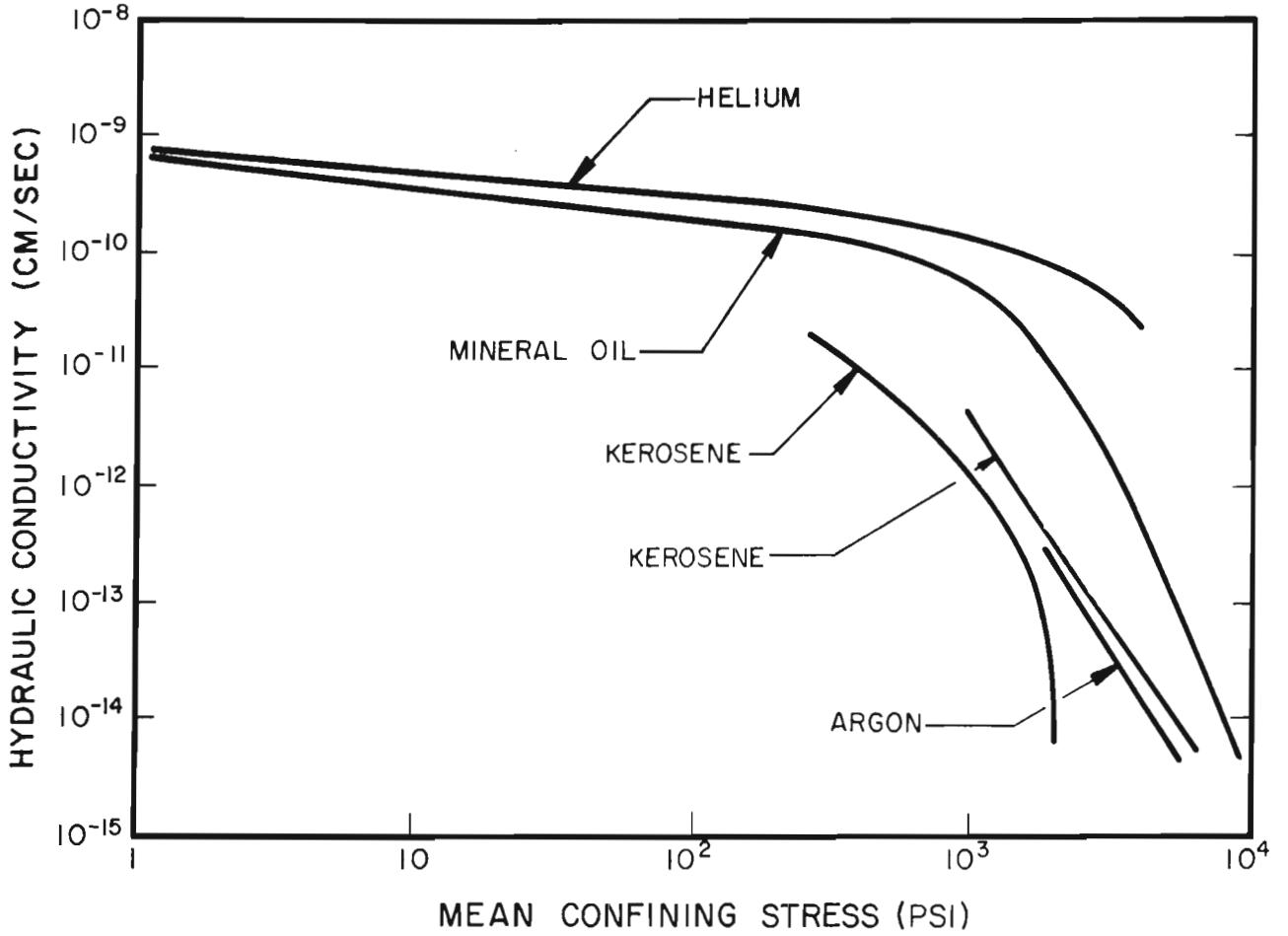
Indirect evidence that the hydraulic conductivity of salt may increase close to an excavation has been obtained from laboratory tests which show the hydraulic conductivity to be dependent on the mean confining stress. For example, results from several sources compiled by Isherwood (1981) show that the hydraulic conductivity of a rock mass may increase by five to six orders of magnitude as the mean confining stress of the surrounding rock is reduced from 10,000 to 0 pounds per square inch (Figure 9). Although the relationship for brine is not shown explicitly in Figure 9, the viscosity and specific gravity of brine suggest that similar increases in hydraulic conductivity with decreased confining stress may apply to brine as well.

Lai (1971) developed an empirical equation that relates hydraulic conductivity to mean confining stress and octahedral shear stress. If the stress distribution around an underground excavation is known, Lai's equation can be used to predict the variation of hydraulic conductivity with distance from the excavation. Figure 10 shows the variation in hydraulic conductivity calculated by this method, assuming a hydrostatic state of stress and a power law for the secondary creep response of the salt. The stress distribution shown is the steady-state condition that occurs when the stress relaxation due to creep is fully developed; this stress state is based on work by Chabannes (1982). The time required to reach the steady-state condition is considered to be small relative to the operational life of a storage facility.

The calculated increase in hydraulic conductivity close to the wall of the excavation is related primarily to the decrease in mean confining stress. The maximum increase is relatively small (approximately one



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NOTE:

FIGURE ADAPTED FROM ISHERWOOD (1981)

