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METHODOLOGY AND CONCEPTS FOR THE DESIGN OF SURFACE STORAGE FILLS AT THE ANVIL POINTS OIL SHALE RETORT FACILITY

By
W. E. Strohm, Jr.
E. L. Krinitzsky

December 1983

Work Performed Under Interagency Agreement
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For
U. S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Laramie Project Office
Laramie, Wyoming

By
Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

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**Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi 39180**

PREFACE

This report was prepared by the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., under U. S. Department of Energy (DOE) Inter-agency Agreement No. DE-IA22-81PC42202 issued by the DOE Pittsburgh Energy Technology Center (PETC). The interagency agreement was initiated under the technical direction of the DOE Laramie Energy Technology Center, Mr. James Westhoff was DOE Program Officer. Mr. Gregory J. Kawalkin of PETC was the DOE Contracting Officer. This report presents the results of the work completed under the interagency agreement between April 1981 and November 1983.

Mr. William E. Strohm, Jr., Research Group, Engineering Geology and Rock Mechanics Division (EGRMD), Geotechnical Laboratory (GL), was the principal investigator during the study and prepared this report except for Appendix C which was written by Dr. E. L. Krinitzsky. A review of an initial draft and comments on geotechnical design methodology, alternate design layouts for a possible relocation fill, with construction schemes and preliminary construction cost estimates were obtained from Mr. Norman T. Ng-A-Qui of D'Appolonia Consulting Engineering, Inc., Englewood, Colo., under WES purchase order number FCA 82-M-0138. A more detailed preliminary construction cost estimate was obtained from the U. S. Army Corps of Engineers Albuquerque District, an experienced contract construction agency. The study was conducted under the general supervision of Dr. Don C. Banks, Chief, ECRMD, GL, and Dr. W. F. Marcuson III, Chief, GL.

COL Tilford C. Creel, CE, was Commander and Director of WES during the study and preparation of this report. Mr. F. R. Brown was Technical Director.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
acres	4046.873	square metres
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
foot-pounds per cubic foot	47.88017	joules per cubic metre
gallons per ton	0.0000041	cubic metres per kilogram
inches	25.4	millimetres
miles (U. S. statute)	1.609347	kilometres
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
square feet	0.09290304	square metres
square miles	2.589998	square kilometres
tons (2000 pounds, mass)	907.1847	kilograms

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

METHODOLOGY AND CONCEPTS FOR THE DESIGN OF SURFACE STORAGE FILLS
AT THE ANVIL POINTS OIL SHALE RETORT FACILITY

PART I: INTRODUCTION

Background

1. The expanding development of oil shale in Colorado and Utah (Wasco 1982) will generate large amounts of waste shale from surface retorting. Relatively large demonstration and production waste fills are planned and conceptual designs have been developed (Rio Blanco Oil Shale Company (RBOSCO) 1981, White River Shale Oil Corporation (WRSOC) 1981, Woodward-Clyde Consultants (WCC) 1980)). However, to date (1982) only small-scale fills of re-torted shale have been constructed, mainly for field compaction, leachate, and revegetation research (WCC 1976, Kilkelly 1981, and Lipman 1975). The proper design of spent shale surface disposal facilities for long-term fill stability (physical/mechanical, chemical, and biological) requires an assessment of the specific processing, disposal, and site conditions and their influence on the ultimate properties of the spent shale. Recent methodology for the design of spent shale disposal facilities (Ng-A-Qui and Taylor 1982) emphasizes the need for an integrated approach to the analysis, design, construction, performance monitoring, and maintenance of spent shale disposal facilities. A major consideration is the relationship of characteristics of spent shale to its behavior within the pile and the interaction of the pile with the site hydrologic and geologic regimes. The Department of Energy (DOE) Laramie Energy Technology Center (LETC) recognized the need for large-scale research fills to improve design technology and through the DOE Carbondale Mining Technology Center requested the U. S. Army Engineer Waterways Experiment Station (WES) to develop methodology and conceptual designs for relocation of existing spent shale and research fills for future spent shale at the Anvil Points facility.

Purpose of Study

2. The purpose of the study was to develop methodology and criteria for spent shale fills and conceptual designs for the existing Paraho retorted shale and for future retorted shales that might be generated at the Anvil

Points facility. Future spent shales to be considered were those from the Paraho and TOSCO processes. The conceptual designs for future research fills were to include provisions for collection and control of surface and seepage water and for monitoring of fill temperatures, settlement and deformations, water infiltration, seepage, leachate, and ground-water conditions.

Scope of Study

3. The research study included the following items:
 - a. Review of pertinent literature and development of design methodology.
 - b. A comparative assessment of potential fill sites within the Anvil Points facility.
 - c. Recommended sites based on engineering, environmental, and economical construction considerations.
 - d. Development of a fill design for relocating the existing spent shale and conceptual research fill designs for:
 - (1) Disposal of spent shales from the Paraho and TOSCO processes.
 - (2) Disposal of raw reject shale.
 - e. Development of operation plans and cost estimates for construction and monitoring of the relocation fill and future research fills.

Scope of Report

4. This report presents methodology for the geotechnical design of spent shale fills with application to conceptual designs for a relocation fill and research fills at Anvil Points. Part II summarizes the methodology for an integrated approach to the design of surface storage fills for processed and raw oil shale. Information on the amount of existing retorted shale and expected amounts of future processed and raw reject shale and a comparative assessment of potential fill sites is presented in Part III. A recommended design for a relocation fill for the existing spent shale is presented in Part IV. Recommended designs and alternatives for research fills are presented in Part V. Construction operation plans, cost estimates, and postconstruction monitoring are included in Parts IV and V. Conclusions and recommendations resulting from the study are presented in Part VI.

Current technology and concepts on disposal fills for processed and raw oil shale are summarized in Appendix A. Engineering properties of Paraho and TOSCO retorted and raw reject shale are summarized in Appendix B. A seismic evaluation of the Anvil Points facility is contained in Appendix C. A detailed preliminary cost estimate for a possible relocation fill for the existing spent shale is given in Appendix D.

PART II: METHODOLOGY FOR GEOTECHNICAL DESIGN OF SURFACE STORAGE FILLS FOR PROCESSED AND RAW OIL SHALE

Introduction

5. The primary objectives in the design of surface storage fills for processed and raw oil shales are: (a) to insure long-term physical stability, and (b) to prevent surface runoff, surface erosion, and possible subsurface seepage from degrading the water quality of streams and ground water below the fill, both during and after construction. This part presents basic concepts and important considerations for meeting these objectives. Disposal fills for processed (i.e., spent shale) are discussed first. Raw reject shale disposal fills and temporary storage fills for raw shale awaiting processing are discussed later in this part. The information presented is based on papers by Ng-A-qui and Taylor (1982), Sharma and Asgian (1981), and Fenner et al (1982) and the report by Hessel and Strasser (1982). Other references are noted when specific information is cited.

Basic Concepts

6. The analysis and design of spent shale fills should be based on the same geotechnical engineering principles and integrated approach used for other types of fills, as outlined in Figure 1. Geotechnical engineering (Banks 1982) is defined in Figure 2. The experience base needed for spent shale fills is very limited, since no large engineered fills have been built. In addition, spent shale is a highly variable material and even with the best available technology, prediction of the long-term engineering properties and performance of large fills is in its infancy. Consequently, an understanding of the source of variability of spent shale materials and its effect on the initial engineering properties is a first step in developing disposal fill design procedures. A second and equally important step is the assessment of long-term changes in the properties of spent shale within a disposal fill. This assessment requires consideration of possible thermal, chemical, hydrological, and physical interactions within the fill and between the fill and the site environment. The site environment is site-specific and depends on the geological, surface and subsurface hydrological, and geotechnical

Figure 1. Geotechnical design methodology

GEOTECHNICAL ENGINEERING

- * Bridges between geology and civil engineering.
- * Makes use of principles of:
 - soil mechanics,
 - rock mechanics,
 - engineering geology,
 - hydrology.
- * Provides means to perform:
 - site screening,
 - site selection,
 - site investigation,
 - site characterization,
 - site evaluation/assessment,
 - design,
 - construction,
 - operation,
 - maintenance.
- * Applied to worthwhile projects in a timely,
safe and economical manner.

Figure 2. Definition of geotechnical engineering

characteristics of the site. Shelton and Pendleton (Peterson 1982) discuss important factors in management of spent shale disposal and research topics.

7. Treatment of the spent shale prior to disposal, the disposal scheme, and possible codisposal and use of retort waste water in fill compaction will have a dominant influence on initial and long-term spent shale properties and interactions within the fill. Therefore, the design must provide for these conditions and specify construction methods, quality control, instrumentation, and an observation program to monitor the performance of the fill (Figure 1). The design must include alternatives that can be implemented during the life of the project in case fill performance indicates that safety criteria for stability are in jeopardy.

8. The lack of experience for large spent shale fills means that initial or conceptual designs must be updated and refined during spent shale production and disposal to develop actual engineering properties, design geometry, construction procedures, and instrumentation and monitoring provisions. Very conservative assumptions are required until a viable experience base can be developed. The immediate need is to define the variability of spent shales caused by processing and disposal and develop an understanding of subsequent interactions within the disposal fill and between the disposal fill and site environment that influence the ultimate engineering properties and long-term performance of the disposal fill.

Spent Shale Variability

9. The variability of spent shale materials is a direct function of the variation in the mineral and chemical composition of the raw shale and of the processes applied to the shale from mining to placement in the disposal fill. Each process changes the physical properties, and retorting changes both the physical and chemical properties. Figure 3 outlines possible sources of variability and lists some of the variables. The importance of the variables and their potential effect on spent shale properties are discussed briefly in the following paragraphs.

Raw oil shale

10. Raw oil shales from the Green River formation are described as fine-grained dolomitic marlstones containing from 1 to 40 percent by weight of refractory organic material (Hessel and Strasser 1982). The organic component

VARIABLES:

- 1 Kerogen grade, mineralogy, chemical constituents, fragmentation, crushing, screening, gradation.
- 2 Temperature, time, decarbonization, chemical and mineral reactions, gradation, moisture.
- 3 Temperature, moisture, particle breakage, gradation, segregation.
- 4 Time, sequence of placement, temperature, segregation, moisture, lift thickness, compaction, particle breakage, mass density, engineering properties.
- 5 Time, temperature, heat flow, chemical reactions, moisture migration, interparticle stresses, breakage, gradation, mass density, engineering properties.
- 6 Topography, geology, geochemical constituents and reactions, surface and foundation engineering properties, surface and subsurface hydrology, infiltration, evapotranspiration, sediment transport, wind, temperature, precipitation.

Figure 3. Spent shale variability

is composed of insoluble kerogen and approximately 20 percent of soluble bitumens. Evaluation of ore grade in minable beds of the Mahogany zone in the Anvil Points mine (East and Gardner 1964) indicated oil yields (Fischer assay) ranging from about 6 to 78 gal/ton* over a 15-ft interval below the Mahogany marker as shown in Figure 4. The air dry specific gravity ranged from 1.6 to 2.6 and correlated inversely with oil yield. Other physical properties and the chemical and mineral constituents varied over a wide range. Within the Piceance basin, the Green River formation contains various grades of oil shale and types of minerals as indicated in Figure 5 and Table 1. Variations in elements of principal minerals are indicated in Table 2. In addition to this natural variability, mining and treatment prior to retorting will add to the variability of the raw shale feed stock. Fragmentation during mining, beneficiation (if any), segregation during transport to the retorting plant, crushing, screening and any separation of organic and inorganic components would compound the variability of the raw material. Thus, the feed stock would likely have constantly varying chemical and physical properties. The gradation, mineral and chemical composition of the feed stock and retorting process will have a large influence on the properties of the spent shale.

Retorting

11. There are numerous types of retorting processes (Allred 1982) as summarized in Table 3. The significance of the retorting process on spent shale characteristics is related to the retorting temperature, time and the resulting amount of decarbonization, chemical constituents, and mineralogy. One important factor is the decomposition of raw shale carbonates. At high temperatures (700°C), carbonate decomposition of calcite and dolomite can produce cohesive hydrate minerals that will increase the strength of spent shale in a disposal fill with time after compaction with added water (Knight et al. 1981; see Appendix A). However, at relatively low temperatures (500°C) that produce no hydrate minerals, cementation reactions would be negligible. Additionally, higher carbonaceous content from low retorting temperatures would inhibit cementation reactions. The particle size of retorted shale influences the occurrence of hydrate minerals. Even at low retorting

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

Figure 4. Variability of oil shale yield, Anvil Points mine
(East and Gardner, 1964)

a. Stratigraphy of Green River Formation (after Bates and Thoen, 1981)

b. Typical electric log (Weeks et al., 1974)

Figure 5. Stratigraphy and electric log of Piceance Creek Basin

Table 1
Minerals Present in Major Stratigraphic Zones
of the Piceance Creek Basin*

Zone	Major Minerals	Lesser Minerals	Minor Minerals
Overburden	Quartz Dolomite	Analcime Calcite Albite K-Feldspar	Illite Pyrite Siderite Aragonite
Mahogany zone	Dolomite**(32) Quartz**(15)	Albite**(10) Calcite(16)	K-Feldspar**(6) Aragonite Siderite† Illite(19) Pyrite ††(1) Analcime †‡(1) Dawsonite
Leached zone	Dolomite** Albite	K-Feldspar** Calcite	Pyrite †† Siderite (Analcime Dawsonite)
Saline zone	Nahcolite††† Dolomite** Quartz**	Halite Dawsonite††† Albite** K-Feldspar	Pyrite Calcite (Siderite Illite)†
Garden Gulch Member (clay zone)	Quartz Dolomite	Albite Illite	Pyrite Calcite K-Feldspar (Siderite Analcime)

Note: Quartz and feldspar directly related to organic content; (32) = typical composition in percent for 104-1/Tonne Mahogany zone (Bates and Thoem, 1981).

* Wilding and Zachara (1980) and Hessel and Strasser (1982).

** Occur throughout Parachute Creek member.

† Minor quantities common, major constituents locally.

†† Ubiquitous accessory mineral.

‡ Characteristic of Mahogany zone.

‡‡ Identifies saline zone, prominent in central part of basin.

Table 2

Concentration of Selected Elements and Probable Mineral Residences in
Raw Shale from the Piceance Creek and Uinta Basins*

<u>Element</u>	<u>Range in Concentration (Weight Percent as Oxide)</u>	<u>Principal Minerals</u>
Silicon	25 to 41	Quartz, albite, feldspar, analcime
Aluminum	4 to 10	Albite, dawsonite, feldspar, analcime, amorphous material
Iron	2 to 4	Pyrite, dolomite, siderite
Magnesium	1 to 8	Dolomite, calcite
Calcium	3 to 4	Calcite, dolomite
Potassium	1 to 2.5	Feldspar
Sodium	1 to 2.5	Dawsonite, albite, analcime
Sulfur	0.7 to 1.2	Pyrite, kerogen
Phosphorus	0.05 to 0.8	Apatite

* Wilding and Zachara (1980).

Table 3

Surface Retorting Processes*

<u>Process</u>	<u>Particle Size cm</u>	<u>Retorting Temperature Range Deg C</u>	<u>Heat Source</u>	<u>Combustion of Residual Carbon</u>
Direct Heating				
Paraho-DH	0.9 to 9	550 to 750	Internal combustion with air or air and hot gases	Yes
Union A	0.3 to 5	Up to 1093	Internal combustion with preheated air	Yes
Superior	<0.3 to 7.5	**	Internally produced combustion gases	Yes
Indirect Heating				
Paraho-IH	0.9 to 9	**	Hot recycled gases	No
Union B	0.3 to 5	510 to 540	Hot recycled gases	No
Union SGR-3	0.3 to 5	Retort 480 to 540 Combuster 820	Externally produced hot gases	Yes
TOSCO II	<1.3	480	1.27 cm ceramic balls	No
Lurgi-Ruhrgas	<0.6	Retort 530, heat carrier solids 630	Small size heat carrier solids (possibly spent shale)	Yes
HYTORT	**	**	Hydrogen-rich gas	No

* Hessel and Strasser (1982); Bates and Thoem (1981).

** No information.

temperatures, the small particles from the Lurgi-Ruhrgas process exhibit large strength gains with time after wetting (Appendix A).

12. The ultimate particle-size range (gradation) of spent shales (para 14) and the compacted strength and permeability are influenced by the retorting process and process variations (Knight et al. 1981). Variations in particle size will also influence erosion rates from spent shale fill slopes and the amount of infiltration and percolation of rainfall and snowmelt water into disposal fills.

13. The chemical properties of retorted shale are highly dependent on the retorting process. High concentrations of saline minerals (e.g., sodium, magnesium, and sulfate) can have an adverse effect on the surrounding environment from any leachate escaping from a disposal fill. A high sodium concentration leachate also could displace calcium in natural clay shale foundation strata, reduce its strength and endanger the stability of the spent shale fill. The types of toxic chemical constituents in leachate from spent shale and resulting effects on the surrounding environment is discussed by Knight et al. (1981) and many others (Appendix A).

Handling and conveying to disposal site

14. The specific treatment and conveyance methods after retorting can change both the physical and chemical properties of spent shale and have a direct affect on disposal fill design. For example, hot spent shale conveyed to the disposal site would have different properties than spent shale that was first cooled and/or moisturized. The method and time of transport can reduce spent shale moisture and temperature and increase particle breakage and segregation by varying amounts. These variations will affect compaction and as-placed properties. An example of the variation in gradation of spent shale from the same retorting process after delivery by truck to a test fill (Appendix B) is shown in Figure 6. This figure illustrates the combined effects of possible variability in feed stock gradation, retorting, and conveyance (hopper loaded trucks) to the fill. After retorting and delivery to the fill, the gravel size (76 to 9.5 mm) feed stock had much smaller particle sizes (e.g., 30 to 60 percent minus 0.074 mm).

Placement at disposal site

15. Activities at the disposal site are critical in achieving desired engineering properties for mechanical stability during and after fill

Notes:

1. Feed stock was 100 percent gravel sizes (76 to 9.5 mm).
2. Samples from Paraho semi-works retort, using direct heat mode.

Figure 6. Variation in gradation of spent shale from the same retorting process, after transport to the fill site.

construction. The time sequence of placement and spreading into lifts can cause further variations in temperature and particle segregation. If hot spent shale accumulated in a pile (from a conveyor), segregation would occur and a large increase in temperature from mass heating could cause burning of residue carbon and result in further particle breakage and other changes in physical properties. If hot spent shale were spread upon delivery, cooling would result and segregation would be reduced. The lift thickness, moisture addition, and type and amount of compaction affects the amount of additional particle breakage, mass density, water content, and porosity. These properties have a dominant influence on engineering properties such as permeability, shear strength, and stress-strain properties. As an example, the variation in gradation of the spent shale when delivered to the test fill (Figure 6) plus additional particle breakage during compaction caused considerable variation in the engineering properties of the compacted spent shale (WCC 1976). Thus, it is especially important that construction procedures, formulated to minimize wide variations in properties of compacted material be specified and enforced.

Interactions within spent shale fill

16. As a spent shale fill is constructed, the in-place material properties can undergo time-dependent changes. Potential geochemical and mechanical interactions are interrelated with moisture migration, chemical reactions, heat transport and mechanical behavior of the fill as indicated in Figure 7. Climatic and surface conditions also influence these interactions. Rainfall and runoff influence the amount of infiltration. Wind erosion and sediment transport influence the mechanical stability of the surface materials. Solar radiation and ambient temperatures influence heat transport. A major factor not included in Figure 7 is the influence of interparticle stresses which increase as fill height increases. Some interactions are accelerated while others are depressed. For example, increased stress can decrease porosity and associated permeability. Increased stress also can destroy particle bonding, and cause further particle breakage, increased mass deformation, and a reduction of mechanical stability of the fill.

Interactions with site environment

17. Interactions of a spent shale fill with site-specific environmental variables (Figure 3) can cause additional changes in the geochemical and engineering properties of the spent shale. These changes could reduce the

Figure 7. Potential geochemical and mechanical interactions within a spent shale fill (after Shrama and Asgian, 1981)

mechanical stability of the fill. Topographic features such as deep gulches or canyons and associated drainage patterns influence surface and subsurface water flow into the fill. A fill within a gulch would receive surface flows coming into the gulch above the fill and any subsurface seepage from water-bearing strata dipping into the fill. The latter would be dictated by the specific site geology. The site geology could also have a major influence on the foundation stability beneath the fill. For example, a fill located on debris deposits or over a thick buried channel could settle excessively. Saturation of underlying debris deposits could result in a sudden collapse of this material and jeopardize the mechanical stability of the fill. The chemistry of surface and subsurface water entering the fill would influence chemical reactions (Figure 7) within the fill as well as the type and quantity of leachate that might escape from the fill. Climatic conditions indicated in Figure 7 could also have a major influence on changes in fill properties. Precipitation events, which are highly variable, influence surface hydrology, erosion and sediment transport. The effects of oil shale solid waste disposal on water quality are discussed by Wilding and Zachara (Peterson 1982).

Spent Shale Characterization

Material parameters

18. Despite the wide variability in spent shales, knowledge of certain material parameters is required in the design of disposal fills. Some of these parameters and associated properties are listed in Table 4. Material properties have been obtained using testing procedures generally applied in geotechnical engineering, and the environmental and soil sciences (WES 1979, WCC 1976, and Bloomsburg and Wells 1978). The dissimilarity between the conventional application of some of these procedures to soil and rock materials and their application to spent shale materials may produce misleading results. Two specific questions may arise from apparently inconsequential modifications in test procedures:

- a. Are samples of the spent shales used in laboratory tests representative of spent shales that will be placed in the disposal fill?
- b. Are significant mechanical and physical-chemical phenomena that govern disposal fill performance being appropriately represented in conventional laboratory tests?

Table 4
Geotechnical Parameters for Spent Shale Characterization

<u>Parameter</u>	<u>Material Property</u>
Index	Void ratio, gradation, particle durability, mass density.
Stress-strain	Moduli, Poisson's ratio, earth pressure coefficients.
Shear Strength	Mass shear strength (cohesion and friction angle), particle strength (bending or fracturing).
Compressibility	Primary and secondary compression, recompression indices.
Permeability	Residual saturation, saturated permeability, relative permeability, drainability.
Nongeotechnical	Corrosion, reactive and toxic properties, microbial properties.

For example, is a scalped sample compacted in a soil testing device representative of the bulk material compacted in the field and do the strength, compressibility, and permeability parameters obtained in laboratory tests on scalped samples adequately represent those in the disposal fill? Will the calculations and modeling based on laboratory test results reliably predict the slope stability, settlement, and drainage phenomena that may exist in the actual fill? Are the effects of particle breakage that influence anisotropic permeability and the particle structure of spent shale adequately represented? Significant differences from comparisons of gradations for samples of spent shale from the same retorting process shown in Figure 8 (before field and laboratory compaction) and in Figure 9 (after compaction) suggest that the existing data are inadequate to answer the above questions. Engineering properties of Paraho and TOSCO spent shales are summarized in Appendix C. The basic problem is the lack of an adequate experience base of information about the performance of large spent shale fills. This missing knowledge emphasizes the need for an appreciation of the intrinsic factors and mechanisms that govern spent shale behavior.

Intrinsic factors and mechanisms

19. The fundamental requirement for evaluating results from various testing procedures and characterizing spent shale materials is an understanding of the intrinsic factors and mechanisms (outlined in Figure 7) that govern material behavior. This understanding may require consideration of the following:

- a. The origin and chemical composition of the spent shale solids.
- b. The distribution and morphology of the solids and voids.
- c. The mechanical and physical-chemical principles governing resistance to shear stress.
- d. Changes in particle morphology that can occur during placement and compaction.
- e. Long-term changes that can occur in the chemistry of the system components, the resulting influence on bonding mechanisms and the physical-chemical basis for strength.
- f. The presence, form, and potential for mobility of pore fluids and ion species.
- g. The chemical reactions among pore fluids and solids.
- h. Microbial activities and changes with time and depth.

KEY:

- A GRAVEL SIZES (76 TO 4.76 MM)
- B SAND SIZES (-4.76 TO 0.074 MM)
- C SILT SIZES (-0.074 MM)

LEGEND:

WCC V FIELD COMPACTION TESTS (WCC 1976)
WCC IV-1B LABORATORY TESTS (WCC 1976)
WCC IV-1B2 LABORATORY TESTS (WCC 1976)
WES LABORATORY TESTS (WES 1979)

NOTE: ALL SAMPLES FROM PARAHO SEMI-WORKS RETORT,
DIRECT HEAT MODE, USING GRAVEL SIZE (76 TO 9.5 MM)
FEED STOCK.

Figure 8. Gradation of samples from the same retorting process prior to field compaction tests and as received for laboratory tests

KEY:

- A GRAVEL SIZES (76 TO 4.76 MM)
- B SAND SIZES (-4.76 TO 0.074 MM)
- C SILT SIZES (-0.074 MM)

LEGEND:

WCC V AVERAGE GRADATION AFTER FIELD COMPACTION (WCC 1976)
WCC IV-1B GRADATION AFTER LABORATORY COMPACTION (WCC 1976)
WES GRADATION AFTER LABORATORY COMPACTION (WES 1979)
*1 STANDARD EFFORT COMPACTION
*2 MODIFIED EFFORT COMPACTION

NOTE: ALL SAMPLES FROM PARAHO SEMI-WORKS RETORT, DIRECT HEAT MODE USING GRAVEL SIZE FEED STOCK (76 to 9.5 MM).

Figure 9. Gradation of samples after field and laboratory compaction

20. The above listing is not all inclusive, but serves to indicate the scope and variability of intrinsic factors and mechanisms that may affect disposal fill design. An attempt to enumerate specific characteristics or material parameters as they relate to retorting processes and disposal systems is beyond the scope of this study and may be of little practical use. In fact, the variability of spent shales (Figure 3) arriving at the disposal fill may exceed the range in characteristics developed for any of the retorting processes. Consequently, it may be necessary to obtain samples of spent shales as they arrive at the disposal fill and perform key property tests to confirm or supplement previous test results and analyses.

21. The basic requirement, however, is to provide stable and environmentally safe storage of all spent shales arriving at the disposal fill. The designer should have a fundamental understanding of the intrinsic factors and mechanisms that govern the behavior of spent shale and knowledge of basic design principles and current practice. He should also have an appreciation of the best available technology for disposal fill design and performance, and use an approach and methodology that recognizes the scope, practical advantages, and limitations of the existing technology.

Disposal Fill Analysis and Design

Approach and methodology

22. Limited knowledge exists about the performance of very high spent shale disposal fills. In fact, the experience base is very limited, as illustrated in Table 5. A conservative but practical approach to disposal fill analysis, design, and construction methodology should therefore be adopted. The approach should include the following items:

- a. Recorded information about pertinent laboratory tests and field demonstrations.
- b. Performance of smaller spent shale fills.
- c. The need for factual information about and continuous assessment of performance of the designed fill.
- d. The exigencies of fill construction and the need for construction alternatives should the need arise.

23. The "typical" project may consist of four major interlocking phases outlined in Figure 10. Alternate designs should be developed and costs estimated to arrive at an optimum final design. The fundamental investigations

Table 5
Existing Experience Base for Spent Shale Fills

<u>Scale Category</u>	<u>Maximum Height ft</u>	<u>Type of Investigation</u>
Laboratory tests	1.5	Confined test samples for geotechnical, chemical, and environmental research
Pilot	<10	Field lysimeter and revegetation research
Semiworks	~40 ~120	Colony Project DOE, Anvil Points
Prototype	?(>800)	Conceptual development plans
Related experience from U. S. earth and rock-fill dams	756	Oroville Dam, California

FOUR INTERLOCKING PHASES:

- Fundamental Investigations
- Analyses and Design
- Construction Plan Development
- Observation Program Design

FUNDAMENTAL INVESTIGATION:

- Review Available Information
- Site-Specific Field Program
 - * Geohydrological characterization
 - * Geotechnical characterization
- Laboratory Program
 - * Foundation materials
 - * Spent shale solids
 - * Water to be used in fill construction

ANALYSIS AND DESIGN PHASE:

- Model Physical Situations and Selecting:
 - * Parameters
 - * Boundary conditions
- Defining Interactions Among Components of Models
- Assessing Interactions Among Components
 - * Calculate measures of performance
 - * Assure safety criteria or predictions are adequate within best available technology limitations

Figure 10. Project investigation phases

should provide basic information that is confirmed or extended during construction. The site-specific field program outlined is considered to be a minimum. Primarily, the investigations phase provides project-specific information needed to model chemical, physical, and mechanical scenarios involved in the analysis and design of the spent shale fill. At present little practical consideration is given to microbial activities and their effects on fill performance. However, the potential influence of such organisms is generally acknowledged (University of Colorado at Denver 1983).

24. Within the conceptual design framework, the gross interacting components of the models and the site environment include the considerations listed in Figure 11. The primary purpose is to make an assessment of the interactions and their effect on spent shale fill performance.

25. After the optimum disposal fill design is developed, construction drawings may be prepared. The drawings should show details pertinent to the fill layout and drainage system, construction scheme, reclamation provisions, and time-storage characteristics. A site-specific observation program should then be planned.

26. A feedback mechanism is an integral part of the observation program. This mechanism will facilitate the continuous evaluation of observations and performance of the fill against design objectives and safety criteria. An accumulated base of evaluated information about the shale fill performance would then be available prior to completion and final abandonment. This procedure will assure a greater level of confidence in the long-term stability of the completed spent shale fill.

27. Essential elements of the observation program should include details on the following items:

- a. Monitoring equipment, procedures, and schedules.
- b. Interpretation and assessment guidelines.
- c. Criteria for evaluating the significance of observations and measurements obtained.
- d. Possible construction alternatives, if observations or measurements indicate that substantial performance problems are imminent or that the fill is becoming unstable.

Major considerations

28. Major geotechnical considerations in spent shale fill design include the following:

- a. Slope stability (short-term and long-term).

ASSESSMENT OF SPENT SHALE PILE DESIGN TO EVALUATE:

- Interaction with Hydrologic Regime
 - * Evaporation
 - * Infiltration and percolation
 - * Runoff
 - * Erosion and sedimentation production
 - * Pile drainage or inflow through fill boundaries
- Interaction with Geologic Regime:
 - * Mechanically stable fill
 - * No excessive movement of foundation materials considering influence of:
 - + Chemical reactions
 - + Biological activity
 - + Physical-mechanical changes and combinations

Figure 11. Cross interacting components of models and associated site environment

- b. Settlement and creep.
- c. Drainage.
- d. Maintenance.

Although these considerations are listed separately, they are interdependent and should be integrated in analyses. For example, slope stability analyses should include the effects of settlement, creep, and drainage conditions.

29. Slope stability. Slope stability assessments should include both static and dynamic (seismic) effects and should account for temporary as well as permanent changes that may occur in the fill. Changes that occur in the geologic and geohydrological regimes and their effect on geotechnical properties both during and after fill construction should also be considered.

Conditions that may have to be evaluated include the following:

- a. Excess pore pressures occurring in the fill and foundation because of fill construction and stress increases.
- b. Inelastic changes in the fill and foundation, such as closing of jointed rock structure, or crushing of spent shale, talus, cobble or gravel size particles.
- c. Spreading of the outer slopes and underlying foundation materials.
- d. Permanent changes in the characteristics of the hydrogeologic regime caused by irreversible changes in the structure and composition of fill and foundation materials.
- e. Chemical and physical or mechanical changes that may occur continuously or cyclically in the fill as a result of interactions between the fill and site-specific geologic and geohydrologic regimes.
- f. The development of a preferentially structured fill mass in response to cyclic, climatic, and construction influences.

30. The application of stability analyses to spent shales presents several problems because intrinsic factors and mechanisms are not well defined. One problem is defining critical failure modes and another is defining locations of potentially critical failure surfaces. Still another is selecting ranges for shear strength parameters that are compatible with expected deformations (related to stress-strain properties) associated with settlement and creep. Considerable engineering judgment and a more conservative approach than normally is used for analyses of earth or rock fills is one solution. Another approach is to conduct additional stability analyses as construction progresses and additional laboratory test data and field observations on performance are obtained.

31. Conventional analytical and numerical methods are considered adequate for disposal fill stability assessment provided that parameters are carefully selected to be consistent with physical situations being modeled and potentially significant phenomena are not overlooked. Particular care should be exercised in developing models of initial, during-construction, and long-term conditions to be used in stability assessments. The natural in situ variability of geologic materials and the construction variability must also be considered. Excessive attention to numerical parameters which are difficult to validate in the field or laboratory should be avoided. A major concern is the laboratory testing of samples containing large size particles. For example, shear strength testing of materials with particle sizes of 2 in. require the testing of samples at least 9 in. in diameter and 18 in. high. Equipment for this size sample is not routinely available and the tests are expensive. Tests on smaller samples using modeled gradations with small particle sizes have not produced acceptable results (WES 1979).

32. Current geotechnical practice accepts factors of safety of 1.5 and 1.2, respectively, for static and dynamic stability of fills or embankments that do not impound water. These numbers may serve as a guide; however, there is no experience base for their use with high spent shale fills. Currently there are no field performance data to validate these factors of safety for spent shale fills and little reason to feel confident that they indicate long-term stability against a massive failure.