FIGURE 9

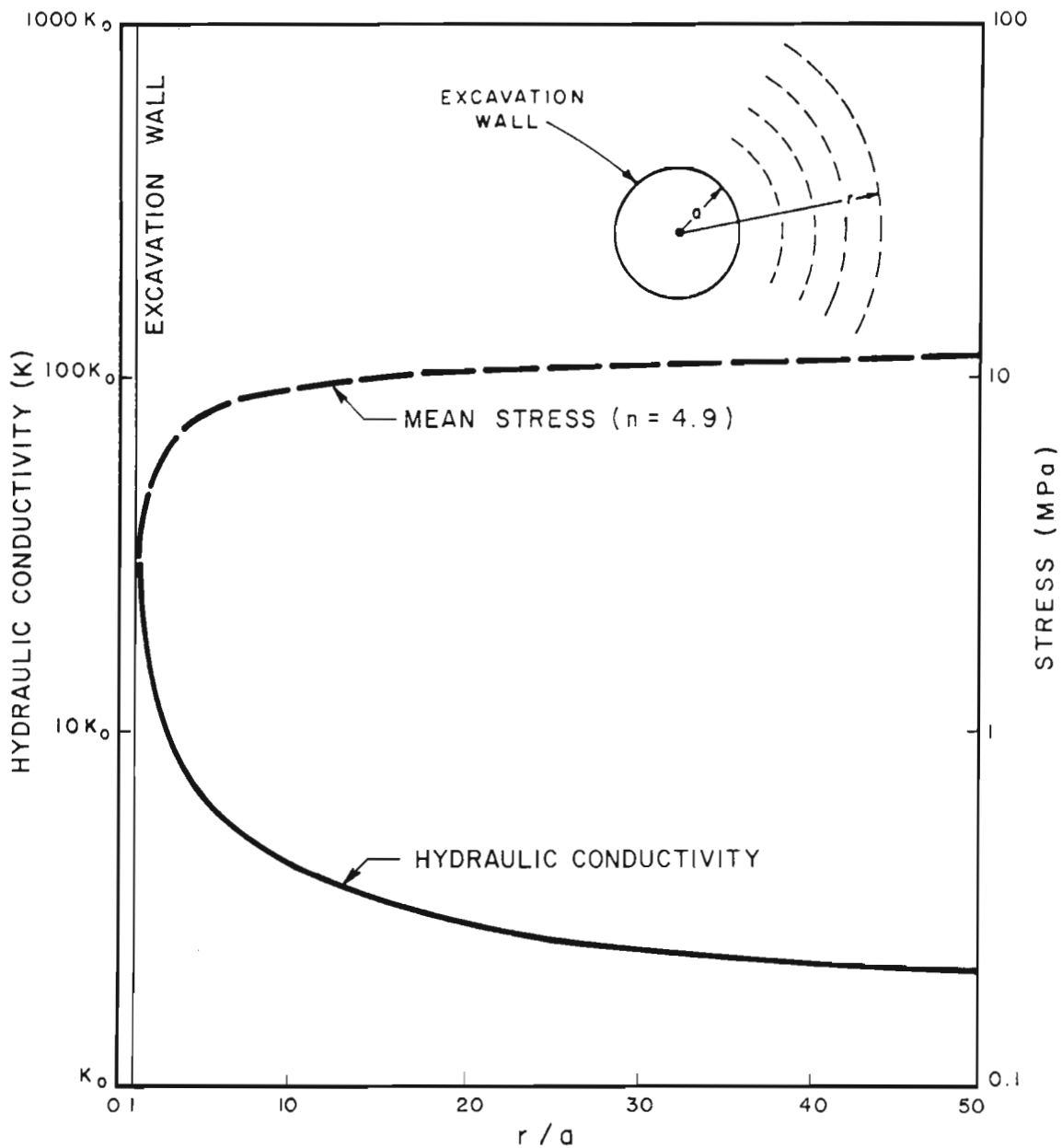
RELATIONSHIP OF SALT HYDRAULIC  
CONDUCTIVITY AND CONFINING STRESS

PREPARED FOR

WESTINGHOUSE ELECTRIC CORPORATION  
ALBUQUERQUE, NEW MEXICO

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$K_0$  = HYDRAULIC CONDUCTIVITY IN UNDISTURBED SALT  
 WIPP STRESS EXPONENT (n) FROM  
 HERRMAN, ET AL. (1980)

FIGURE 10

HYDRAULIC CONDUCTIVITY AND  
 STRESS DISTRIBUTION AROUND  
 AN UNDERGROUND OPENING IN SALT

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REFERENCE  
 MODIFIED FROM LAI (1971)

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order of magnitude increase) because the mean confining stress does not reduce to zero. The magnitude of this increase is less than that predicted for fractured rock, but the lateral extent of the disturbed zone is greater for salt. Hydraulic conductivity increases of less than an order of magnitude will probably not result in a significant increase in system flow; furthermore, it is unlikely that a contrast of less than an order of magnitude could be distinguished by current field testing techniques for low hydraulic conductivity materials such as salt.

This analysis takes into account only one mechanism by which a zone of increased hydraulic conductivity could form in salt. Fracturing of the rock due to stress relief can affect the hydraulic conductivity of rocks disturbed by mining. Such fracturing would be expected in areas where net tensile stresses in excess of rock strength are introduced in the rock due to the underground excavations. It has been shown at the WIPP site that, under conservative assumptions, these tensile stress areas extend no more than a few feet above or below an opening cut in the evaporites (Harrington, 1979).

In summary, mining potash within Control Zone IV would result in a zone immediately surrounding the openings in which the hydraulic conductivity of the rock would be greatly increased because of fracturing. Farther from the mine, the hydraulic conductivity of the salt would be slightly increased, but this change would be within the normal range of uncertainty for salt hydraulic conductivity values. Therefore, no preferential paths for ground water flow between a potash mine developed within Control Zone IV and the WIPP facility would be expected to be created due to stress-induced change in hydraulic conductivity.

### 3.1.3 Subsidence

Underground mine openings eventually close because of the weight of the overlying rocks. The closure process, which may manifest itself on a gross scale as surface subsidence, has been extensively studied, especially in coal fields, to determine its effects on mine safety and the integrity of surface structures. The rate of subsidence depends on the

depth of the openings, the extraction ratio (the area of the openings divided by the area of the mine), and the nature of the overlying rocks.

Both in coal and potash mines, the surface area affected by subsidence exceeds the area of the underground openings. The angle between the vertical and a line connecting the limit of the surface subsidence and the edge of the underground opening is called the angle of draw; this angle is typically about 45 degrees for potash mines near the WIPP site (U.S. Department of the Interior, 1975). The surface area affected can be estimated by applying a 45-degree angle of draw to the area and depth of the underground workings. If, for example, a potash mine is located at a depth of 2,000 feet, this procedure suggests that subsidence will affect the ground surface out to a distance of about 2,000 feet from the limits of mining. Applying this to the WIPP site, mining at the inner edge of Control Zone IV would not result in subsidence effects closer to the WIPP site center at the ground surface than the outer 2,000 feet of Control Zone III.

A generalized subsidence equation has been developed based on coal mining experience in the Appalachian region of the United States (General Analytics, Inc., 1974). Although this equation was derived for a different geologic setting, it can be used to provide a preliminary estimate of the magnitude of the subsidence. The equation is as follows:

$$S = sHbe \quad (5)$$

where:

- S = maximum subsidence, feet
- s = subsidence factor, dimensionless
- H = cavity height, feet
- b = fraction of cavity remaining after backfill, dimensionless
- e = extraction ratio, dimensionless.

This equation assumes that the mine will be extracted in such a manner as to produce maximum subsidence at the center of a subsidence trough.

A subsidence factor (ratio of vertical surface displacement to cavity height) of 0.67 is commonly reported in the Carlsbad potash mining area

(U.S. Department of the Interior, 1975). Typical mines using 40 to 60 percent final extraction ratios, no backfill, and six-foot openings in production areas would be predicted to cause maximum subsidence at the surface on the order of two feet.

This disturbed rock would represent an area of higher hydraulic conductivity through which waters of the overlying Rustler Formation (Figure 4) could potentially enter the underground mine workings. Nevertheless, this phenomenon has not been observed in the potash mines located in the Delaware Basin. It should be noted that the vertical separation between these mines and the overlying aquifers is smaller than the corresponding separation between the WIPP facility and any potential potash mine at the WIPP site.

This preliminary assessment indicates that subsidence effects from potash mining in Control Zone IV would occur in a zone located above the McNutt Potash Member, would extend into the outer 2,000 feet of Control Zone III at the ground surface, and would cause a maximum of 2 feet of subsidence. Because of the buffer zone provided by Control Zone III, any potential subsidence effects resulting from potash mining would not affect the WIPP facility.

### 3.2 SOLUTION MINING

The feasibility and methods of solution mining were discussed previously in Section 2.1.2.2 of this report. This section discusses the consequences of such mining related to the WIPP. Although it is unlikely that solution mining will be used for potash or evaporite mineral extraction near the WIPP site (see Section 2.1.2.2), the remote possibility that potash or other evaporite minerals could be extracted by solution mining for resource recovery or that caverns may be developed for purposes of underground storage has nevertheless been evaluated. Should this occur, the solution mining extraction system is envisioned to include a series of injection/production wells which would be hydraulically connected by hydrofracing. Design considerations such as well spacing and final cavern size would be dictated by economics of well

development, site geology, percentage extraction, and subsidence. The design decisions and construction impacts of solution mining which could potentially affect the WIPP facility are the span of the caverns (which could lead to subsidence), the extent of hydrofracing, and the redistribution of stresses around the cavern.

### 3.2.1 Cavern Span and Stress Redistribution

While issues of strata control are not as critical in solution mined cavern development as in room-and-pillar mining, it follows that an operator would limit cavern size so as not to induce roof collapse which would disrupt mining operations and possibly lead to subsidence. If the cavern size approached the critical limit in a one-gallery system, a new series of wells may be drilled to produce a new cavity isolated from the previously developed cavern.

Analyses of probable stable roof span were performed to estimate the size, in plan area, of the largest feasible solution cavern. Solutioning was assumed to occur at the approximate depth (2,000 feet) of the WIPP storage horizon in Control Zone IV and near the boundary between Control Zones III and IV. This depth and location of the hypothetical solution mine would result in the shortest possible separation between the cavern and the WIPP storage facility. Geologic conditions were assumed and parameters chosen to model a feasible mining operation at the WIPP site. The analyses assume that a 10-foot layer of anhydrite forms the immediate roof. The roof rock above this layer is assumed to be composed of an 80-foot layer of less rigid halite below another 10-foot layer of anhydrite. Beam action is assumed to occur within these stratigraphic units during solution mining of the strata below. It is assumed that pressure communication exists above and below these roof members such that the effectiveness of internal cavern brine pressures in supporting the immediate roof is lost. Under these assumptions, beam analysis (Wright, 1973) indicates that the maximum feasible calculated roof span that will remain stable is of the order of 750 feet.

Field experience gives a broad range of values for maximum stable spans, but generally tends to support theoretical predictions. Jacoby (1973) reports stable roof spans of 300 to 400 feet for caverns in bedded salt around single injection wells. In contrast, Walters (1979) reports that solutioning operations in a series of coalesced wells near Hutchinson, Kansas, resulted in unstable roof spans of from 800 to 1,000 feet at a depth of 725 to 900 feet. In another case history in dome salt (Jacobs/D'Appolonia, 1979), the maximum span of cavern No. 6 at West Hackberry dome, Louisiana, was reported as 839 feet at a depth of 3,300 feet.

Collapse of a cavern of this size or larger could lead to subsidence. Such subsidence would be similar to that resulting from a conventional mine, discussed earlier in Section 3.1.3. As shown previously, the angle of draw would probably be no more than 45°. Therefore, even if the cavern were in the deepest salt stratum, say 4,000 feet, the effects of subsidence would extend no farther than 1,850 feet into Control Zone III at the storage facility level, leaving a buffer of approximately 3,400 feet to Control Zone II. At the surface, the subsidence effects would extend 4,000 feet into Control Zone III.

To determine the zone of influence resulting from the maximum cavern span, a brine-filled cavern with a roof span of 900 feet is assumed at a depth of 2,000 feet. The internal cavern pressure is estimated at 1,054 pounds per square inch, which is assumed to be equal to the static column of brine at this depth, and is given by the following equation:

$$P_i = \gamma \times h \quad (6)$$

where:

$$\begin{aligned} P_i &= \text{internal cavern pressure} \\ \gamma &= \text{unit weight of brine} \\ h &= \text{height of brine column} \end{aligned}$$

The closed-form solution for von Mises effective stress based on secondary creep (Chabannes, 1982), presented earlier in Section 3.1.1.2, was used to estimate the distance to the point at which the stress is 250 pounds per square inch. The value is calculated to be 900 feet within the horizontal plane of the brine-filled cavern. Therefore, the

necessary separation to eliminate stress interaction effects is approximately 1,300 feet (900 feet due to the cavern; 400 feet due to the WIPP facility).

### 3.2.2 Hydrofracing for Solution Mining

Cavern development would probably occur from a series of wells spaced about 500 feet apart (Jacoby, 1973). Hydraulic fracturing would be designed to establish initial fluid communication between wells. As discussed in Section 2.2.2.1, the hydrofracing operator has a reasonable degree of control over the extent of fracturing. From hydrofracing tests performed in the Carlsbad area, it can be expected that to fracture a distance of 500 feet will take between 10 to 25 minutes assuming a pumping rate of 30 barrels/minute and a well-head pressure of 1,500 pounds per square inch (Shock and Davis, 1970).

The propagation of fractures through the formation is determined by the state of stress of the rock, the local stratigraphy and rock strength, and any structural discontinuities, as well as by operator controls. In a smooth-wall borehole drilled into a laterally continuous rock mass in a hydrostatic state of stress, such as at the WIPP site, fractures generally tend to propagate radially from the wells. A fracture under these conditions would not be expected to propagate in a particular direction over a distance much greater than the well spacings. Consequently, well spacing would set a practical limit on the propagation distance of fractures, a distance about one-tenth the width of Control Zone III. Accidental fracturing to a distance much greater than 500 feet would require a noticeably greater amount of pumping time, an unlikely event because once communication has been established between wells at a closer spacing the pumping would cease and thus prevent further fracturing.

### 3.2.3 Summary of Analyses

Based on the analyses in Section 3.2.1, the maximum possible stable roof span for a solution cavern is estimated to be about 900 feet. This span width based on analytical methods is also supported by field



experience. The zone of influence associated with the brine-filled cavern of this size is estimated to be about 900 feet. Combining this value with the 400-foot zone of influence of the WIPP facility indicates that a buffer zone of about 1,300 feet is needed to eliminate any stress interaction. The 5,200-foot-wide Control Zone III is sufficiently wide to provide this buffer zone. In addition, the width of Control Zone III would also provide a buffer due to accidental hydrofracing or any subsidence due to solution mining. Therefore, the analyses indicate underground solution mining or activities associated with solution mining of potash or any other evaporite minerals may be conducted within Control Zone IV without affecting the WIPP facility.

### 3.3 HYDROCARBON DRILLING

Development of the hydrocarbon resources present at the WIPP site by drilling from within Control Zone IV (either vertically or directionally under the inner three zones) would not create a potential for affecting the integrity of the WIPP facility. Drilling operations conducted from within Control Zone IV are far removed from the emplaced waste and their zones of influence do not encroach near the WIPP facility. The results of analyses presented in Figures 8 and 10 suggest that the zone of influence of a small-diameter borehole would be minimal.

### 3.4 HYDROCARBON PRODUCTION STIMULATION

Stimulating the production of hydrocarbons can be conducted using one of several techniques (Section 2.2.2). Primary stimulation through hydrofracing and/or acidizing could be used in areas of the Morrow Formation. The potential ramifications of hydrofracing (or the similar acidizing operation) were examined to envelop the zone of influence of such activities.