33. Settlement and creep. Settlement of the spent shale fill can include three major components occurring in the fill and its foundation. The components are:

- a. Immediate settlement.
- b. Consolidation settlement.
- c. Secondary compression or creep.

34. Immediate settlement of the fill surface will occur due to a reduction in voids of the foundation soils and of the spent shale below the fill surface. Physically, each lift of spent shale compresses the spent shale below and a continuous reduction of void space in the lower zones occurs in response to construction of new lifts. Consolidation settlement occurs in saturated fills or foundations and compression is dependent on the time rate of pore water pressure dissipation. When the fill reaches the final construction elevation, movement does not cease immediately, but may continue as a result of secondary compression or creep.

35. Three items are important with respect to settlements. They are:

- a. Excess pore water pressure dissipation.
- b. Differential settlement.
- c. Creep magnitude and rate.

36. Excess pore water pressures may be generated in saturated and unsaturated fills in isolated zones and foundations. Depending on the distribution and continuity of interconnected voids and characteristics of drainage paths, excess pore water pressures could lead to instability. Zones selectively structured during spent shale placement and subsequent fill construction could contribute to the formation of saturated zones. Thus, items such as spent shale angularity and crushing susceptibility should be considered in stability assessments. Cementation, often attributed to aging of spent shale, can contribute to excess pore water pressure development (by decreasing the permeability) and offset any gain in shear strength.

37. Differential settlement is significant because of its impact on the following:

- a. Surface features of the fill.
- b. Structures placed in the fill.
- c. Structures bridging the fill.
- d. Cracking, which could allow water to enter the fill and cause unanticipated saturation.
- e. Features of the fill that may initiate progressive failure because of strain incompatibility with stiffer zones, such as a cement-stabilized front face.

38. Drainage. Three components included in drainage are surface runoff and diversion, surface runoff from the spent fill, and outflow from the fill base and slope faces. Primary considerations are quantity, quality, and changes both spatially and with time.

39. In many projects, water rights considerations dictate that precipitation that falls off the property cannot be allowed to touch the spent shale. Thus, positive diversion measures are required and could include the following:

- a. Check dams.
- b. Lined or unlined ditches around the fill.
- c. Pipes or conduits under and through the fill.

40. Diversion of surface drainage away from the fill should make maximum use of topography, construction sequence, and available materials. Pipes or conduits must be designed to withstand the effects of differential settlements,

embankment spreading, and vibrations induced by water flow. They must also be designed to prevent leakage. The need for continual maintenance must also be considered.

41. Surface water runoff from the fill is considered to be contaminated and should be stored and reused, evaporated, or treated and discharged. Thus, evaporation ponds or retention dams are required in the design.

42. Outflow from the fill base or the slope faces can be treated similar to runoff from the fill or it could be retained in the fill. Retention in the fill could be achieved by construction of an impervious liner (para A25f.), or controlling fill construction procedures and specifications to prohibit movement of water in the fill. Liner designs should include measures to prevent rupture caused by differential settlements of foundation materials. The effect on stability of saturation with a fully lined fill base should be carefully assessed and accounted for in design analyses and construction details.

43. Maintenance. One of the main objectives in the design of disposal fills is to minimize or eliminate the need for long-term maintenance. Ideally, at the end of construction and surface reclamation the fill should be stable forever. This ideal implies that the chemical, physical, mechanical, and biological conditions in the fill will be in equilibrium with the geologic, hydrologic, and ecologic regimes at the site.

44. In addition to the stability, settlement, and drainage considerations previously discussed, maintenance is concerned with erosion protection and other measures to protect features of the fill that are susceptible to detrimental long-term changes. Erosion protection refers to the effects of wind, water, and ice or freeze-thaw cycles. Features include fill configuration, drainage installations, and retention dams or evaporation ponds.

45. Fill configuration, surface features, and drainage details are key elements in reducing maintenance. Specific considerations include the following:

- a. Topography.
- b. Slope angles and bench frequency.
- c. Surface treatment.
- d. Appurtenant structures.

46. It is particularly important to configure a fill to eliminate interfaces with the topography that produce sharp angles requiring abrupt changes

in the direction of surface water flow. This accomplishment will reduce the need for massive erosion-resistant linings and energy-dissipating structures. Slope angles and bench frequency should be optimized to either impede surface runoff or facilitate its use depending on surface treatment, specific spent shale characteristics, and internal or near-surface structure (e.g., increased compaction towards the outer slope). Surface treatment refers to soil and/or vegetative cover, riprap, and chemical additives. Controlling factors include the availability of materials; the chemical, biological, and physical-mechanical stability of the cover-spent shale interface; and progressively detrimental mechanisms initiated by interface instability. The effect of surface treatment on flora and fauna is another factor. It is particularly undesirable to have as permanent features pipes, conduits, or pumps on other structures that require active maintenance.

47. It is important to recognize that maintenance factors provide the keystone in the methodology for adequate long-term performance. The potential effects of time on spent shale disposal fill performance is well recognized but is one of the least evaluated conditions in conceptual development plans. The reason again is the lack of an experience base for high spent shale fills.

Raw Shale Storage and Disposal

48. Processing of raw oil shale for surface retorting could include stockpiling of mined shale for crushing, temporary storage of crushed shale, and disposal of raw reject shale fines (particles too small for retorting). Special considerations for these materials are discussed in the following paragraphs.

Raw shale storage

49. Mined shale. Temporary storage fills or stockpiles for mined shale can be designed using current geotechnical practices for surface stockpiling of hard rock. However, provisions should be included to prevent the escape of accumulated fines and dust into the air or into surface streams or ground water and to prevent accidental ignition and burning of oil shale rock.

50. Crushed shale. Stockpiles of crushed shale for feed stock can be designed using current geotechnical practices for aggregate stockpiles and contained storage structures (e.g., silos or bins). However, the small size particles and increased amounts of dust will be more susceptible than mined

rock to possible ignition and burning. Outdoor exposure will cause oxidation and increase the potential for pollution of streams and ground water. Consequently, outdoor storage would require provisions for controlling dust emission, reducing air circulation within the stockpile, and capturing surface runoff and seepage from the stockpile. The captured liquids would need to be monitored and perhaps evaporated or treated before release. The alternative is the use of covered or contained storage being considered in some development plans (RBOSCO 1981).

Raw reject shale disposal

51. Analysis, design, construction, and maintenance of raw reject shale disposal fills should use the same methodology used for spent shale. Major concerns are (a) dust emission, (b) oxidation and hydration that could cause ignition of oil shale particles, and (c) escape of contaminants into streams and ground water. Compaction and surface sealing with soil or artificial sealants are two primary methods for addressing these concerns. Another major concern is ignition and burning of raw reject shale that comes in contact with hot retorted shale. One procedure is to design separate disposal fills for raw shale and another is to provide positive isolation using soil barriers and layers in a combined disposal fill. Use of the latter procedure requires clear construction plans and specifications, close field supervision and inspection during construction, and availability of adequate soil material not required for reclamation. The construction method for a small fill for raw shale reject is described in Appendix A.

PART III: STORAGE REQUIREMENTS AND
EVALUATION OF POTENTIAL SITES

52. The design of a possible relocation fill for the existing spent shale and conceptual designs of research fills for future spent shales at Anvil Points requires environmentally suitable sites on the Anvil Points Reserve. The storage requirements and evaluation of sites is described in this part. The fill storage requirements include those needed for possible relocation of the existing retorted shale in West Sharrard drainage and for research fills utilizing future output from operation of the research retort at Anvil Points or from nearby retorts. The existing raw reject shale was placed in a newly designed fill (WCC 1979) that was completed in 1981.

Fill Storage Requirements

Existing retorted shale

53. The quantity of retorted shale on the west side of West Sharrard drainage has been estimated at 198,000 metric tons (Carland et al. 1982). This quantity is 218,260 short tons or 179,630 cu yd using a factor of 1.215 cu yd per short ton. Thus a storage capacity of 200,000 cu yd is considered adequate for possible relocation of the existing spent shale into a compacted, environmentally stable fill.

Future storage capacity

54. Over a five year interval it was estimated by the Laramie Energy Technology Center that the maximum operating level could be 175,000 tons/year. This rate amounts to 875,000 tons in five years. Of this amount 10 percent or 87,500 tons was estimated to be raw reject shale. The resulting five-year storage capacity requirements are listed below:

	<u>tons</u>	<u>cubic yards</u>
Retorted shale	787,500	648,000
Raw reject shale	87,500	72,000

Thus a storage capacity of 7×10^5 cu yd would be adequate for retorted shale and 8×10^4 cu yd would be adequate for raw reject shale.

Evaluation of Potential Fill Sites

Criteria

55. An initial map study and field reconnaissance was made of the Anvil Points facility in May 1981 to locate possible fill sites that would not be in major drainage gulches. It was desired to find sites with the following characteristics:

- a. A storage capacity of 10^6 cu yd.
- b. As small a drainage area as possible to minimize surface runoff.
- c. A maximum capability for collection and control of surface runoff.
- d. Adequate room for a collection/evaporation pond or retention dam to prevent escape of any contaminated water.
- e. Sufficient surface soils for use in constructing an impermeable blanket beneath a fill and for revegetation of fill surfaces.

It was also desired to restrict locations to the relatively impervious Wasatch formation. This formation underlies the Anvil Points area below approximately elevation 6400 ft (Donnell 1969). Groundwater investigations in the West Sharrard drainage (Carland et al. 1981) indicated that surface seepage was confined to the alluvial deposits overlying the Wasatch formation, an indication that it is relatively impermeable.

56. Because steep-sided gulches cover most of the Anvil Points Oil Shale facility (Figure 12), relatively flat areas within the facility boundaries with adequate storage capacity are nonexistent. Consequently, gulches off of major drainages were the only alternatives within a reasonable distance of the retort plant.

Site evaluation

57. During the field reconnaissance nine locations were considered and six potential sites were located as shown in Figure 12. Upon receipt of a new topographic map in February 1982 with 10-ft contours, an evaluation of potential sites was made considering the above criteria, vegetation coverage, and access requirements. Pertinent characteristics of the six sites are summarized in Table 6. A relative ranking of the sites based on environmental (drainage area, vegetation cover, soil cover, and proximity to a major drainage channel) and economical (distance from retort plant and access requirements) factors is also shown in Table 6. These factors are discussed for each site in the following paragraphs.

Figure 12. Locations of potential fill sites

58. Site 1. This site (Figure 12) is a steep-sided (65 percent slope), branching gulch located east of the West Sharrard drainage as shown in Figure 13. The gulch extends from approximately elevation 5680 ft near the south boundary of the facility in Section 17 to a ridge at elevation 7000 ft, a distance of approximately 3900 ft. The storage capacity to elevation 6050 is 3.1×10^6 cu yd or 3.7×10^6 tons. The total drainage area is approximately 68 acres above elevation 6000 ft where a research fill crest could be located 1100 ft inside the south boundary. The small, dry drainage channel shown in Figure 14 indicates that only small flows occur during heavy precipitation or snowmelt. The alternating light and dark impermeable beds of clay stone, siltstone, and occasional sandstone are shown in Figure 15. Figure 16 is an overview of the site showing the sparse vegetation.

59. Soil cover is composed of 0 to 6 in. of sandy and silty clay soil with gravel size fragments and sandstone cobbles on the slopes. Similar soils exist approximately to a maximum depth of 10 ft in the bottom. This area was not covered in a survey of soil resources (Radian Corp. 1981). Adequate soil for reclamation purposes is marginal and may require use of weathered siltstone and clay stone from the slopes.

60. The toe of a possible research fill would be approximately 460 ft inside the facility boundary, allowing adequate space for evaporation/collection ponds. Sufficient soil exists in the bottom and on lower slopes for use as an impermeable compacted soil base. Cobbles and rock can be recovered for later use and stockpiled higher up in the branching gullies (to act as temporary sediment collection and water diversion dams) or along the bottom near the mouth of the gulch.

61. Access to the site (for foundation preparation) can be obtained by construction of approximately 700 ft of haul road from the existing pond area in the West Sharrard drainage. The main draw of the site 1 gulch is lower in elevation than the base of the existing retorted shale pile. Thus, the existing retorted shale could be moved by 850 ft of temporary conveyor, elevated across the West Sharrard drainage. Future fresh retorted shale could be moved to site 1 by 900 ft of elevated conveyor from the plant level across the West Sharrard drainage and the intervening ridge, into site 1. Additional haul road would be required to service construction equipment (compactor/dozer) as the fill height increased.

Figure 13. View of site 1 located to the east of West Sharrard Drainage (looking north)

Figure 14. Small drainage channel in bottom of site 1

Figure 15. Alternate impermeable beds of siltstone, claystone and thin sandstone, Wasatch formation, site 1

Figure 16. Overview of site 1 showing sparse vegetation (looking south)

62. Site 2. Site 2 is a narrow, steep-sided (70 percent slope) gulch inclined to the east off of the West Sharrard drainage, approximately 1300 ft north of the existing retorted shale pile (Figure 12). This site is shown in Figure 17 and extends from elevation 5900 ft to a ridge at elevation 7100 ft, a distance of 3100 ft. This gulch has a very narrow "L"-shaped mouth that can be isolated from the main drainage by construction of a small retention dam. The storage capacity to elevation 6250 ft is 1.4×10^6 cu yd or 1.7×10^6 tons. The drainage area above the mouth is 51 acres. Small flows occur during heavy precipitation or snowmelt. Vegetation is sparse with a few junipers in the bottom and along the ridges. Soil cover is composed of 0 to 6 in. of silty clay with gravel and cobbles on the slopes. Similar soils probably exist to a maximum depth of 5 ft in the bottom. The soil resources survey (Radian Corp. 1981) indicates that the soils for the area of this site are derived from materials weathered and carried downslope from shale and sandstone beds exposed at higher elevations. The variable soil depth is composed principally of loamy (silty clay) to clayey materials with a random distribution of stones and cobbles.

63. The mouth of the gulch is restricted and affords little room for a collection/evaporation pond behind a retention dam. The narrow bottom would also restrict foundation preparation activities to hand labor and use of a small dozer/compactor.

64. Access to site 2 is by foot and would require 800 ft of haul road up the West Sharrard drainage. A conveyor to lift existing retorted shale up into the gulch and a steep pioneer road would be required for fill construction operations as the fill height increased. Feeding freshly retorted shale to the site by conveyor from the plant level would require a 1400-ft long, elevated conveyor from elevations 5950 to 6100 ft, an incline of 150 ft or a 10 percent grade.

65. Site 3. The third site is located adjacent to the mine road in a south sloping saddle area (Figure 12) between two major drainages. Photographs of the site are shown in Figure 18. The site extends from elevation 6100 to 6160 ft (south to north) along the bottom and to elevations 6200 and 6320 ft on the east and west, respectively. The storage capacity is 0.6×10^6 cu yd or 0.8×10^6 tons for a pile heaped to elevation 6370 ft. The drainage area is approximately 0.5 acres and vegetation cover is estimated at 10 percent.

Figure 17. Looking up into site 2 to the east

a. Upper end of saddle area (looking north)

b. Lower end of saddle area (looking south)

Figure 18. Site 3

66. Soil cover is silty clay in the bottom probably to a maximum depth of 10 ft and silty clay with gravel and some rock fragments on the slopes. The soil resources survey (Radian Corp. 1981) indicates the area has variable soil depth with soils weathered from shale and sandstone beds.

67. The site extends 800 ft from the mine road north. Sufficient area exists on the south side of the site for water collection/evaporation ponds.

68. The site is 4500 ft (0.85 miles) from the retort plant and truck hauling would be required. Access to the site is by trail road which could serve as a haul road initially. During construction of a research fill, 600 ft of pioneer or haul road for construction equipment access and a 300 ft conveyor to place materials would be required.

69. Site 4. This site is located north of the abandoned water tank on a hill west of the housing area (Figure 12). The site is a shallow gulch as shown in Figure 19a and extends 3500 ft west from elevation 5740 ft up steep back slopes to the mine road ridge at elevation 6700 ft. The storage capacity is 0.9×10^6 cu yd or 1.1×10^6 tons to elevation 6000 ft. Vegetation cover is 100 percent as shown in Figure 19b and the drainage area is approximately 41 acres.

70. Drainage in the bottom is moderate after a 20-minute rain as shown in Figure 19c and would be moderate after heavy snowmelts. Adequate room exists at the mouth of the gulch for collection/evaporation ponds.