#### 3.4.1 Hydraulically Induced Fractures for Hydrocarbon Recovery

Because the well developer has a reasonable degree of control on the geometry of the induced fractures (Section 2.2.2.1), it is possible to predetermine a zone of influence for a potential hydrofracing operation. The approach used to evaluate a potential hydrofracing operation

to enhance recovery of the hydrocarbons below the WIPP site was to identify a methodology that can be used to analyze fracture characteristics and determine the extent of disturbance caused by typical operations.

The calculation procedure is that given by Geertsma and de Klerk (1969). This method estimates the extent of hydraulically induced fractures and is widely accepted in the industry for this purpose (Daneshy, 1973; 1975). The following simplifying assumptions were necessarily made in applying this technique:

- o The formation being fractured and adjoining formations are homogeneous and isotropic with regard to those properties that influence the fracture propagation process.
- o The deformation of the formation(s) during fracture propagation can be derived from linear elastic stress-strain relationships.
- o The fracturing fluid behaves like a purely viscous liquid, i.e., any peculiar flow behavior due to the addition of gelling agents or other additives is neglected.
- o Fluid flow in the fracture is laminar.
- o Simple geometric fracture extension patterns are assumed as radially symmetrical propagation from a point.
- o A circular propagation mode might be expected from injection through a narrow band of perforations.

Figure 11 provides a design chart that relates the fluid characteristics, pumping schedule, and rock strength properties to the fracture widths and lengths. The curve is used by first selecting values (in the units listed) for the following design parameters:

- o  $C$  = fracturing fluid (fluid loss) coefficient, a measure of the efficiency of fluid in propagating fractures,  $\text{cm}/\text{sec}^{1/2}$
- o  $\mu$  = absolute fluid viscosity,  $\text{dyne-sec}/\text{cm}^2$

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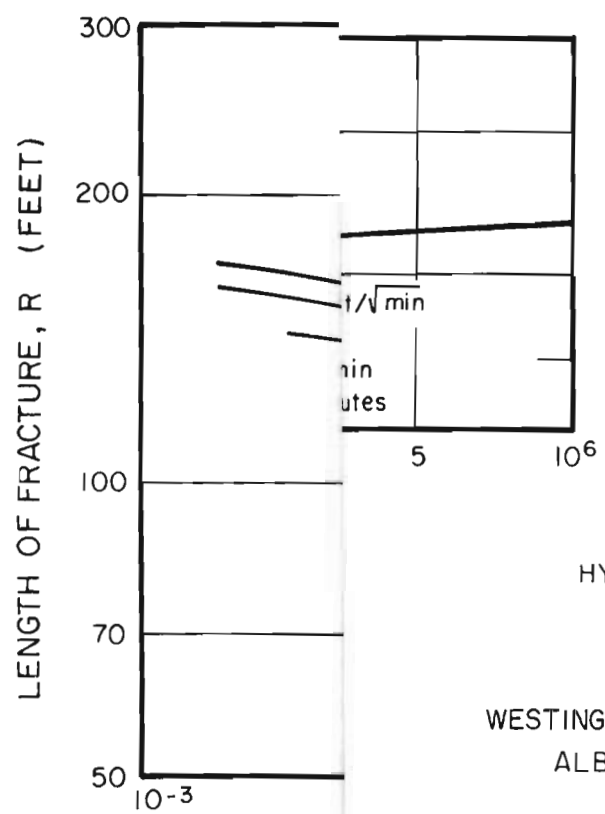
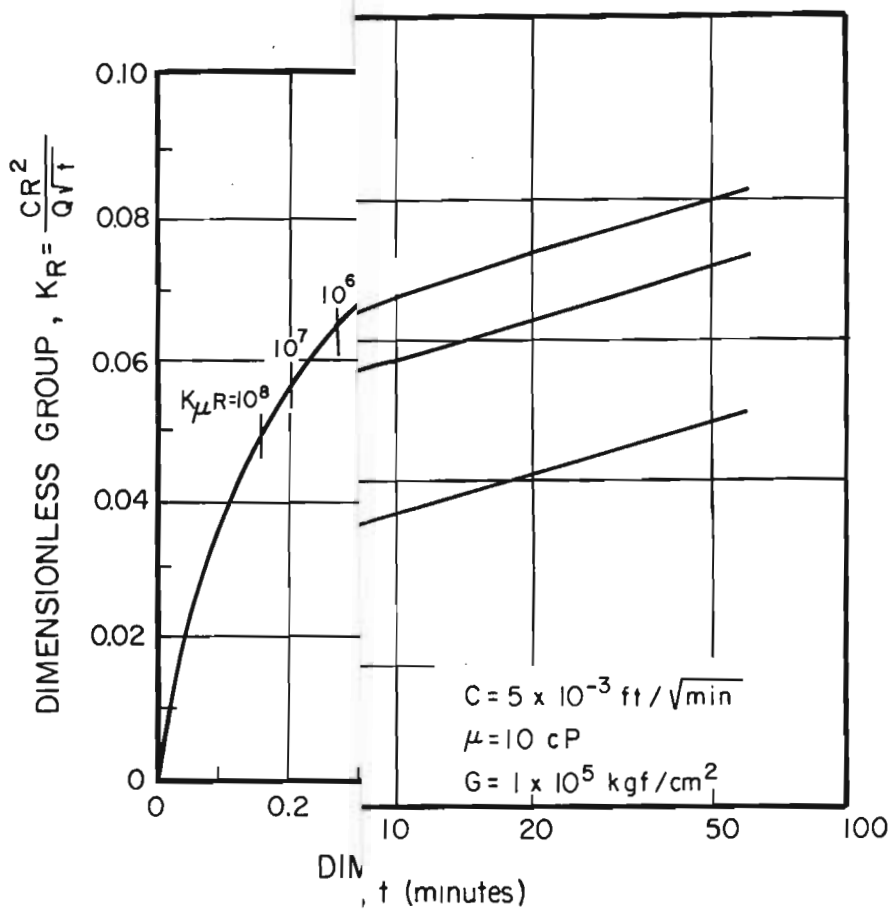


FIGURE II

HYDROFRACING ANALYSIS

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- o  $Q$  = fluid injection rate,  $\text{cm}^3/\text{sec}$
- o  $t$  = time duration of injection, sec

These values must be selected to account for the rock strength properties of the formation, expressed as the shear modulus ( $G$ ,  $\text{g}/\text{cm}^2$ ).

Figure 11 relates a set of convenient dimensionless groups to allow determination of the fracture length ( $R$ , cm) and width ( $W$ , cm) near the wellbore when pumping stops. The procedure is to first calculate  $K_u$  and then locate this value along the curve.  $K_R$  and  $K_u$  values are then read from the ordinate and abscissa, respectively.

Using the described procedure, several curves relating fracture length to the specific independent variables were generated (Figure 11). Typical ranges of these variables are included in the sensitivity curves. The lengths of propagated fractures are most sensitive to the rate and time of pumping and the fluid loss coefficient and are relatively unaffected by differences in the rock shear modulus over a reasonable range.

As indicated in this figure, the typical extent of hydraulically induced fractures is on the order of a few hundred feet. This does not approach the potential location of waste in the WIPP facility under hydrofracing conditions considered typical for such operations in the Delaware Basin; that is, in the Morrow Formation at a depth of approximately 10,000 feet. Accordingly, hydrofracing does not appear to represent a breach mechanism for releasing waste.

### 3.5 HYDROCARBON PRODUCTION

Withdrawal of hydrocarbons from reservoir horizons through wells developed from within Control Zone IV could, theoretically, lead to subsidence at the WIPP site. The area potentially affected is that underlain by the hydrocarbons being extracted plus a surrounding area determined by the angle of draw. Such subsidence is not typically associated with gas production.

## 4.0 POSTULATED WASTE-RELEASE EVENTS

This chapter examines the potential consequences of feasible resource recovery operations conducted within Control Zone IV of the WIPP site. These evaluations focus on defining those activities that could cause or contribute to circumstances by which the integrity of the emplaced waste would be compromised. Each resource recovery activity was examined to assess how a communication event could be initiated or how the assumptions/conditions upon which the SAR communication events are based (U.S. Department of Energy, 1981b; Chapter 8.0) could be substantially changed. For purposes of consequence analyses, the impact of the creation of a solution-mined cavity is assumed to be similar to developing an underground potash mine. This is based on analytical analyses in which the zone of influence associated with a potash mine (1,900 feet) is greater than that associated with a solution-mined cavern (900 feet). Therefore, in the discussion in this chapter, references to a potential potash mine would be applicable to a solution-mined cavern.

Examples of the effects that, theoretically, resource recovery operations could have on aspects of communication events are the following:

- o The time of isolation between waste emplacement and facility breach may be reduced. Thus, the radionuclide inventory may differ from that assumed in the communication events.
- o The mechanism of the event that breaches the facility and creates a pathway for releasing radionuclides to the biosphere may be changed.
- o The mechanism for moving radionuclides through the breach may differ from previously assumed conditions.

The following sections address the relationships between resource extraction activities exercised within Control Zone IV, including directional drilling beneath Zones I, II, and III, and those aspects of communication events that lead to dose consequences.

#### 4.1 TIME OF ISOLATION

The following considerations form the basis for assessing the possible influence of resource recovery in Control Zone IV on the time of isolation of the waste emplaced in the WIPP facility:

- o The DOE policy for resource recovery at the WIPP site, and this natural resources study, is only germane for the duration of institutional controls at the site. The WIPP long-term waste isolation assessment (U.S. Department of Energy, 1981b; Chapter 8.0) has investigated events that could occur once the control of the site has been relinquished.
- o The WIPP long-term waste isolation assessment assumes a breaching time of 1,000 years after waste emplacement for all events that involve breaching the WIPP facility and subsequent transport through ground water. The time of transport through the geosphere of any released radionuclides is sufficiently long to make the actual time of the breach unimportant. The direct-access event is analyzed for its occurrence at both 250 and 1,000 years after waste emplacement.
- o In the WIPP long-term waste isolation assessment, the physical and chemical forms of the waste are assumed to be such that the waste is as soluble as the encapsulating salt.

Accordingly, unless an activity conducted within Zone IV could result in a very rapid breaching of the storage zone with waste discharge directly to the biosphere, such activities would not change the time of isolation assumptions made in the WIPP long-term waste isolation assessment. The physical remoteness and the enforcement of institutional controls at the site reasonably preclude direct access to the emplaced waste during the time in which the DOE policy for controlling resource extraction remains in effect. It is concluded, therefore, that resource recovery activities in Control Zone IV at the WIPP site would not affect the time of isolation of the waste in the WIPP facility, as reflected in the SAR communication events.

## 4.2 BREACHING EVENTS AND PATHWAYS

The zone of influence for potash mining operations conducted within Zone IV does not intercept the WIPP waste emplacement horizon (Sections 3.1 and 3.2) and typical hydrocarbon recovery operations conducted from within Zone IV would not create a fractured pathway to the waste (Sections 3.3, 3.4, and 3.5). Breaching of the WIPP facility by such activities is not considered plausible. The induced disturbances may, however, create zones in which the hydraulic conductivity of the rock surrounding the WIPP facility is enhanced. Breaching of the WIPP facility because of water flow along these preferential paths requires dissolution of the intervening Salado salt and implies a renewable supply of fresh (i.e., unsaturated with salt) water. Potential breaching events and pathways associated with resource recovery are discussed below.

### 4.2.1 Drilling

Exploratory drilling conducted in Control Zone IV is too far removed (at least one mile) to breach the WIPP facility or generate a preferential water flow path toward the emplaced waste. The SAR analysis specifically considers breaching the WIPP facility by drilling directly atop the waste emplacement area. The events analyzed in the SAR (Communication Events 1 and 4) result in minimal consequences; the effects of drilling within Control Zone IV are even less.

#### 4.2.1.1 Potash Exploration

In the case of exploratory drilling for potash, the 400-foot vertical separation between the McNutt Potash Member and the waste emplacement horizon gives further assurance that such a borehole would not cause a breaching of the sealed WIPP facility.

An improperly sealed potash exploration hole could create a means by which surface and/or Rustler waters could directly encounter the Salado salt. A potash borehole drilled in Control Zone IV could eventually propagate downward because of salt dissolution, but the rate of salt dissolution in such a borehole would be extremely slow. Under the most

conservative assumptions, a very long time period (millions of years) would be required to dissolve a flow path through the one-mile-wide buffer strip (i.e., Control Zone III) before the WIPP facility would be breached.

#### 4.2.1.2 Hydrocarbon Exploration

The consequences of deep exploratory drilling for hydrocarbons have been explicitly examined in the WIPP SAR (U.S. Department of Energy, 1981b; Chapter 8.0), as follows:

- o SAR Communication Event 1 (Figure 12) analyzes the radiation dose consequences of a breach by an oil or gas exploratory borehole penetrating the Rustler aquifer, the WIPP facility, and the Bell Canyon aquifer. This event specifically considers the breach occurring in the center of the emplaced waste area, thereby maximizing the rate at which flowing water can dissolve the waste and release radionuclides.
- o SAR Communication Event 4 postulates a direct interception of the emplaced waste, with transfer to the surface, by an oil or gas exploratory borehole.

Drilling within Zone IV, either vertical or directional once below Control Zones I, II, and III, would not create such breaching events.