71. Soils consist of 2 in. of brown loam (silty clay), 6 in. of stoney loam, and 5 ft of calcareous stoney loam (Radian Corp. 1981) in the lower elevations. Soils in the upper elevations consist of variable depths of silty clay with random rock derived from exposed shale and sandstone beds.

72. Access to the site is from a trail road up to the abandoned water tank and an old trail road further west along the south ridge of the site. Approximately 3000 ft of improved road would be required. The midsegment of the site lies outside the facility boundary in Section 18 and an easement might be required. The site is approximately 7000 ft (1.3 miles) from the retort plant and truck hauling of retorted shale would be required.

73. Site 5. The fifth site (Figure 12) is located southwest of the abandoned water tank (west of the housing area). The site includes a bowl-shaped area and two adjacent gullies with steep back slopes. The general area is shown in Figure 20. The site extends from elevation 5660 ft to elevation 6600 ft at the mine road ridge, a distance of 3400 ft. The total storage

a. Looking northwest into site 4

b. Looking southeast down into site 4

c. Muddy water flowing in drainage channel, site 4

Figure 19. Site 4

Figure 20. Looking west into site 5 from top of abandoned water tank
on hill west of housing area

capacity of the site is 1.1×10^6 cu yd or 1.3×10^6 tons. The total drainage area is approximately 86 acres and vegetation coverage is approximately 35 percent.

74. Drainage out of the site would be moderate after heavy showers or snowmelt (based on site 4 observations). Adequate room exists for collection/evaporation ponds. The minimum distance to the boundary line from toes of possible research fills is approximately 450 ft. Soils consist of a variable depth of silty clays with random rock derived from exposed shale and limestone beds (Radian Corp. 1981).

75. Access to the site requires construction of approximately 1000 ft of haul road from the old water tank ridge to service construction equipment. A moveable elevated conveyor (1000 to 1200 ft long) could be used to transport retorted shale into the site from the water tank ridge. The water tank ridge is approximately 7000 ft (1.3 miles) from the retort plant and truck hauling would be required to this location.

76. Site 6. The sixth site is located approximately 2500 ft south of site 5 (Figure 12). The site includes a narrow steep-sided gulch and a rough steep-sided bowl-shaped area. The site extends from elevation 5650 ft to elevation 6400 ft at the mine road ridge, a distance of 2400 ft. The storage capacity is 1.3×10^6 cu yd or 1.6×10^6 tons. Vegetation cover is approximately 60 percent.

77. The drainage area is approximately 63 acres and drainage would be moderate from heavy showers or rapid snowmelt (based on observations at site 4). Soils in the area are similar to those in the site 5 area.

78. Access to site 6 would require approximately 4000 ft of haul road over rough terrain. A trail road exists partway into the site from the housing area road. Access would require easement across land outside the reserve boundary (Figure 12).

Site selection

79. As indicated in Table 6, sites 1 and 3 are considered the two most promising sites. Site 3 is considered the best site since it is in a saddle between drainages, has the smallest drainage area, and is most accessible. However, the storage capacity is limited to 0.6×10^6 cu yd. Site 1 is considered the next best site. While it has a relatively large drainage area, there is adequate room for collection/evaporation ponds and very little vegetation that would have to be cleared. It also has the largest storage capacity, is nearest to the retort plant, and is at a lower elevation.

Table 6
Characteristics of Potential Research Fill Sites

Site No.	Maximum Storage Capacity*		Distance to Facility Boundary		Drainage Area Above Initial Fill Crest acres	Estimated Vegetation Coverage, Fill Area percent	Estimated Maximum Surface Soil Depths		Distance from Retort Plant ft	Description and Existing Access	Fill Construction Access Requirements	Relative Ranking	
	cu yd x 10 ⁶	tons** x 10 ⁶	Toe of Fill ft	Initial Crest of Fill ft			Slopes ft	Bottom ft				Environ-mental	Econom-ical
1	3.1	3.7	480	1100	68	3	0.5	10	1000	Steep-sided, branching gulch east of retort plant, access by foot across West Sharrard Drainage.	700 ft of haul road; 800 ft of elevated conveyor as fill height increases; 200 ft more of haul road to service/maintain construction equipment.	2	2
2	1.4	1.7	3400	3400	51	5	0.5	5	1200	Steep-sided gulch off West Sharrard Drainage above retort plant, access by foot.	800 ft of haul road and 200 ft of conveyor (as fill height increases); addition haul road to service/maintain equipment.	3	4
3	0.6	0.8	2200	2250	0.5	10	1.0	10	4500	Saddle area adjacent to mine road; access by vehicle.	None initially; 300 ft of conveyor and 600 ft of haul road to service maintain equipment as fill height increases.	1	1
4	0.9	1.1	2400	2450	41	100	1.0	10	7000	Shallow gulch with steep backslopes; access by foot from old water tank hill west of housing area; easement required for portion of fill area outside facility boundary.	Rebuild 1000 ft of old road from old water tank hill up west ridge of site.	4	3
5A	0.4	0.5	450	700	74	40	1.0	10	7000	Steep-sided, wide bowl (5A) and adjacent branching gulch (5B); access by foot from old water tank hill west of housing area.	1000 ft of haul road and elevated conveyor from old water tank; ridge over very rough terrain.	6	5
5B	0.7	0.8	550	800	12	30	0.5	10	7000				
6	1.3	1.6	1300	1400	63	60	1.0	10	9000	Narrow steep-sided gulch and adjacent steep-sided bowl. Access by foot about 2000 ft from a trail road.	4000 ft of haul road from road south of housing area over rough terrain outside facility boundary.	5	6

* Slope of 1 Vertical on 1.5 Horizontal (1.5:1 or 67% slope) used for estimating storage capacity.

** Based on average fill density of 90 pcf (60% standard compaction effort); factor of 1.215.

80. Sites 2, 4, 5, and 6 are the least promising sites. Site 2 drains directly into West Sharrard drainage and has very little room for a collection/evaporation pond. Access would be difficult since it is higher in elevation than the retort pond. Site 4 has better access than sites 1 and 2 but would require an easement and removal of a large amount of vegetation. Hauling costs would be greater than for sites 1 and 3. Site 5 has the largest drainage area, a significant amount of vegetation and is relatively close to the reserve boundary. Access would be more expensive than for sites 1, 2, and 3. Site 6 is the most remote, has a large amount of vegetation, a large drainage area, and would be the most expensive to develop. In addition, access requires an easement across land outside the facility.

81. Based on the evaluation, sites 1 and 3 are considered the two best sites. Site 1 could be restricted to retorted shale and site 3 could be used for raw reject shale.

PART IV: RELOCATION FILL FOR EXISTING SPENT SHALE

Background

82. Existing spent shale at the Anvil Points facility has been accumulating in a pile on the west side of the Sharrard Drainage since the 1940's. A brief history of the sources of spent shale dumped in the pile is shown in Table 7 from a study by PNL (Garland et al. 1982) of ground-water conditions in the West Sharrard Drainage. In 1982, a geotechnical investigation of the pile was initiated by the WES for LETC to determine the in situ pile conditions, physical properties of the spent shale and foundation materials, and the existing stability of the pile. Conclusions of the WES investigation and recommendations on stabilization measures are contained in the resulting report (Meade and Dickinson 1984). This part presents a conceptual design and construction operation plan for the possible relocation of the existing spent shale.

Relocation Site

83. The location recommended for possible relocation of the existing spent shale is in the east gully at site 1, described in Part III and shown in Figure 21. (The west gully is recommended for a future research fill; see Part V.) The east gully can hold up to 200,000 short tons of material with a face slope as flat as 1V on 3H. Site conditions are described below.

Topography and drainage

84. The east gully at Site 1 has variably steep side slopes (1V on 1H to 1V on 1.7H) and sparse vegetation consisting of grasses and scrub juniper and cedar trees (Figure 16). The drainage pattern is of the ridge and gully type. The east gully drainage extends from elevation 5740 ft, some 2600 ft to a ridge at elevation 7050 ft (average gully slope of 1V on 2H). The total drainage area is approximately 26 acres.

Surface soils

85. The surface soils consist of clayey sands to sandy clay (SC) with sandstone gravel and cobbles. These residual soils are weathered products of the underlying clay and shale beds of the Wasatch formation. The depth of the surface soils varies from approximately 6 to 12 in. on flatter slopes.

Table 7

Summary of Solid Waste Disposal at the DOE
Anvil Points Oil Shale Research Facility*

Research Operations	Dates	Mined	Retorted	Disposal	
				Raw	Retorted
				(Thousands of Metric Tons)	
US Bureau of Mines	1946-1956	428		284**	
N-T-U Gas Combustion #3	1947-1955		61	45+	61+
Royster, Gas Flow, Gas Combustion #1, 2	1948-1955		14		14++
Six Company Group	1964-1968	509		410**	
Gas Combustion #3			18	45+	18+
Gas Combustion #1, 2			4		4++
Paraho Development Corp.	1973-1978				
Oil Shale Demonstration	1973-1976	90	59	25+	22+
Office of Naval Research and DOE	1977-1978	176	119	30+	97+
Totals in West Sharrard Drainage	1946-1978			145	198

* Garland et al., 1982.

** Area below and east of mine, Anvil Points Drainage.

+ West Sharrard Drainage.

++ Area west of maintenance shops.

Figure 21. Location of possible relocation fill at site 1 for existing spent shale

Sandstone gravel and cobbles have accumulated in the bottom of the gully on top of a thin deposit of sediments from the adjacent slopes. The physical properties of surface soils, weathered from the Wasatch formation are shown in Table 8. Compacted specimens of gravelly clayey sand, with 40 percent fines exhibited a relatively high drained shear strength of $c' = 0.2 \text{ kg/cm}^2$ and $\phi' = 31 \text{ deg}$. Specimens of a weathered Wasatch clay bed with 94 percent fines indicated a lower strength of $c' = 0.1 \text{ kg/cm}^2$ and $\phi' = 21 \text{ deg}$. These strengths are typical of clayey soils.

Geologic conditions

86. The entire area of site 1 is underlain by the Wasatch formation (Eocene series, Donnell 1961) and consists of brightly colored, near horizontal beds of clay and shale. Shades of red, purple, gray, lavender, and yellow are common, indicating a variety of clay minerals. Lenticular sandstone beds are intermittent throughout the site. The exposed beds are weathered to depths up to approximately 12 in. and are easily eroded by rainfall and snow-melt water. The clay and shale beds are impervious, while the thin layers of jointed sandstone are relatively pervious. However, no seepage occurs from the exposed beds. The Wasatch formation extends from elevation 6400 ft to about elevation 1400 ft and the depth beneath the site is some 4300 ft. Consequently, ground-water aquifers are not likely to exist beneath the site. The steep slopes and narrow gully bottom indicate the shallow depth (less than 5 ft) of accumulated sediments in the bottom of the gully. The steep slopes of the gully also indicate that the unweathered Wasatch beds have a high strength and pose no stability problems.

Conceptual Fill Design

87. As discussed in Part II, the variability of spent shale material properties, the site-specific geologic and hydrogeologic conditions, and their interaction need to be considered in developing a fill design. Preliminary drilling and sampling of the existing spent shale pile indicate that the gradation ranges from gravel sizes to powdered ash and that the water content ranges from 0 to 14 percent. Hotspots in the pile with temperatures as high as 500°C have also been found. Because of the wide variability of the existing spent shale materials and subsequent weathering plus thermally induced changes, the physical and engineering properties can be expected to vary over a wide range. Consequently, only a conceptual design can be developed at present.

Table 8
Engineering Properties of Surface Soils, Anvil Points

Sample No.	Location	Description	Gradation, percent			Atterberg Limits			Specific Gravity of Solids	One Point Compaction		Drained Direct Shear Strength		Estimated Permeability*
			Gravel	Sand	Fines	LL	PL	PI		Water Content %	Dry Density pcf	c' kg/cm ²	φ deg	
1	Surface of slope, west of Site 1	Gravelly clayey sand (SC) brown (residual soil)	21	39	40	31	19	12	2.69	12.0** 11.9+	102** 102+	0.2	31	1.0
2	Exposed cut in West Sharrard Drainage	Clay (CH), brown with sand (weathered Wasatch bed)	0	6	94	52	16	36	2.81	11.3** 11.5+	108** 107+	0.1	21	10
3	Below ponds, West Sharrard Drainage	Sandy clay (CL), brown with gravel (alluvium)	12	26	62	36	15	21	2.68	11.4** 12.1+	106** 106+	0.25	26	0.01
4	Site 3, bottom of saddle area	Clayey sand (SC), brown with gravel (topsoil)	11	48	41	35	20	15	2.60	14.4** 14.9+	99** 99+	0.1	34	10

* Standard effort compaction at water content shown.

** Molding water content and dry density of direct shear test specimens.

+ Estimated from consolidation phase of direct shear test at 1, 3 and 6 kg/cm².

Site plan

88. The primary concerns for a relocation fill in the east gully are to control surface drainage and infiltration. Runoff from the natural slopes behind the fill area can be collected in ditches and routed away from the fill. Surface runoff from the fill surface can also be collected in ditches and routed to a collection pond for monitoring, evaporation, or treatment before release. Fill slopes of 1V on 3H and 1V on 2H are alternatives considered in conceptual designs until the range in engineering properties of the existing spent shale can be defined and an optimum design formulated. The potential for infiltration of precipitation and snowmelt water into the fill cannot be evaluated until the permeability range for compacted conditions is defined. Specific aspects of the conceptual design are discussed below.

Surface drainage

89. There are two major considerations in controlling surface drainage. The first is to intercept runoff above the fill and direct it around the fill. The second is to separately collect and route runoff from the fill to a collection pond for monitoring, evaporation, or treatment before release. Control of surface drainage from natural slopes behind the fill site will require three diversion dikes at locations shown in Figure 22 for a relocation fill with a 1V on 2H face slope. The same diversion dikes and ditches can be used for a face slope of 1V on 3H as shown in Figure 23. The dikes will divert a major portion of the upslope drainage into ditches to be constructed at locations also shown in Figures 22 and 23. A pond below the toe of the fill will collect runoff from the fill and adjacent slopes. The size of drainage ditches and the collection pond are based on the maximum point storm and 24-hour precipitation records, respectively, at Grand Junction (de Nevers 1978). The July 1974 point storm (1.0 in. in 15 minutes and 1.37 in. in 1 hour) is considered more severe for peak flows entering diversion dikes and ditches than the October 1980 24-hour rainfall record of 2.5 in. The latter is applicable to total storage capacity for runoff from fill surfaces and adjacent slopes. The short duration point storm and 24-hour rainfall were used with the kinematic wave model option of the HEC-1 flood hydrographic package (HEC 1981) to estimate surface runoff and peak flows. The Soil Conservation Service (SCS) curve number option was used for estimating excess runoff. The natural slopes were considered impervious (SCS curve 98) and the fill surfaces as pervious (SCS curve 85). The resulting maximum peak flow for

Figure 22. Surface drainage collection, relocation fill with 1V on 2H slope, east gully, site 1

Figure 23. Surface drainage collection, relocation fill with 1V on 3H slope, east gully, site 1

the short duration point storm was 75 cfs at the easternmost dike. Peak flows at the two other dikes were 6 cfs.

90. Runoff diversion. Diversion of the peak flow of 75 cfs from the easternmost dike (Figure 23) requires a 2-ft-deep ditch with a 1.5-ft-wide bottom and 1V on 1H side slopes. Smaller ditches (1 ft deep, triangular) are needed for the other two dikes. Runoff from the fill and adjacent slopes can be directed to the collection pond in 1-ft triangular ditches along the sides of the fill. Sandstone rocks at the site can be used to line the side ditches for erosion protection.

91. Collection pond. The size of the collection pond to contain runoff from the fill and adjacent slopes for the 24-hour rainfall of 2.5 in. requires a storage capacity of 62,400 cu ft. This volume can be contained in a pond with an average depth of 7 ft and an average area of 9000 sq ft (e.g., 90 by 100 ft). As shown in Figures 22 and 23, a collection pond with sufficient capacity can be located at the mouth of the east gully without blocking natural drainage from the west gully.

Fill design

92. One primary objective for the relocation fill is to minimize infiltration of rainfall and snowmelt that could result in leachate seeping out of the fill. This objective can be accomplished by compacting the fill material to reduce permeability and by incorporating compacted soil layers to form impermeable barriers. Another primary objective is to prevent excessive erosion of the fill surface that would reduce the capacity of the collection pond. In addition, erosion of soil from the natural slopes behind the fill could eventually fill up the diversion dikes and ditches. Provisions to handle overtopping of the dikes and ditches after completion of the relocation fill is another objective.