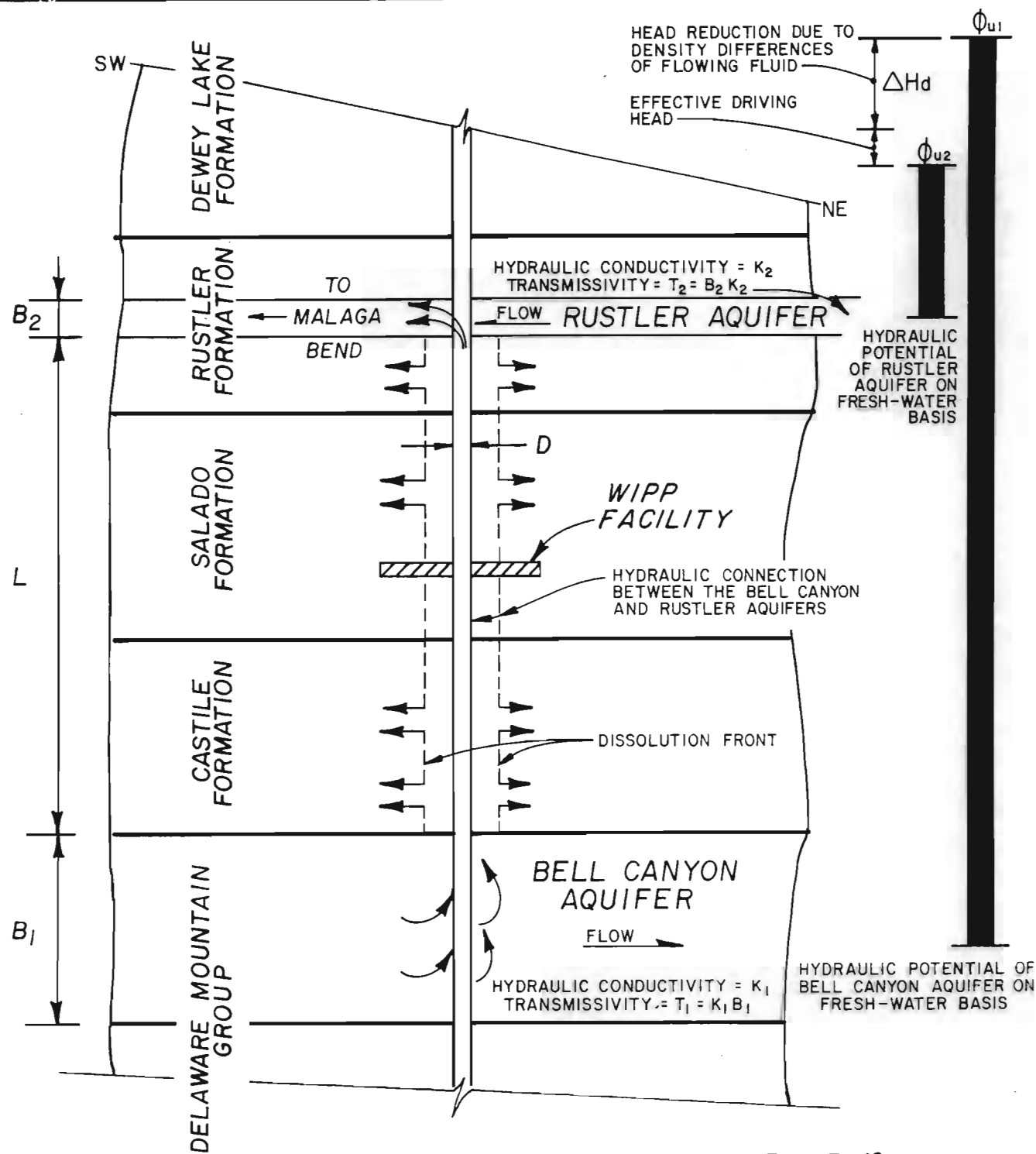
#### 4.2.2 Underground Potash Mining

The effects of potash mining (including solution mining) within Control Zone IV would not be discernible at the WIPP facility (Sections 3.1 and 3.2). Neither the rock fracturing due to opening underground entries nor the subsequent subsidence of abandoned mined areas would create a passageway through which ground water could enter the emplaced waste area or through which radionuclides could be released.

A lobe of slightly higher permeability rock would extend toward the WIPP from any potash mine developed in Control Zone IV. If this mine were hydraulically connected to the Rustler aquifers, this disturbed zone could be selectively dissolved by inflowing waters. There is no reason,



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FIGURE 12

SCHMATIC REPRESENTATION  
 SAR COMMUNICATION EVENT I

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REFERENCE:  
 U.S. DEPARTMENT OF ENERGY (1981b),  
 FIGURE 8.3-1

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however, to assume that this leached zone would intercept the WIPP waste emplacement horizon, except by dissolving all of the salt in the volume between the potash mine level (maximum depth of about 1,700 feet) and the WIPP waste emplacement level (depth of about 2,150 feet) for a distance of one mile (i.e., Control Zone III). For comparison, SAR Communication Event 2 considers the selective leaching of the WIPP disposal horizon by Rustler waters introduced immediately upstream and removed immediately downstream of the facility limits (Figure 13). The radiation dose consequences of SAR Communication Event 2 are, therefore, greater than those that would occur by breaching the WIPP facility with Rustler ground waters that eventually dissolve the intervening salt between a potash mine in Control Zone IV and the emplaced waste. If a stagnant pool were formed and molecular diffusion was the dominant delivery mechanism, SAR Communication Event 3 is seen as a conservative representation (Figure 14).

#### 4.2.3 Hydrofracing

Hydrofracing hydrocarbon reservoir rocks at the WIPP site or hydrofracing to establish communication between holes for a solution mining operation would not cause a breach of the waste disposal facility (Sections 3.2.2 and 3.4.1). In hydrocarbon production, the pay zones for development are too far removed for typical production stimulations processes to cause a breaching event. Hydrofracing associated with solution mining would occur primarily in Control Zone IV, and possibly in the outer part of Control Zone III, and would be separated from the WIPP facility by most of Control Zone III. It should be recognized further that the SAR communication events postulate much more extensive fracture geometries than could credibly be produced by hydrofracing, as follows:

- o SAR Communication Event 1 postulates a continuous, 3,170-foot-long hydraulic connection (e.g., fracture network) which intersects the WIPP facility and connects the Bell Canyon and Rustler aquifers.
- o SAR Communication Events 2 and 3 postulate a continuous, 1,500-foot-long hydraulic connection

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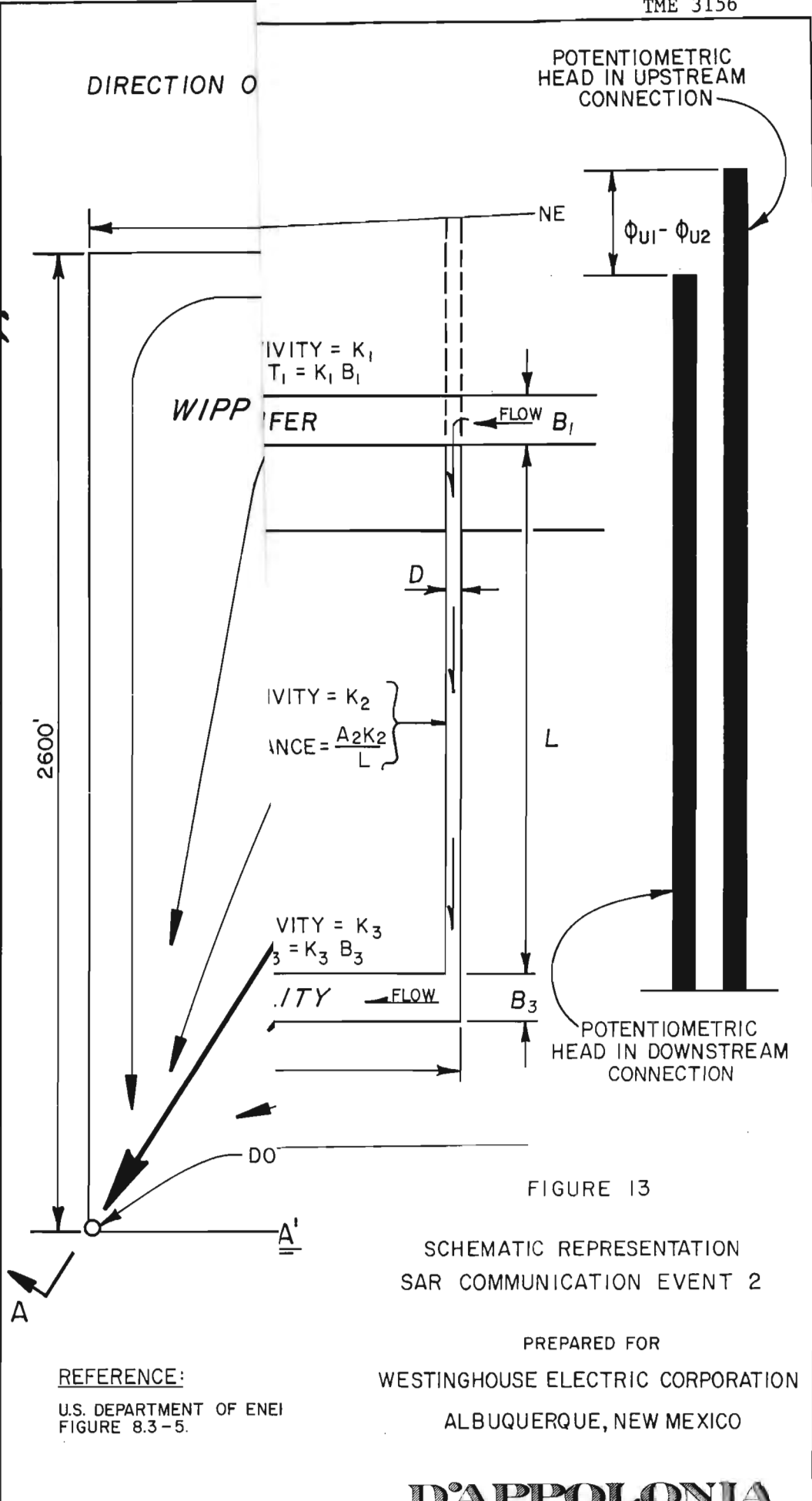


FIGURE 13

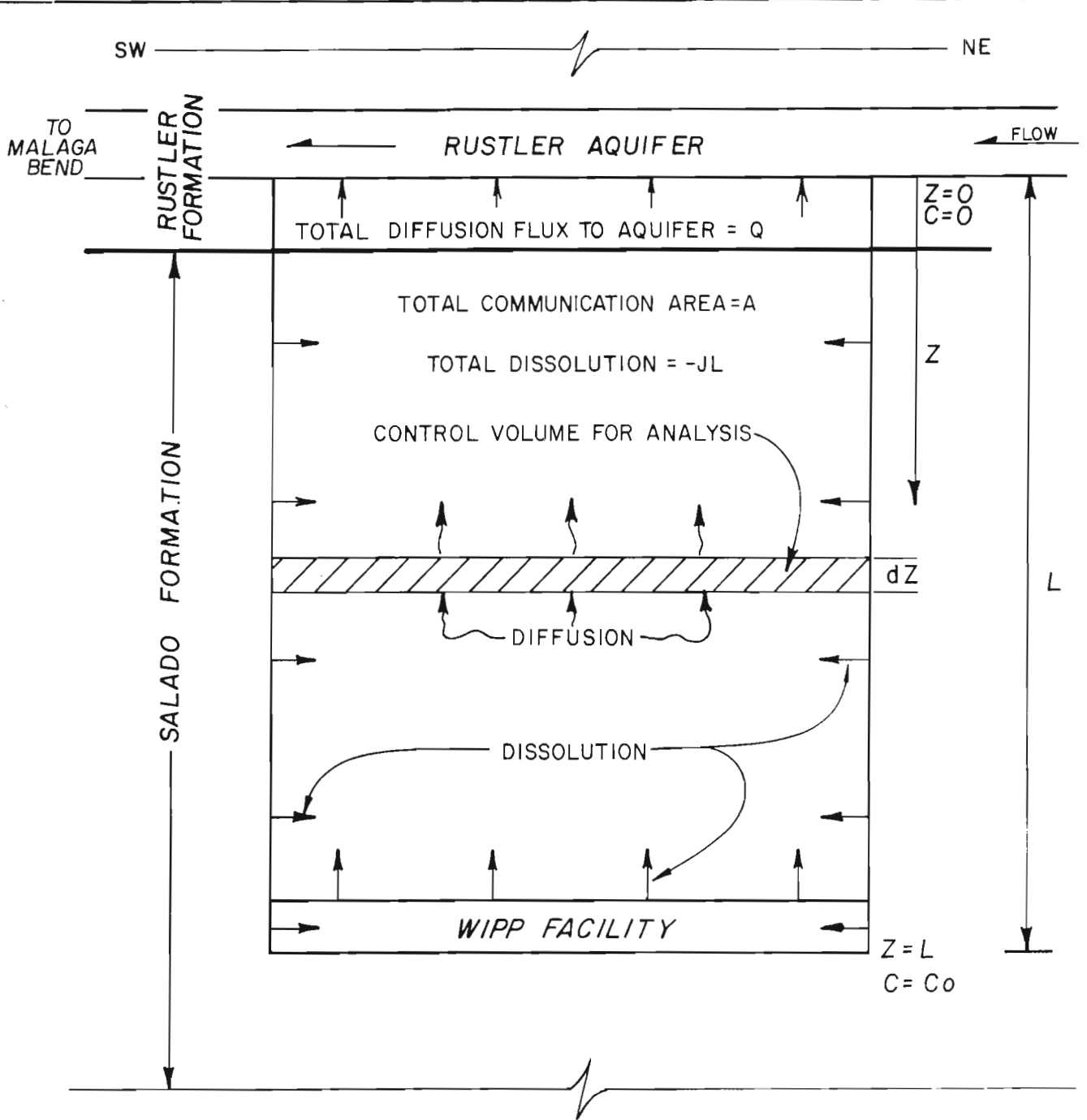
SCHMATIC REPRESENTATION  
 SAR COMMUNICATION EVENT 2

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REFERENCE:  
 U.S. DEPARTMENT OF ENEI  
 FIGURE 8.3-5.

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FIGURE 14

SCHEMATIC REPRESENTATION  
SAR COMMUNICATION EVENT 3

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REFERENCE:  
U.S. DEPARTMENT OF ENERGY (1981b),  
FIGURE 8.3-9.

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(e.g., fracture network) between the WIPP facility and the Rustler aquifer.

Water flow in these events is modeled using the Hagen-Poiseuille equation, or similar method, which is an industry-accepted method for analyzing laminar flow through hydraulically induced fractures.