93. Mechanical stability. The existing uncompacted spent shale pile has steep slopes of 1V on 1.2H to 1V on 1.4H (36 to 39 deg, March 1983 field survey). The slopes of the pile have been steeper in the past and even then slope failures have not occurred. These slopes indicate a minimum conservative, effective stress shear strength of $\phi = 36$ to 40 deg, neglecting cohesion and assuming a factor of safety of 1.0. It is believed that the relocation fill with material compacted to standard effort density will have a higher strength and will be stable with a 1V on 2H face slope. Compacting the spent shale in the east gully will result in a "V"-shaped fill with rough

sides, conforming to the gully sides, as indicated in Figure 22, that will provide added stability against sliding. In addition, the dog leg shape of the gully would restrict sliding to the lower portion of the fill below elevation 5900 ft. This geometry reduces the critical fill height to 140 ft. Figure 24 shows a relocation fill section with the 1V on 2H face slope. The more conservative section with a 1V on 3H face slope is also shown in Figure 24 and would produce a narrower and shallower fill (Figure 23).

94. Because of the wedge shape of the proposed relocation fill (1V on 2H or 1V on 3H), massive sliding below elevation 5900 ft would only occur by slippage of the fill along the gully sides. Thus, the critical resistance against sliding would be the strength along the contact between the spent shale fill and the clay and shale beds of the Wasatch formation in the gully sides. A three-dimensional wedge sliding analysis using a lower bound contact shear strength of $c' = 0$ and $\phi' = 20$ deg indicates a factor of safety against mass sliding of 1.6 for a 1V on 2H face slope and 2.7 for a 1V on 3H face slope. Shallow surface slides in the face slope are possible. For an assumed lower bound effective stress shear strength of $c' = 0$ and $\phi = 36$ deg, the factor of safety is 1.4 for a 1V on 2H face slope and 2.2 for a 1V on 3H face slope. A total stress shear strength of $c = 1.0 \text{ kg/cm}^2$ and $\phi = 34$ deg was measured on a compacted sample of old spent shale from a trench in the existing pile (Table B6, sample WCC II). Thus the assumed lower bound strength of $\phi' = 36$ deg is considered reasonable. If measures were included to prevent significant infiltration of rainfall and snowmelt, water would not accumulate at the base of the fill. Thus, long-term changes from hydro-reactions would not be expected and the long-term mechanical stability would not decrease. In addition long-term settlement or creep deformations would not be expected.

95. Infiltration and erosion protection. Figure 25 shows recommended benching, with infiltration and erosion protection measures for the face slope. Soil-covered benches at 25 ft vertical spacing, with drainage to the side ditches and coarser spent shale at the backslopes would minimize erosion and infiltration. Extension of the soil layers into the fill would intercept any downward seepage. The soil can be obtained as the gully sides are scraped down to unweathered material during incremental construction of the fill. This precaution may not be necessary if field permeability tests during construction indicate that vertical permeabilities are equal to or less than

Figure 24. Possible relocation fill sections, east gully, site 1

Figure 25. Relocation fill infiltration and erosion protection details

1 ft/yr (10^{-6} cm/sec). Closer spaced soil-covered benches would require the same amount of soil but would require steeper back slopes that would be expensive to stabilize (by riprap or with lime-stabilized compacted soil or spent shale layers). The 1V on 2H face slope would have less exposed surface for infiltration, but the steeper slope would be subject to greater erosion than the 1V on 3H slope. A check of the stability against shallow surface slides for the slightly steeper slopes shown in Figure 25 indicates factors of safety of 1.2 and 1.9, respectively, for the 1V on 1.6H and 1V on 2.6H face slopes. Upon completion of the fill, the top surface at elevation 6000 ft can be graded and sealed with a 3-ft compacted soil layer. Ditches lined with existing sandstone rock can be added to intercept any overflow from the dikes and ditches and route the flow across the top into the natural drainage south of the fill (Figures 22 and 23).

Collection pond

96. The collection pond (Figures 22 and 23) would require an embankment 20 to 25 ft high founded on unweathered Wasatch material in the mouth of the east gully. Soils excavated to form the embankment and pond could be used to construct the compacted soil embankment with side slopes of 1V on 2H.

Figure 26 shows a pond and embankment section for the possible relocation fills. A lower bound shear strength of $c' = 0.1 \text{ kg/cm}^2$ and $\phi' = 20 \text{ deg}$ for an embankment compacted to standard effort density (Table 8) would provide a factor of safety of 1.4 for complete saturation and 1.8 for no saturation (simplified Bishop stability charts, Tesarik and McWilliams 1981).

97. Lining of the pond is not considered necessary because of the impermeable nature of the Wasatch formation and the fact that sandstone strata are not evident in exposed slopes at lower elevations below the pond location. However, if excavation reveals open joints or cracks in the unweathered Wasatch surface, a lining of compacted soil, 2 ft thick may be necessary. The surface soils and clay and shale strata of the Wasatch formation will produce an impervious material when compacted in the embankment. To check for possible, but unlikely seepage beneath the embankment, seepage observation wells should be located as shown in Figure 26.

Instrumentation

98. A minimal instrumentation program is considered necessary to verify the relocation fill design provisions and to insure that any adverse conditions (considered unlikely) could be detected. Two combination inclinometer,

Figure 26. Collection pond sections for possible relocation fill, east gully

settlement and piezometer wells, one half way up the face slope and one behind the final crest, as shown in Figure 27, would provide for detection of movements and any water accumulation at the base of the fill. The bottom of the inclinometer casing (3-in. I.D.) should be set 5 ft into the underlying Wasatch formation to provide a fixed reference point for movements. The use of telescoping casing would allow settlement measurements to be made. A well screen and 2-ft blank section in the casing at the base of the fill would allow detection and collection of any seepage water. Any accumulated water in the well could be sampled and analyzed to determine the potential source. A typical section for these instrumentation wells is shown in Figure 28.

99. The open casing would also provide access for temperature measurements and measurement of relative changes in moisture and density of the spent shale with time. The temperature could be measured with a thermal probe and the moisture-density measurements could be made with a nuclear moisture-density probe. Measurement of absolute moisture-density values would require special calibration of the nuclear probe with the actual spent shale at known densities and moisture because of the unknown effects of residual carbon and hydrogen compounds in the spent shale.

100. These two instrumentation wells could be carefully installed and checked during fill construction. With proper protection during construction, the wells could be used to obtain all necessary measurements to monitor fill behavior during and after construction.

101. The two seepage monitoring wells (Figure 26) should be installed close to the toe of the collection pond embankment to an estimated depth of 10 ft below the base of the embankment. These wells could be used to detect any seepage that might escape from the collection pond and should be installed as soon as the pond is constructed. A typical section for these wells is also shown in Figure 28.

Monitoring

102. Soundings and measurements in the instrumentation and seepage wells should be made weekly during construction and after significant rains and snowmelts. After construction, monthly measurements should be made for the first six months and then quarterly until it is evident that no adverse conditions are likely. Annual observations of the fill site and check measurements should be made until it is evident that the site is completely stable with regard to existing environmental regulations.

a. RELOCATION FILL SECTION, IV ON 2H FACE SLOPE

b. RELOCATION FILL SECTION, IV ON 3H FACE SLOPE

SEE FIGURES 22 AND 23 FOR PLAN.

Figure 27. Locations for instrumentation wells

Figure 28. Instrumentation and seepage observation wells

Relocation Fill Construction

103. Construction of the relocation fill includes the following items:

- a. Site preparation: construction of drainage dikes and ditches, collection pond construction, and installation of seepage observation wells, and excavation to unweathered Wasatch material in the initial segment of the gully.
- b. Excavation, treatment, and transport of spent shale to the east gully.
- c. Fill construction: placement and compaction of the spent shale and intermittent soil layers, field compaction control testing, field permeability tests, and installation of instrument wells, side ditch construction, and final top surface soil layer and drainage ditches.

Recommended procedures and a construction operation plan are described in this section. A preliminary schedule and cost estimate are also included. The scheme for excavation and transport of the spent shale and associated preliminary costs was developed by D'Appolonia Consulting Engineers, Inc., of Denver, Colo. All geotechnical aspects of the relocation fill construction should be supervised by an experienced geotechnical engineer.

Site preparation

104. An access and haul road will be required into site 1 to reach the east gully from the spent shale pile in the West Sharrard Drainage. As shown in Figure 29, the haul road could follow an abandoned road south from the existing ponds, across the drainage channel and around the toe of the ridge between the West Sharrard Drainage and into site 1. A culvert and fill would be required to cross the West Sharrard drainage channel. Regrading of the abandoned road and grading of a new road into site 1 would also be required.

105. Drainage dikes and ditches. The dikes and drainage ditches behind the fill (Figure 22) will require considerable hand labor because of the rough terrain. A small dozer could be used after gaining access to the dike area by driving it up the south flank of the southeast ridge at site 1 to a saddle at elevation 6103 ft (see Figure 22). Tools, fuel, and equipment also could be hauled by a dozer to this location. The dozer could then be used to cut a trail, push soil down to the easternmost dike, and be used to construct this dike. It could also be used to construct the other two dikes and ditches. However, the easternmost ditch will require considerable hand excavation along the steep slope.

106. Collection pond. The collection pond construction would require a dozer for excavation and a small sheepsfoot roller attachment for compaction. Water would also be required from a water trailer with a gasoline pump and small fire hose. The collection pond soil embankment should be compacted in 8-in. lifts to standard effort dry density at optimum water content (estimated, respectively, at 115 pcf and 12 percent). Field in situ density and water content tests of the compacted soil would be required to confirm the compaction requirements. Field permeability tests should be made to verify that the compacted soil is impervious (permeability less than 1 ft/yr). The downstream slope of the pond embankment for the 1V on 3H relocation fill would require riprap (Figure 23) for protection from small flows out of the west gully. The sheepsfoot roller could also be used to compact a soil lining, if needed, for the collection pond. The seepage observation wells would be installed upon completion of the pond embankment by auger drilling, setting of the plastic casing and well point sections, sand backfilling, and sealing by grouting above the well screen section.

107. Initial gully excavation. In preparation for the spent shale fill, the initial (lower) segment of the east gully should be excavated to remove sandstone rocks and soil to expose the unweathered Wasatch material. The sandstone rocks should be collected and stockpiled along the slope for later use in the side ditches. The small dozer can be used to push excavated soil up the gully into a stockpile for later use in the first soil layers and benches. Subsequent excavation up the gully would proceed as the fill height increased.

Excavation and transport of spent shale

108. Excavation and transport of spent shale from the existing pile would consist of the following sequential operations:

- a. Excavation and spraying hotspots with water.
- b. Screening, moisture addition, and stockpiling.
- c. Loading and conveying to the east gully.

The above items would be accomplished in a staging area at the south end of the pile, as shown in Figure 29. Spraying uncovered hotspots in the pile with water from fire hoses could produce toxic fumes. Safety precautions, such as protective clothing, face masks, and toxic fume detection equipment may be necessary to provide safe working conditions. Runoff from spraying of hotspots and moisture conditioning of dry material will require ditches to collect the water in the existing ponds.

Figure 29. Location of construction operations for relocation fill construction with truck haul transport of spent shale

109. Material handling system. A backhoe (or front-end loader) operating at the base of the pile would be used to excavate the spent shale. A dozer would assist by pushing material from other parts of the pile base to the backhoe. Excavated material would be dumped onto a vibrating screen or sloping grizzly (if clods of material break apart easily) with 3-in. openings to separate out plus 3-in. pieces. Removal of the coarser pieces is considered necessary to improve compaction of the spent shale and to provide coarser material for the erosion-resistant zone in the face of relocation fill. Water would be sprayed on dry material being dumped on the screen to control dust. A front end loader would be used to move the fines from beneath the screen to a separate stockpile where water could be added by spraying to condition the material for compaction. In the case of potential slope instability, excavation could be accomplished with a dragline machine operating from the top of the pile. If the pile material is finer textured than anticipated, spreading and raking could be used to remove particles larger than 3 in. instead of a vibrating screen or grizzly. Two options, truck hauling and conveyors are considered for transport of the spent shale to the east gully.

110. Truck transport. Moving the spent shale to the east gully by truck could make use of the proposed haul road (Figure 29). A maximum grade of 10 percent was considered acceptable for the haul route. The trucks would carry spent shale to a hopper at the toe of the fill where a belt conveyor would take the material up the face of the fill to the working surface. The conveyor system would be extended up the fill slope as the fill height increased. The discharged pile would be continuously dozed, graded, and compacted. Plus 3-in. material would be spread and compacted in the outer 5 to 7 ft of the fill. Coordination by radio with the staging area would control delivery of needed material.

111. Conveyor transport. Transport by conveyor would follow the route shown in Figure 30 (a full-scale drawing, Plate 2 is in the pocket at the end of the report). A maximum grade of 15 percent was considered acceptable for this route. A front-end loader would dump the conditioned fine or coarse spent shale into a hopper at the staging area to control the flow onto the conveyor. Approximately 1250 ft of belt conveyor would be required to reach the toe of the relocation fill and an additional 1250 ft would be required to reach the final top of the fill at elevation 6000 ft. Unloading points and chutes on the southeastern ridge of the east gully would pile the spent shale

Figure 30. Location of construction operations for relocation fill construction with conveyor transport of spent shale

in the gully or onto the working surface. The same placement procedure described above would be used.

Fill compaction

112. It is believed that standard effort dry density can be achieved when the minus 3-in. spent shale is spread in 8-in. lifts at a placement water content of 10 to 14 percent and compacted by 4 to 6 complete coverages of a vibratory roller (padded or smooth faced, 7 to 10 ton static weight). This procedure is based on previous field compaction tests (Appendix A). The plus 3-in. material can be compacted adequately in 12-in. lifts using the same compaction procedure, without addition of moisture. The soil layers will require addition of water on the fill during grading to achieve optimum water content. Compaction in 6 to 8-in. lifts will be required to achieve standard effort dry density. During weekends or 24-hour-delay periods, an 8-in. soil layer should be compacted and graded to prevent infiltration from rainstorms or heavy snowmelt. Any frozen soil should be removed and replaced during nonfreezing temperatures.

Side ditch construction

113. Side ditches along the fill edges should be constructed concurrently with the fill. Stockpiled sandstone rock should be used to line the ditches for erosion protection. Temporary ditches along the edge of the working surface should be maintained using half-round drainage pipes (18-in.-diameter) to route drainage from the gully to the side ditches.

Quality control

114. A quality control program should be used to achieve required design objectives and adequate compaction. The program would consist primarily of recording and documenting the types and locations of various materials within the fill and as-compacted condition. The following tests and measurements should be included with pertinent information recorded.

a. Material.

- Grain size distribution.
- Atterberg limits.
- Specific gravity of solids.
- Water content at the fill.
- Temperature at the fill.
- Moisture content versus standard effort compaction.

b. Placement procedure.

- Equipment.

- Lift thickness and location.
- Number of compactor coverages.

c. End results.

- In situ water content and density.
- Permeability.

Certain tests, such as in-place density and water content should be conducted daily at a minimum of three per lift. At least two permeability tests should be performed on every tenth lift. The use of nuclear moisture-density apparatus for in situ density and water contents of spent shale and soil layers will require calibration against a direct method (e.g., volume displacement method for density and oven drying for water content). Qualified soil technicians should conduct the tests under the supervision of an experienced geotechnical engineer.

Instrumentation wells

115. Incremental installation of the two instrumentation wells as the fill height increases will require extension of the casing at least 5 ft above the working surface. A warning flag should be attached to the top of the casing. A protective mound at least 3 ft high should be carefully compacted around the casing to the same density as the fill. The work should be done before allowing fill placement near the casing to prevent damage by heavy equipment. The casing should be inspected daily and readings taken weekly during construction. Qualified persons should install the instrumentation casing and take the readings. An experienced geotechnical engineer should supervise the work and evaluate the readings. A qualified scientist should be in charge of recovering and analyzing water samples.

Regrading existing pile site

116. The area left by removal of the existing spent shale pile should be regraded to provide an environmentally safe area. Removal of the pile and its previous effect as a stability berm on the slope below any existing structures should be evaluated. Cleanup of the area may be necessary to remove any contaminated soil to various depths at any locations where old process water pits are evident. Such material should be hauled and disposed of at a safe location in the plant area.

Cleanup operations

117. The work areas, including temporary stockpile locations, screening locations, and ponds in the staging area should be cleaned up and restored to environmentally safe conditions. Particular care should also be taken to

clean up fugitive spent shale that may have accumulated along the haul road or conveyor route (especially at transfer points).

Preliminary costs and schedules

118. Preliminary construction cost and schedule estimates made by D'Appolonia Consulting Engineers, Inc. (DEIC), were based on their internal construction records and experience. Relocation of the spent shale using the truck haul option was estimated to cost approximately \$4/per cubic yard or a total of \$800,000 (assuming 200,000 cu yd of spent shale). A construction period of approximately 8 weeks was estimated, providing no unforeseen hazardous conditions arose during construction. The estimate does not include construction of surface water runoff control structures or handling of very hot materials (greater than 200°C) that cannot be transported on a standard conveyor system. A final cost estimate for bidding purposes requires detailed plans and specifications and compaction tests during excavation to define optimum properties. Detailed information on the final configuration of the pile area after removal of the existing spent shale is also required.

119. A second preliminary cost estimate, including plans and specifications, contracting, and contract supervision and administration was obtained from the Albuquerque District of the U. S. Army Corps of Engineers. The total cost with a 25 percent direct construction cost contingency was \$2,302,938. A summary of the cost items and time is given in Appendix D.

120. For the conveyor transport system option, the approximate cost estimated by DEIC was \$6/cy or a total of \$1,200,000. The estimate of construction time is approximately 8 to 10 weeks. The same restrictions apply as for the truck option. Because of the higher relative cost over truck hauling, the conveyor option is not considered further in this report.

PART V: RESEARCH FILLS FOR FUTURE SPENT SHALES

Objectives

121. A research demonstration fill is needed to extend geotechnical design methodology and to provide a means for applying environmental research results from small-scale laboratory and field tests. It is anticipated that the Anvil Points retort research facility will produce significant quantities of Paraho spent shale in the future. It is also anticipated that TOSCO II (referred to simply as TOSCO) spent shale may be available from a source close to Anvil Points. A large-scale research fill (or fills) at the Anvil Points facility could provide safe disposal of these spent shales, needed field test data, and an experience base on long-term performance. The objectives of the research fill(s) would be as follows:

- a. Validate or improve geotechnical design methodology and prediction capabilities for long-term mechanical stability from results of measured fill performance.
- b. Determine in situ changes in moisture, temperature, and chemical reactions and their effects on infiltration, permeability, shear strength, settlement or creep, and other important properties and interactions.
- c. Provide a large-scale field test environment for application of three dimensional hydro-chemical research models, and application of small-scale leachate and reclamation research results.
- d. Provide a large-scale field test environment for evaluation of new monitoring techniques and instrumentation.

A conceptual geotechnical design of the research fill(s) for spent shales from the Paraho and TOSCO processes is presented in this part. A conceptual design for a raw reject shale fill is also included. The proposed designs include provisions for accomplishing the above objectives. Refinements in the design will be required as the actual spent shales are produced and tests are made to check physical properties, especially if codisposal is used. Codisposal using treated (stream stripping) waste water for cooling and moisturizing and with raw reject fines and process dust added to the disposal stream would require extensive laboratory and field tests. No such tests have been performed to date.

Design Considerations

Spent shale quantities

122. Anticipated quantities of Paraho spent shale over a five year period (Part III) are approximately 700,000 tons. It is assumed that a similar quantity of TOSCO spent shale will also be available during the same period. Consequently, two research fill concepts are considered. One is a combination fill to accommodate Paraho spent shale initially and then TOSCO spent shale subsequently in a separate portion of the fill. The other is to provide a separate research fill for each type of spent shale.

Research fill site

123. The recommended research fill site at Anvil Points is Site 1, described in Parts III and IV. The west gully (Figure 21) can hold approximately 1.5 million tons of spent shale while the east gully can hold approximately 600,000 tons. If the relocation fill in the east gully for existing spent shale is not required, then the two gullies can be used for separate research fills for the Paraho and TOSCO spent shales. The topography, surface soils, and geologic conditions in the west gully are the same as described for the east gully in Part IV. Use of the west gully will require a dike and drainage ditch at the upper end to intercept surface drainage behind the fill area. The drainage area above the dike is 39 acres and the point storm of record could produce a peak flow of 28 cfs, based on a similar hydrologic analysis as described for the relocation fill (paragraph 89).

Paraho spent shale properties

124. The geotechnical properties of Paraho spent shale have been summarized in Appendix B. If it is assumed that future Paraho spent shale will be produced by the direct heat mode and will have a variability in particle size gradation similar to the WCC IV and WES samples (20 to 30 percent gravel and 3 to 20 percent fines, Figure B1), then the properties summarized in Appendix B can be used. The important geotechnical properties noted in Part II are shear strength, compressibility, and permeability (Table 4).

125. Shear strength. The assumed shear strength is based on the shear strength shown for samples WCC IV-1B and WES in Table B6. Assuming that the in situ density will range from a low density near the surface to standard effort density at depth (due to compression), the following average effective shear strengths for the fill mass are considered appropriate.

- a. Unsaturated total stress strength: $c = 1.6 \text{ kg/cm}^2$, $\phi = 34.5 \text{ deg}$
- b. Saturated effective stress strength: $c' = 0.8 \text{ kg/cm}^2$,
 $\phi' = 32.0 \text{ deg}$

126. Compressibility. The saturated compressibility of Paraho spent shale samples defined above (Figure B6) was on the order of 1 to 3 percent for standard to low compaction effort and vertical pressures equivalent to fill heights of 70 to 150 ft. An average compression value of 1 percent is assumed for unsaturated and 2 percent for saturated fill conditions. Most of the compression will occur during construction. Data are needed on long-term settlements and creep and can be obtained from the research fill.

127. Permeability. Data on saturated permeability, shown in Appendix B, indicate a range of 0.1 to 1000 ft/yr, depending on density and initial median grain size. Thus, saturated permeability would be expected to decrease with depth as compression, particle breakage, and density increased. Field compaction without moisture addition can produce in place dry densities nearly as high (96 to 97 percent) as maximum dry densities requiring 20 to 25 percent moisture (at 90 to 100 percent saturation). Once saturated, the permeabilities are significantly higher than when the material is compacted dry (paragraph B14). However, the main considerations are the amount of water the material can hold before free drainage occurs, the unsaturated water percolation rate, and the development of a saturated condition.

128. Vertical seepage. Free water was noted in compaction tests (WES 1979) at water contents of 23 to 25 percent (90 percent saturation). This high affinity for water is consistent with the porous nature of the spent shale pieces indicated by electron micrographs (WES 1979). Consequently significant percolation of water through the compacted material would be low until the material attained about 90 percent saturation. For example, the material at a dry density of 90 pcf could hold approximately 30 to 40 percent water by volume before free water would start to drain out. This volume corresponds to an accumulated surface inflow of 3 to 4 in. of rainfall (or snowmelt water) per foot of fill depth. Once this initial wetting (also by addition of moisture for compaction) occurs, then 0.3 to 0.4 in. of rainfall would cause free percolation of water through the wetted portion of the spent shale fill. This phenomenon is confirmed by in situ water contents of 14 to 20 percent in cool sections of the existing spent shale pile.

129. Surface erosion. Surface erosion of Paraho spent shale is not well documented. Observations of the existing pile indicate that significant water erosion of the coarse material on the steep slopes has not occurred (because of its high porosity, no sheet flow occurs). Wind erosion is also minor. When small whirlwinds crossed the slope, platy particles were lifted up and observed to tumble down the slope with a tinkling sound. Consequently, it appears that the coarse Paraho spent shale on slopes will not be subject to significant erosion. The research fill is needed to verify this conclusion.

TOSCO spent shale properties

130. For the conceptual design of a research fill, it is assumed that the TOSCO spent shale will have properties similar to those summarized in Table B7. Selected values of important engineering properties, based on low to standard effort compaction, are outlined below.

131. Shear strength. The WES tests on saturated specimens at dry densities of 96 to 98 pcf indicated effective stress shear strength parameters of $c' = 0$ to 1.0 kg/cm^2 and $\phi = 34$ to 37 deg . The strengths decreased respectively for specimens at molding water content, saturated, and saturated residual conditions. Unconfined compression specimens cured 28 days exhibited a 1.5 to 2.5 fold increase in strength. The results of tests for ARCO on as-compacted specimens with dry densities of 85 to 95 pcf indicated strength values of $c = 0.4$ to 1.4 and $\phi = 35 \text{ deg}$. These values agree with WES test values for as-compacted specimens. Based on these data, the following strength values are selected.

- a. Unsaturated total stress strength: $c = 1.0 \text{ kg/cm}^2$ and $\phi = 36 \text{ deg}$
- b. Saturated effective stress strength: $c' = 0.1 \text{ kg/cm}^2$ and $\phi = 35 \text{ deg}$

132. Compressibility. WES compression tests on saturated specimens did not show consistent results. The average compression was about 3 percent. Tests for ARCO on saturated, low-density specimens indicated relatively large compression values up to 16 percent upon saturation under a small vertical load of 0.7 psi and 6.5 to 30.5 percent under a load of 100 psi. The percent compression was related directly to molding dry density. Because the TOSCO spent shale could be compacted to near standard effort dry densities of 96 to 98 pcf, a compression value of 3 to 6 percent was selected for fill depths up to 150 ft.

133. Permeability. Saturated permeabilities from WES tests ranged from 2 to 5 ft/yr, indicating a nearly impervious condition. The permeability decreased slightly with increase in vertical pressure. A saturated permeability rate of 3 ft/yr is assumed. More importantly, free drainage occurred in WES tests at water contents above 25 percent by weight or 40 percent by volume. For initial saturation, 4 in. of rainfall per foot of fill at a dry density of 96 pcf would be required. However, the low saturated permeability indicates a relatively low drainage rate that could cause a soft, boggy surface condition to a depth of several feet. This condition was reported for the Colony test fill after ditch breaks and rainstorms (paragraph A18). Actual unsaturated infiltration rates and depths of seepage for the compacted spent shale are needed and can be obtained from the research fill.

134. Erosion resistance. The TOSCO spent shale was easily eroded on slopes of the Colony test fill (ARCO 1974). Erosion was aggravated by difficulties in compacting the slopes and the resulting loose fill. Thus, special provisions are needed to obtain well compacted slopes and for erosion protection of the finished slopes.

Criteria for meaningful results

135. A major objective for the research fills is to evaluate long-term mechanical stability and verify or modify design methodology. If a fill with a conservative design (e.g., 1V on 4H slopes) were built and exhibited no measurable distress, then the margin of safety would be unknown and nothing would be gained. Thus, the design margin of safety for mechanical stability needs to be low enough for significant deformations or creep to occur and enable the actual stability to be evaluated. This approach can be achieved by using a moderate factor of safety (e.g., 1.2 for mass sliding and 1.1 for shallow slides) with provisions for increasing the stability (e.g., by adding a stabilizing berm) if needed. Preliminary estimates of slope ratios for the moderate factors of safety suggested above are summarized in Table 9. The estimates were made using Bishop's simplified method (Tesarik and McWilliams 1982). The factors of safety for the more critical slope height of 360 ft were checked by using a computer program for the Corps of Engineers modified Swedish method (USACE 1970). Steep slopes are indicated in Table 9 for both the Paraho and TOSCO spent shale fills. In fact, it may be difficult to approach a low enough factor of safety to cause measurable deformations that are needed for evaluating field performance. It should be noted that cohesion

Table 9

Preliminary Estimate of Slope Ratios for Moderate Factors of Safety

Fill Condition	In Situ Density pcf	Shear Strength			Slope Height ft	Slope Ratio	Factors of Safety		Corps of Engineers Method**
		Cohesion kg/cm ²	Friction Angle deg	Simplified Bishop Charts*			Computer		
Paraho Spent Shale									
As compacted	110	1.6	34.5	160	1V on 1H	2.4	--	--	
					1V on 1.5H	>3.0	--	--	
				360	1V on 1H	1.7	1.7	1.6	
					1V on 1.5H	2.1	1.7	1.6	
Saturated, no seepage	120	0.8	32.0	160	1V on 1H	1.6	--	--	
					1V on 1.5H	1.9	--	--	
				360	1V on 1H	1.2	1.2	1.2	
					1V on 1.5H	1.5	1.6	1.5	
Saturated, with seepage	120	0.8	32.0	160	1V on 1H	1.4	--	--	
					1V on 1.5H	1.7	--	--	
				360	1V on 1H	0.9	0.6	0.5	
					1V on 1.5H	1.1	1.0	1.0	
					1V on 2H	1.3	1.4	1.4	
TOSCO Spent Shale									
As compacted	110	1.0	36.0	160	1V on 1H	2.0	--	--	
					1V on 1.5H	2.5	--	--	
				360	1V on 1H	1.5	1.5	1.4	
					1V on 1.5H	1.8	1.9	1.9	
Saturated, no seepage	120	0.1	35.0	160	1V on 1H	1.1	--	--	
					1V on 1.5H	1.4	--	--	
				360	1V on 1H	1.0	1.0	0.9	
					1V on 1.5H	1.3	1.2	1.2	
Saturated, with seepage	120	0.1	35.0	160	1V on 2H	1.1	--	--	
					1V on 2.5H	1.3	--	--	
				360	1V on 2H	1.2	1.2	1.2	
					1V on 2.5H	1.3	1.4	1.4	

* Tesarik and McWilliams 1982

** Modified Swedish method (USACE 1970)

values greater than zero increase the factor of safety for the steep slopes (compared to the flatter slopes required for the zero cohesion condition assumed for the relocation fill, paragraph 96). This concept is illustrated in Figure 31 for Paraho spent shale and shows the decrease in factor of safety with decrease in cohesion (1.6 to 0.8 kg/cm² for as-compacted and saturated conditions).

Influencing factors

136. Since infiltration and accumulation of water in the fill influences the mechanical stability, provisions are also needed for controlling the amount of infiltration and measuring its effect on stability. In addition, the variability of the spent shale material properties, placement density and moisture will influence short-term stability. Subsequent hydro-chemical interactions will influence the long-term deformations, shear strength and ultimate mechanical stability. Although these aspects are considered in the conceptual designs developed in this part, in situ measurements and monitoring of the research fill will be necessary to obtain quantitative information.

Conceptual Design for Combined Research Fill, West Gully

Fill geometry

137. A preliminary layout of the fill geometry for a combined research fill for Paraho and TOSCO spent shale is shown in Figure 32. A profile of the total fill sections is shown in Figure 33. The concept of an initial fill for Paraho material along the back portion of the west gully and a subsequent fill for TOSCO material in front of the Paraho fill was suggested as an alternative by D'Appolonia Consulting Engineers in a review of preliminary layouts. This plan has several advantages.

- a. Two types of spent shale can be accommodated with a minimum of influence of one spent shale material on the other.
- b. Paraho spent shale can be placed in a separate initial segment as it becomes available and advanced ahead of TOSCO spent shale.
- c. Any vertical or horizontal monitoring instrumentation or vertical drainage barriers (or horizontal drains) placed in the Paraho fill segment can be extended vertically or horizontally to the surface as the adjoining TOSCO fill segment is constructed.

Figure 31. Factor of safety versus slope height and slope ratio, Paraho fill

Figure 32. Plan location of combined research fill area for Paraho and TOSCO spent shales

Figure 33. Total sections of combined research fill for Paraho and TOSCO spent shales

The main disadvantage is that the Paraho fill slope below elevation 6150 ft would eventually be covered by the TOSCO fill. Consequently, long-term monitoring of surface erosion would not be possible in the lower segment of the Paraho fill. In addition the TOSCO fill would increase the mechanical stability of the Paraho fill. However, significant performance data could be obtained if the Paraho fill segment were constructed to a height of about 100 ft before placement of TOSCO spent shale was started.

Surface drainage

138. Surface drainage control measures are needed to collect rainfall and snowmelt runoff from the fill surfaces and adjacent slopes. The dike and diversion ditch above the fill area in the west gully will divert a major portion of the runoff from natural upland slopes. Runoff from the fill slopes can be collected in bench ditches, diverted to side ditches at the edge of the fill, and then routed to a collection pond.

139. Runoff diversion. Runoff above the dike for the point storm of 1.37 in. in 1 hour (para 91) will generate an estimated peak flow of 56 cfs at the dike (Figure 32). The total inflow is estimated to be 28,200 cu ft with a 15 cfs outflow diversion ditch (3 ft deep and 10 ft wide). A dike 20 ft high and 80 ft wide with a trapezoidal retention volume of 32,000 cu ft is needed to retain the excess inflow. The largest peak flow below the dike at the start of construction is estimated to be 22 cfs and would require a temporary diversion conduit (e.g., 8 ft wide by 4 ft deep, half round aluminum pipe) to route runoff across the fill. The maximum peak flow for side ditches along the edge of the fill is estimated to be 10 cfs and would require a 3-ft-deep by 7-ft-wide ditch. The ditches would need to be lined with sandstone riprap for erosion protection down the side of the 1V on 1.5H face slope. Berm ditches 2 ft deep and 4 ft wide would contain bench slope runoff.