#### 4.2.4 Hydrocarbon Production

Hydrocarbon production horizons are typically deep, rigid strata that would not be expected to manifest subsidence once the gas is removed (Section 3.4). Furthermore, the plasticity of the salt formations in the Delaware Basin would decrease the possibility of any fracturing induced by such deep subsidence from breaching the WIPP facility and an event like that represented by SAR Communication Event 1 is not considered credible.

#### 4.3 DRIVING MECHANISMS

The WIPP long-term waste isolation assessment (U.S. Department of Energy, 1981) considers, aside from direct access, three mechanisms to induce waste transport:

- o Water flow between two aquifers - Radionuclides are carried with a flow of ground water from the Bell Canyon to the Rustler aquifer.
- o Water flow within one aquifer - Ground water flows from the Rustler aquifer, through the WIPP underground facility, and returns to the Rustler.
- o Stagnant (nonflowing) connection to one aquifer - Radionuclides are transferred by molecular diffusion within a stagnant pool that connects the emplacement area with the Rustler aquifer.

Resource recovery operations conducted within Control Zone IV would not add another type of driving mechanism; for example, the flow of natural gas to the surface would not be expected to move wastes from the WIPP facility. The potential for resource extraction within Zone IV increasing the magnitude of analyzed driving mechanisms is examined below.

#### 4.3.1 Hydrocarbon Production Stimulation within the Bell Canyon Formation

The sandstones of the Delaware Mountain Group contain limited hydrocarbon resources (Section 1.1.2.2). If any such resources within the Bell Canyon Formation were found to be suitable for development, production stimulation to increase the permeability of the reservoir rock could occur.

Hydrofracing the Ramsey sand will cause the hydraulic conductivity of this stratum to be locally increased. This enhanced hydraulic conductivity could affect the assumptions concerning the hydraulic conductivity of the Bell Canyon Formation made in the modeling of Communication Event 1 in the SAR (Figure 12). The locally increased hydraulic conductivity would not, however, change the steady-state flow rate through the hydraulic connection, which extends from the Bell Canyon Formation, through the WIPP facility, and into the Rustler Formation. The more regional boundary conditions would not be changed by these local effects, and the rate at which the Rustler Formation could accept the flow would remain constant.

#### 4.3.2 Flooding Potash Mines with Waters from the Capitan Formation

The liquid breach and transport events analyzed in the WIPP SAR consider inflows from small sources of water. Within the Delaware Basin there are no aquifers that can credibly supply water in large enough quantities to dissolve the emplaced waste and the surrounding salt rapidly. To the north of the site, forming the boundary of the Delaware Basin, is the Capitan Formation, a major source of fresh water (Figure 3). Bingham and Barr (1979) evaluated an event in which waters from the Capitan Formation flood potash mines in the vicinity of the WIPP site, stating that "[s]ince the Capitan is roughly 15 km [9 miles] away and lies beneath the Salado Formation, only a complex series of events can bring the water to the site."

Some potash mines now operate over the Capitan Formation and some of the wells drawing water from the Capitan pass through these mines. The

scenario described by Bingham and Barr (1979) postulates that the Capitan waters eventually flood the overlying potash mines, perhaps through the failure of the well casings that penetrate near these mines. If a network of operating or abandoned mines has honeycombed the McNutt Potash Member of the Salado Formation, the water may flow toward the WIPP facility.

This flow could conceivably dissolve the salt between the potash mines and the emplaced waste horizon. The dissolution of salt associated with this flow would be very slow because as the water traveled its circuitous path, it would become saturated with salts soon after leaving the Capitan aquifer. This flow of brine would be unable to open new flow pathways in the salt and the molecular diffusion driving mechanism (Figure 14) would be relatively ineffectual because of the minimal gradient of total dissolved solids established.

It could be argued that allowing the development of potash mines within Control Zone IV of the WIPP site could allow the Capitan waters to penetrate closer to the emplaced waste during the period in which institutional controls remain effective. The potentiometric gradient between the Capitan and the ground surface in the WIPP site area is insufficient to drive fresh water or a column of saturated brine to the surface. Accordingly, the pathway through which saturated brine transporting radionuclides could be transferred to the biosphere would have to include the geosphere transport through the Rustler Formation. Since this geologic transport time is much longer than the period in which institutional controls could be expected to be in effect, the DOE resource recovery policy is not germane to the radiation dose consequences of such an event.

## 5.0 SUMMARY AND CONCLUSIONS

Studies have been conducted to evaluate the potential effects of developing the mineral and energy resources underlying or accessible from within (and outside of) Control Zone IV at the WIPP site. These assessments serve as input to the DOE decision-making process and reevaluation regarding the interim policy for resource recovery at the WIPP site. During the study, it was assumed that resource recovery was not allowed in Control Zones I, II, and III.

The methodology used in developing this evaluation can be summarized as follows:

- o Determine the extraction technologies/activities that are applicable to the potash and hydrocarbon resources present at the WIPP site.
- o Evaluate the type, extent, and degree of disturbance of the rock strata in the vicinity of the WIPP facility induced by these extraction activities.
- o Assess whether such disturbance would affect the radiation dose consequences previously reported in the WIPP SAR long-term waste isolation assessment.

The conclusion of this study is that activities related to potash and hydrocarbon resource extraction and solution mining from within (and outside of) Control Zone IV, using currently available and applicable technology, will not compromise the integrity of the WIPP waste emplacement facility and increase the likelihood of a breaching event.

Specific conclusions drawn from this study follow:

- o The DOE policy for natural resource recovery is only important when considering communication events that could occur during the time period when this policy is in effect. After the loss of institutional controls, the types and magnitudes of events that could occur, such as those analyzed in the SAR, are fundamentally independent of former resource recovery restrictions at the site. Considering waste decay and geosphere transport



rates, the DOE resource recovery policy has little influence on the time of waste isolation before a plausible waste-release event could occur and/or on the radiation dose consequences of such an event.

- o The disturbances induced by potash exploration and conventional mining or solution mining in Control Zone IV are physically too far removed to affect the integrity of the WIPP facility. Breaching the waste storage area by these activities is not credible and induced changes in host rock hydraulic conductivity are not discernible.
- o Exploration and production of hydrocarbons from within Control Zone IV likewise would not affect the waste emplaced in the WIPP facility. The extent of disturbance induced by production stimulation in the form of hydrofracing or acidizing is controlled by the specific design and execution of this operation. Evaluations of what can be considered typical operations, as discussed in this report, indicate no impact to the integrity of the WIPP facility.
- o The communication events, including the types of breaching mechanisms, flow paths, and driving forces analyzed in the WIPP SAR, are applicable to current resource extraction technology in Control Zone IV and beneath Control Zones I, II, and III (for hydrocarbons). The SAR events represent, in fact, the potential effects of developing resources within the area of the WIPP facility itself, after institutional controls are lost.

In summary, DOE could reevaluate its interim policy to prudently allow resource recovery in Control Zone IV. This is supported by an evaluation of the consequence analyses for resource extraction, as discussed in this report, and the additional consideration that any resource recovery operation will be reviewed by the BLM (for surface claims) and the Minerals Management Service (for underground claims) prior to its implementation. In this fashion, any planned activities will be evaluated on a case-by-case basis to ensure that the integrity of the WIPP facility will not be jeopardized.

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