140. Collection ponds. Maximum inflow volume to the collection pond for the Paraho fill (pond A, Figure 32) from the 24-hour, 2.5-in. rainfall of record is estimated to be 189,000 cu ft for total runoff. This quantity could be contained in a trapezoidal pond 15 ft deep and 120 ft long with a 70-ft-wide embankment. A second pond (pond B) for the TOSCO fill, located upstream from pond A would need to contain approximately 100,000 cu ft. A pond 10 ft deep and 70 ft long with a 60-ft-wide embankment is needed for this quantity of runoff. When the TOSCO fill is started, pond B would be constructed and the runoff from the Paraho fill could be diverted around pond B. A conduit beneath

the TOSCO fill would be required to recover any seepage coming out of the base of the Paraho fill. The pond embankments should be constructed of compacted surface soils and have 1V on 2H side slopes. Observation wells similar to those for the relocation fill (Figure 26) would allow detection and monitoring of any subsurface seepage escaping from the ponds. Because the Wasatch formation is impervious at the site, special linings for the ponds are not anticipated unless pervious sandstone strata are encountered during construction. In this case, a 3-ft-thick compacted soil lining may be required.

Erosion and infiltration protection

141. It is not anticipated that the compacted Paraho fill slope will be susceptible to any significant water or wind erosion, based on the performance of the existing pile. Placement and compaction of coarser material in the outer zone (e.g., 6 ft) of the fill face should provide adequate erosion protection. If this assumption is not verified during construction, then an alternative would be to add sandstone riprap, or to add the flatter stability berm (Figure 32) with a cement-treated, compacted outer shell and use this treatment for the remainder of the fill at the original slope of 1V on 1.5H. For the erosion-susceptible TOSCO spent shale, a 1V on 2H slope may be required with either sandstone riprap or a cement treated and compacted shell. The suggested benches, slopes and treatment techniques are illustrated in Figure 34. Infiltration of surface water can be minimized by the impervious soil layers also shown in Figure 34. As an alternate seepage barrier, a polyvinyl chloride liner material (rated as good for petroleum and refinery sludge, Dakessian et al. 1980) could be used. However, performance of such liners over a very long time is uncertain. These layers will provide positive control and collection of any downward percolation and will direct any leachate out to the bench ditches for sampling or removal by ditches to collection ponds. This scheme would isolate the majority of the total fill from infiltrating water. The soil layer or artificial liner could be sloped to convey downward seepage out into a covered collector for evaluation of unsaturated flow, permeability, and drainability (field capacity) for known water applications.

Expected fill deformations

142. Deformations of the wedge-shaped research fill may be significantly different than for long embankments where two-dimensional analyses are used. In the wedge-shaped fill, arching can occur across the gully. Arching will

Figure 34. Slope protection for outer slopes of Paraho and TOSCO fill sections

reduce vertical stresses and increase horizontal stresses along the gully. At the same time the horizontal stresses towards the fill face could increase along the gully in the center of the fill. Consequently, the magnitude and distribution of stresses will be more complex than in the two-dimensional case and could only be estimated, even with a three-dimensional stress analysis using a finite element technique and elastic parameters (Poisson's ratio and constrained modulus, Figure B9). This type of analysis would be premature until elastic properties are determined for the actual spent shales to be used for the research fills. In addition, the analyses should be verified against actual field deformation measurements. It is expected that most of the settlement and outward bulging of the slope will occur during construction, but the magnitude of bulging or creep cannot be reliably determined in this conceptual design.

143. The actual in situ stresses will influence changes in density, particle breakage, and permeability. These properties will have a major influence on long-term in situ reactions and stability. Consequently, it may be necessary to alter the design on the basis of field measurements as construction proceeds.

Field measurements and instrumentation

144. Tentative types of field measurements, methods, and instruments are summarized in Table 10. Surface hydrology data could be obtained from onsite recording rain gages and weirs in drainage ditches, sediment sumps, photographs, and profile surveys of ditches and bench drains after rainstorms or snowmelts. One year of base line data collection should be accomplished before construction starts. Infiltration rates, moisture changes, density changes, settlement/creep, horizontal movements, and temperatures could be measured as fill height increased and at selected bench locations after construction. Settlement, horizontal movement and deep leachate collection and water movement could be combined in a single boring as indicated previously in Figure 28 and paragraph 98. These installations are needed at a minimum of three benches up the middle of the fill. Horizontal modulus, stress-strain, strength, particle breakage, and bonding/cementing changes with time would require periodic undisturbed samples from borings. Leachate quantity, content, specific conductivity, and salinity measurements would require special installations including borings at selected benches as construction

Table 10
Suggested Research Fill Measurements

<u>Field Measurements</u>	<u>Measurement Method or Instrument Type*</u>
Surface Hydrology	
Rainfall or snowmelt	Rain gages
Surface runoff	Wiers
Erosion susceptibility	Photographs, line surveys
Sediment transport and deposits	Samplers and ground surveys
Infiltration rates	Double ring infiltrometer (ASTM D 3385) and subsurface seepage collection devices
Moisture changes	Tensiometers and nuclear moisture-density downhole gage
Permeability	
Unsaturated	Double ring infiltrometer with tensiometers or nuclear moisture-density probe
Saturated	Field permeability tests
Drainability (field capacity)	Seepage collection devices
Residual saturation	Tensiometers
Compression saturation	Deep buried tensiometers
Density changes	Nuclear moisture-density probe
Settlement or creep	Surface monuments and inclinometers with slip joints
Horizontal movement	Inclinometers
Horizontal modulus, stress strain, strength	Pressuremeter tests**
Changes in strength, particle breakage, particle bonding or cementation	Undisturbed samples
Leachate quantity and content	Field lysimeters and wells
Specific conductivity	Vertical gage string
Salinity	Salinity sensors
Temperature	Vertical or horizontal thermistor gage string or thermocouple probe

* EPA 1980a and Harbert et al. 1979.

** Strohm et al. 1978.

progressed. Coordination of research needs, sample locations, specific installations, and type of instrument needs to be accomplished with the environmental oil shale program research group. Instrument and collection installations in the lower Paraho fill would have to be extended vertically or horizontally (as appropriate) when the TOSCO fill reached the installation location.

Construction provisions

145. Research fill construction, including site preparation, drainage dike and ditches, collection ponds, transport, and compaction would be similar to construction of the relocation fill described in paragraphs 103 to 107 and 112 to 116. The designs are based on compaction of moisturized spent shale to 60 to 100 percent of standard effort density. Compaction to 100 percent of standard effort density would require water contents of 15 to 20 percent for Paraho and TOSCO. Adjustments in water content and compaction procedures will be required during construction depending on results of laboratory compaction tests on actual materials. The outer 10 ft of the fills should be compacted to 100 percent of standard effort density. Installation of instrumentation, field compaction and quality control tests (paragraph 114), and permeability tests during construction should be supervised by an experienced geotechnical engineer.

Construction costs

146. Based on estimated costs for the relocation fill, it is estimated that costs for the research fill will be six to eight dollars per cubic yard, including instrumentation installation. The total construction cost could amount to about five million dollars for each fill.

Conceptual Design for Separate Research Fills

Paraho research fill, west gully

147. If the existing spent shale pile is not relocated to the east gully of site 1, then separate research fills for Paraho and TOSCO spent shales could be constructed. The Paraho fill could be constructed in the east gully and the TOSCO fill constructed in the west gully. The main advantage is that long-term performance observations and field measurements would not be influenced by a different adjacent fill.

148. A separate research fill in the west gully for Paraho spent shale could start at elevation 5780 ft (see Figures 32 and 33) with the same initial face slope (1V on 1.5H) and alternate berm as previously discussed (paragraph 135). Design and construction would be the same as described in paragraphs 137 to 145.

TOSCO research fill, east gully

149. A separate research fill for TOSCO spent shale in the east gully would have the same layout as for the relocation fill (1V on 2H slope) with bench slopes of 1V on 1.5H as shown in Figure 34. The design would be the same as described previously in paragraphs 137 to 145. The cost for a separate research fill in the east gully would be increased by costs for an extension of the conveyor system to place material into the gully.

Conceptual Design for Raw Reject Shale

150. It is assumed that raw reject shale would be from the Paraho process plant, located on or adjacent to the DOE facility. Raw reject oil shale fines should be disposed of separately from retorted shale because of the autoignition hazard experienced at the Anvil Points disposal pile area. If raw reject fines are added to moisturized and cooled spent shale as planned in the Union project (UOC 1982), then a separate research fill should be constructed to determine the suitability of this method for combined disposal. The conceptual design for raw reject shale only is described first and then the possibility of a combined fill for raw reject shale added to the cooled, moisturized spent shale stream is discussed.

Raw reject shale site

151. Site 3 (Figure 12 and paragraph 65) in the saddle area adjacent to the Anvil Points Mine road is considered suitable for a research fill for raw reject shale fines. The site is covered with approximately 1 to 10 ft of clayey sand with gravel (Table 8). This topsoil should be removed and stockpiled for use as a final cover. The site can hold approximately 460,000 cu yd with a triangular shape and 1V on 2H side slopes. However, the total estimated fill volume needed is only 72,000 cu yd (paragraph 54). Past experience (Table 7) indicates that raw reject fines could amount to 25 percent of the shale to be retorted. Thus, for 875,000 tons of raw shale, 25 percent amounts to 218,000 tons and a compacted volume of 179,000 cu yd. Consequently, the raw reject shale fill is designed to accommodate 200,000 cu yd.

Fill design

152. Figure 35 shows a plan layout for a fill volume of 200,000 cu yd. Because of the drainage on the north side of the saddle area, a ditch around the north side of the fill would be required to collect runoff until the final soil cover was in place and vegetation growth established. A cross section and profile section of the fill are shown in Figure 36. Two collection ponds would be required as shown in Figure 36.

153. The shear strength of raw reject shale placed without significant compaction (e.g., compaction only by hauling and spreading equipment) is assumed to have a minimum friction angle, ϕ of 35 deg for a dry density of 80 pcf (paragraph B44). Slopes of 1V on 2.5H and 1V on 3H would have factors of safety, respectively, of 1.9 and 2.2. Saturated permeabilities at this condition are high (e.g., 10^{-2} cm/sec or 10^3 ft/yr, Table B8). The raw shale relocation fill at Anvil Points (WCC 1979) was constructed in 1981 with a 1V on 1.5H slope and covered with soil. This recent fill has not shown any significant erosion on settlement as of May 1983. Thus, the flatter slopes for the raw shale research fill should be stable over the long term.

154. The unsaturated permeability and field capacity are not known but would be expected to be high (i.e., considerable rainfall would be required before downward percolation becomes significant). Additional laboratory tests are needed to determine these parameters. Also needed is information on the effect of increased compaction or decrease in permeability.

155. If rainfall and snowmelt water accumulated in the top 12 in. of the fill, subsequent evaporation would leave significant salt deposits (see Table 1 for mineral types) and cause bonding or cementation of the fine-grained particles. This condition, shown in Figure 37, was observed for Paraho raw reject fines at the existing waste pile in the West Sharrard Drainage at Anvil Points. The colors of the mineral deposits were yellow to orange and white. Consequently, it is expected that a cemented zone of leached mineral deposits will form in a crust perhaps up to 2 ft thick. Subsequent rainfall would wash some of the surface mineral deposits downslope and into existing streams if collection ditches and ponds were not constructed to contain the runoff.

156. To minimize erosion of these surface mineral deposits, application of soil cover should be accomplished as the raw reject fill is constructed. A serrated (e.g., notched by dozer tracks) or longitudinal rutted slope would help key in and hold the soil cover layer.

Figure 35. Plan for raw reject shale research fill

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Figure 36. Sections for raw reject shale research fill

Figure 37. Evaporation deposits on raw shale fines block

Field observations

157. Field observations should include wells to monitor any accumulated infiltration at the base of the fill and any leakage below the collection ponds. Wells would be similar to those shown in Figure 28. The wells in the raw shale fill could also be used to measure settlement. Double ring infiltrometer tests with buried tensiometers should also be made during construction to measure unsaturated permeability and field capacity. Surface runoff samples and samples of wet surface material in the fill should be collected for characterization and evaluation of leachate. Observations during and after construction should be made to determine the type of evaporated mineral deposits, performance and stability of the soil cover, and amount and character of runoff for known rainstorms or snowmelts. A rain gage at the fill site and weirs in the ditches would be needed for the latter observations.

Construction

158. The rate of construction of the raw shale research fill would depend on retorting operations at Anvil Points and could conceivably take a number of years to complete. Thus, it may be necessary to construct the research fill in segments that can be stabilized with soil cover for several months of inactivity at the plant site. This schedule could be accomplished by starting the fill on one side of the saddle area (e.g., northwest) and route runoff to pond 1 initially. Once the saddle area was covered, the northeast ditch and pond 2 would have to be in operation.

Cost

159. A preliminary rough cost for the raw shale research fill construction is estimated at three dollars per cubic yard because of easy access for truck hauling. At this unit cost, the total fill cost could amount to \$600,000 plus instrumentation and field observations.

Conclusions

Methodology

160. The primary objectives in the design of surface disposal fills for processed and raw oil shales are: (a) to insure long-term physical stability, and (b) to prevent surface runoff, surface erosion, and possible subsurface seepage from degrading the water quality of streams and ground water below the fill, both during and after construction. Consequently, it is concluded that the analysis and design of spent shale disposal fills should be based on sound geotechnical engineering principles, an integrated approach that considers all influencing factors and conditions, considerable experience, and good judgment. However, no large engineered fills have been built and the experience base needed for spent shale fills is very limited for this highly variable material.

161. Even with the best available technology, prediction of the long-term engineering properties and performance of large fills is in its infancy. Consequently, an understanding of the source of variability of spent shale materials and its effect on the initial engineering properties is a first step in developing disposal fill design procedures. A second important step is the assessment of long-term changes in the properties of spent shale within a disposal fill. This assessment requires consideration of possible thermal, hydrochemical, and physical interactions within the fill and between the fill and site environment. The site environment is site-specific and depends on the geological, surface and subsurface hydrological, and geotechnical characteristics of the site.

162. It is apparent that the variability of spent shale materials is a direct function of variations in mineral and chemical composition of the raw shale and of the processes applied to the shale from mining to placement in the disposal fill. Each process changes the physical properties and retorting changes both the physical and chemical properties. The amount of decarbonization during retorting and the gradation after retorting have a dominant influence on the geotechnical properties. The amount of decarbonization affects the pozzolanic minerals available for subsequent particle bonding or cementation after moisturizing and compaction. The percentage of fine-grained particles (e.g., 0.074 mm) increases the tendency for bonding. Spent shale

gradations can vary from coarse (3 in. maximum size with 5 percent < 0.074 mm for Paraho spent shale) to fine (90 percent < 0.074 mm for Lurgi spent shale) and the gradation can vary considerably for a single process (e.g., 2 to 26 percent < 0.074 mm for Paraho spent shale). Gradation and in-place fill density influence unsaturated permeability, water retention before drainage, and saturated permeability. These properties influence the amount of surface water infiltration, potential for saturation at depth, possible leachate seepage out of the fill, and surface runoff.

163. Treatment of the spent shale prior to disposal, the disposal scheme, and possible codisposal and use of treated waste water for cooling, dust suppression, and conditioning of the spent shale for compaction will have a dominant influence on initial and long-term properties and interactions within the fill. The design must include alternatives that can be implemented during the life of the project, in case performance observations indicate that safety criteria are in jeopardy.

164. The lack of experience for large spent shale fills means that initial designs must be updated and refined during spent shale production and disposal. Refinements in design geometry, construction procedures, and instrumentation and monitoring provisions should be based on tests to develop actual engineering properties and observed fill performance. Conservative assumptions are required until a viable experience base can be developed. The immediate need is to define the variability of spent shales caused by processing and disposal and to develop an understanding of subsequent interactions within the disposal fill and between the disposal fill and site environment that influence the ultimate engineering properties and long-term performance of the disposal fill.

Current technology

165. The current technology for the design and construction of spent shale disposal fills has not been proven by experience since no large engineered fills have been constructed. A major problem is the large quantities of spent shale that will be generated for surface disposal and the lack of available sites other than large gulches in the rugged oil shale country of the western United States. The conceptual designs developed include research fills to obtain needed information on quantity of infiltration, potential leachate seepage, and mechanical stability (e.g., RBOSC 1981). A unique design for control and bypass of natural flood drainage beneath a large

proposed disposal fill has also been developed and the project includes a research fill (UOC 1982). Construction and long-term monitoring of research fills are needed to establish an experience base to improve and extend current technology.

Geotechnical properties

166. Research studies have developed considerable information on the geotechnical properties of compacted Paraho and TOSCO and to a lesser extent Lurgi and Union B spent shales. However, no extensive information has been developed on spent shales codisposed with treated process water for cooling and moisturizing and with reject raw shale fines and process dust. In addition, little information has been developed on the water retention capacity and unsaturated permeability of compacted spent shales. While the influence of curing time and temperature on gain in strength has been developed for Paraho, TOSCO, and Lurgi spent shales using tap or distilled water, no information is available for the effect of treated waste water. Thus, considerable laboratory research is needed to establish basic information on these geotechnical properties.

Anvil Points relocation fill

167. It is concluded that the ridge and gulch topography of the Anvil Points facility severely limit good sites for a possible relocation fill for the existing spent shale pile. A secondary gulch (site 1) connected to the large Sharrard drainage was selected as the most economical and environmentally suitable location. Because of the heterogeneity of the existing spent shale material and expected variability of geotechnical properties, design slopes of 1V on 2H and an alternate of 1V on 3H with benches were selected. Horizontal layers to restrict vertical infiltration were included. Hot zones found in the existing pile will require spraying with water during excavation to cool and moisturize the hot material. Construction of the relocation fill will require construction of a haul road and conveyor system to transport the processed spent shale to the relocation fill.

Research fills

168. Because of the variability of spent shales, it was concluded that only conceptual designs could be developed initially and would have to be refined when properties of the actual spent shales to be used were determined. Conceptual designs for combined and separate research fills for Paraho and TOSCO spent shales were developed. To provide meaningful results, steep

slopes are needed for detecting deformations and defining the margin of safety with regard to mechanical stability. An alternative for stability berms was included in case the steep slopes become unstable. It was apparent that instrumentation and field monitoring need to be coordinated with the research community to insure that all research needs are incorporated. It was also concluded that the research fills can provide needed information on erosion resistance of spent shale face slopes, unsaturated permeability, water retention, depth of infiltration and accumulation of free water at depth, potential for seepage of leachate out of the fill, important hydrochemical and thermal interactions, and long-term performance. Research fills are the best means for advancing the methodology and improving current technology for the design and construction of spent shale disposal fills.

Recommendations

169. Based on the results of the study, the following recommendations are made:

- a. A laboratory research program should be initiated to develop information on the basic geotechnical properties of compacted spent shale codisposal mixtures with emphasis on the water retention capacity, unsaturated permeability, compression-pressure and temperature relationships, and the influence of curing time and temperature on shear strength. Trends of geotechnical properties in relation to gradation and compacted density need to be established.
- b. The conceptual research fill designs developed in this study should be refined and constructed to provide needed information on in situ properties and long-term performance. Alternatively, research fills planned by others (e.g., the Union Oil Company planned research fill) should be augmented to obtain the needed information to advance the methodology and technology for design and construction of surface disposal fills, especially for codisposal of spent shales with treated waste water, raw shale fines, and process dust.

REFERENCES^a

- Allred, V. Dean, Ed. 1982. Oil Shale Processing Technology, The Center for Professional Advancement, East Brunswick, N. J.
- Banks, Don. 1982. "Geotechnical Siting Considerations," Proceedings of the Symposium on Low-Level Waste Disposal, NUREG/CP-0028, CONF-811218, Vol. 1, Oak Ridge National Laboratory, Oak Ridge, Tenn.
- Barosh, P. J. 1969. "Use of Seismic Intensity Data to Predict the Effects of Earthquakes and Underground Nuclear Explosions in Various Geologic Settings," Bulletin 1279, 1969, U. S. Geological Survey, Washington, D. C.
- Bloomfield, R. A., and Stewart, B. M. 1981. "Design Parameters for Oil Shale Waste Disposal Systems," Bureau of Mines Report of Investigation, 1981 Report No. RI 8544, U. S. Department of Interior.
- Bloomsburg, G. L., and Wells, R. D. 1978. "Seepage Through Partially Saturated Shale Wastes," Final Report, University of Idaho, Report No. Bu Mines OFR 63-79, September 1978, Contract H0252065, Office of Assistant Director-Mining, Bureau of Mines, Department of Interior, Washington, D. C. NTIS (PB 297 300/AS).
- Bureau of Mines. 1972. "Final Environmental Statement, FES 72-3, Oil Shale Retort Research Project, Anvil Points, Colorado," February 18, 1972, Bureau of Mines, U. S. Department of the Interior. NTIS (PB 203 318-F).
- Colorado Department of Health. 1982. "Technical Guidelines on Siting of Hazardous Waste Disposal Sites," Waste Management Division, Office of Health Protection, Denver, Colo.
- Corps of Engineers. 1977. "Earthquake Design and Analysis for Corps of Engineers Dams," Engineer Regulation 1110-2-1806, 30 April 1977, Washington, D. C.
- D'Appolonia Consulting Engineers, Inc. 1975. Engineering and Design Manual, Coal Refuse Disposal Facilities, prepared for U. S. Department of Interior, Mining Enforcement and Safety Administration, Washington, D. C. Available from U. S. Government Printing Office, Washington, D. C. 20402, Stock No. 024-019-00012-8.
- Dakessian, S., Fong, M., and White, R. 1980. "Lining of Waste Impoundment and Disposal Facilities," Metrecon, Inc., Contract No. 68-03-2173, Report No. EPA/530/SW-870C, September 1980, U. S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati, Ohio. NTIS (PB81-166365).
- de Nevers, N., et al. 1978. "Analysis of the Environmental Control Technology for Oil Shale Development," U. S. Department of Energy (DOE), Report No. C00/4043-1, February 1978, Contract No. EY-76-S-02-4043 with College of Engineering, University of Utah, Provo.

^a References available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, are annotated with NTIS (Publication Number).

- Department of Energy. 1981. "Peer Review of: Oil Shale Research in Solid Waste Management," May 1981, DOE Office of Oil Shale and Office of Health and Environmental Research, Washington, D. C.
- Donnell, J. R. 1969. "Paleocene and Lower Eocene Units in the Southern Part of the Piceance Creek Basin, Colorado," U. S. Geological Survey Bulletin 1274-M, Branch of Distribution, U. S. Geological Survey, Alexandria, Va.
- East, J. H., and Gardner, E. D. 1964. "Oil Shale Mining, Rifle, CO, 1944-56," Bureau of Mines Bulletin 611, U. S. Department of the Interior, Washington, D. C.
- Ecker, R. M., Walters, W. H., and Skaggs, R. L. 1979. "Hydrology Monitoring Program, Rifle Oil Shale Facility Site, Colorado," Report PNL-3220/UC-91, Pacific Northwest Laboratory, Richland, Wash.
- Environmental Data Service. 1973. "Earthquake History of the United States," J. L. Coffman and C. A. von Hake, Eds., Department of Commerce, National Oceanic and Atmospheric Administration, Pub 41-1.
- Environmental Data Service. 1979. "Earthquake History of the United States," J. L. Coffman, Ed., Department of Commerce, National Oceanic and Atmospheric Administration, Pub 41-1, 1971-76 Supplement.
- Environmental Protection Agency. 1980a. "Energy Project Review and Permitting Status Report, Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming," September 1980, EPA, Denver, Colo.
- Environmental Protection Agency. 1980b. "Environmental Prospective on the Emerging Oil Shale Industry," by EPA Oil Shale Research Group, Edward R. Bates and Terry L. Thoem, editors, Report No. EPA-600/2-80-205a, Industrial Environmental Research Laboratory, Office of Research and Development, U. S. Environmental Protection Agency, Cincinnati, Ohio. (ORD Publications, CERI, US EPA, 26 W. Clair St., Cincinnati, OH 45268, Stock No. 625/9-81-005).
- Fenner, J. L., Pilz, J., and Nelson, J. D. 1982. "Spent Oil Shale Waste Management," Preprint 82-032, Las Vegas, Nev., April 26-30, 1982 Convention, American Society of Civil Engineers, New York.
- Fred C. Hart Associates, Inc. "Review of DOE Report, Oil Shale Report, Extinction and Stabilization Plan Anvil Points, Colorado-NVO-206," August 15, 1979, U. S. Department of Energy, Laramie Energy Technology Center, Laramie, Wyo.
- Garland, T. R., Wildung, R. E., and Zachara, J. M. 1981. "A Case Study of the Effects of Oil Shale Operations on Water Quality, I. History of Operations and Hydrologic Controls," Draft Report PNL-SA-9716, February 1982, Pacific Northwest Laboratory, Richland, Wash.
- Garland, T. R., Wildung, R. E., and Harbert, H. P. 1979. "Influence of Irrigation and Weathering Reactions on the Composition of Percolates from Retorted Oil Shale in Field Lysimeters," Report PNL-SA-7473 (presented at 12th Annual Oil Shale Symposium, Golden, Colo.), Pacific Northwest Laboratory, Richland, Wash.

- Harbert, H. P. III, Berg, W. A., and McWorter, D. B. 1979. "Lysimeter Study on the Disposal of Paraho Retorted Oil Shale," August 1979, Colorado State University, under grant No. R803788 from Industrial Environmental Research Laboratory, Cincinnati, Ohio, Report No. EPA-600/7-79-188.
- HEC. 1976. "Storage, Treatment, Overflow, and Runoff Model, 'STORM'," July 1976, U. S. Army Engineer Hydrologic Engineering Center, Davis, Calif.
- HEC. 1981. "Computer Program 723-X6-L2010, HEC-1, Flood Hydrograph Package, Users Manual," September 1981, US Army Engineer, Hydrologic Engineering Center, 609 Second Street, Davis, CA 95616.
- Heistand, R. N., Atwood, R. A., and Richardson, K. L. 1980. "Paraho Development Corporation," Paraho Environmental Data, Part I. Process Characterization, Part II. Air Quality, Part III. Water Quality, Report No. DOE/EV-0086, UC 66e & 91, June 1980, U. S. Department of Energy, Office of Environment (MS E-201 GTN), Washington, D. C.
- Hessel, D., and Strasser, G. 1982. "Western Oil-Shale Development: A Technology Assessment, Volume 4: Solid Waste from Mining and Surface Retorts," Report PNL-3830, Vol 4, UC-11, Pacific Northwest Laboratory, Richland, Wash.
- Holtz, W. G. 1981. "Compaction and Related Properties of Retorted Oil Shale," Preprint 81-013, May 11-15, 1981 National Meeting, New York, American Society of Civil Engineers, New York.
- Hynes, J. L., and Sutton, C. J. 1980. "Hazardous Wastes in Colorado, A Preliminary Evaluation of Generation and Geologic Criteria for Disposal," Information Series 14, Colorado Geological Survey, Department of Natural Resources and Colorado Department of Health, Denver, Colo.
- Kilkelly, M. K., Berg, W. A., and Herbert, H. P. III. 1981. "Field Studies on USBM and Tosco II Retorted Oil Shales: Vegetation, Moisture, Salinity, and Runoff, 1977-1980," June 1981, Colorado State University under grant No. CR804719 for Industrial Environmental Research Laboratory, U. S. Environmental Protection Agency, Cincinnati, Ohio, Report No. EPA 600/7-81-139.
- Kirkham, R. M., and Rogers, W. P. 1981. "Earthquake Potential in Colorado, A Preliminary Evaluation," Bulletin 43, Colorado Geological Survey, Department of Natural Resources, Denver, Colo.
- Knight, M. J., et al. 1981. "The Disposal and Reclamation of Spent Oil Shale from the Green River Formation," Volume VI of An Assessment of Energy-Related Development in the Western Oil Shale Region, Argonne National Laboratory, Draft, July 1981, for U. S. Department of Energy, Laramie Energy Technology Center, Laramie, Wyo., Contract No. 31-109-Eng-38.
- Krinitzsky, E. L., and Chang, F. J. 1977. "State-of-the-Art for Assessing Earthquake Hazards in the United States, Specifying Peak Motions for Design Earthquakes," U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

- Lipman, S. C. 1975. "Union Oil Company Revegetation Studies," Proceedings of the Environmental Oil Shale Symposium, Quarterly of the Colorado School of Mines, Vol 70, No. 4, October 1975, Golden, Colo.
- Lutton, R. J., et al. 1982. "Tests for Evaluating Sites for Disposal of Low-Level Radioactive Waste," NUREC/CR-3038, U. S. Nuclear Regulatory Commission, Washington, D. C.
- McKell, C. M., et al. 1978. "Revegetation Studies for Disturbed Areas and Processed Shale Disposal Sites," Final Report on Summary and Recommendations, Utah State University, Institute for Land Rehabilitation to White River Shale Project.
- Meade, R. B., and Dickinson, R. M. 1984. "Development of a Geotechnical Stabilization Plan for the Existing Retorted Shale Pile, Anvil Points, Colorado," Report (in publication), Technical Information Center, U. S. Department of Energy, Washington, D. C.
- Mildner, W. F. 1982. "Erosion and Sediment," Bulletin of the Association of Engineering Geologists, Vol XIX, No. 2, Allen Press, Inc., Lawrence, Kans.
- Ng-A-Qui, Norman, T., and Taylor, M. J. "Spent Shale Disposal Pile Analysis and Design," presented at the Eastern Oil Shale Symposium, Lexington, Ky., 11-13 October 1982, D'Appolonia Consulting Engineers, Englewood, Colo.
- Nevada Operations Office. 1979. "Oil Shale Project, Extinguishment & Stabilization Plan, Anvil Points, CO," U. S. Department of Energy, Report NVO-206, July 1979.
- Pacific Northwest Laboratory. 1981. "Terrestrial Effects of Oil Shale Development" in Part 2 Ecological Sciences, Pacific Northwest Laboratory Annual Report for 1980 to the DOE Assistant Secretary for Environment," Report PNL-3700 PT2/UC-11, Pacific Northwest Laboratory, Richland, Wash.
- Paraho Development Corporation. 1980. "Paraho Environmental Data, Part IV Land Reclamation and Revegetation," Report No. DOE/EV-0086, U. S. Department of Energy, Office of Environment (MS E-201 CTN), Washington, D. C.
- Paraho Development Corporation. 1981. "Design and Plan for Demonstration of a Surface Oil Shale Retorting Module," Preliminary Description of Proposed Action, April 1981, Task 7: NEPA Compliance, submitted in response to DOE Cooperative Agreement No. DE-FC03-80ET14103, PDC, Grand Junction, Colo.
- Peterson, K. K., Ed. 1982. "Oil Shale, The Environmental Challenges II," Proceedings of an International Symposium, August 10-13, 1981, Vail, Colo., Colorado School of Mines Press, Golden, Colo.
- Radian Corporation. 1981. "Soil Resources, Anvil Points Oil Shale Facility, Garfield County, Colorado," Final Report, September 1981, Contract DE-AC20-80LC10443, U. S. Department of Energy, Laramie Energy Technology Center, Laramie, Wyo.

Rio Blanco Oil Shale Company. 1981. "Tract C-a, Modification to the Detailed Development Plan, Lurgi Demonstration Project," submitted February 1981 to U. S. Geological Survey Deputy Conservation Manager - Oil Shale by Rio Blanco Oil Shale Company, Aurora, Colo.

Rutherford, D. W. 1979. "A Geochemical Baseline Survey of Selected Toxic Elements in Surficial Materials in the Vicinity of the Paraho Demonstration Oil Shale Processing Plant, Anvil Points, Garfield County, Colorado," Thesis T-2232, Colorado School of Mines, Golden, Colo.

Sharma, D., and Asgian, M. 1981. "Disposal of Retorted Oil Shale: Principal Issues and Their Management," Preprint SME-AIME Fall Meeting, Denver, Colo., 18-20 November 1981, Society of Mining Engineers of American Institute of Mining Engineers, Littleton, Colo.

Stollenwerk, K. G., and Runnells, D. D. 1981. "Composition of Leachate from Surface-Retorted and Unretorted Colorado Oil Shale," Environmental Science and Technology, Vol 15, No. 11, November 1981, American Chemical Society.

Strohm, W. E., Jr., Bragg, G. H., Jr., and Zeigler, T. W. 1978. "Design and Construction of Compacted Shale Embankments, Vol 5, Technical Guidelines," Report No. FHWA-RD-78-141, Federal Highway Administration, Washington, D. C.

University of Colorado at Denver. 1983. "Oil Shale Environmental Research and Coordination; Progress Report," Contract No. EV-10298, U. S. Department of Energy, University of Colorado at Denver, Denver, Colo.

U. S. Army Corps of Engineers. 1970. "Stability of Earth and Rock-Fill Dams," Engineer Manual EM 1110-2-1902, Washington, DC.

U. S. Army Engineer Waterways Experiment Station. 1979. "Geotechnical Properties of Oil Shale Retorted by the Paraho and Tosco Processes," Final Report, November 1979, Technical Report GL-79-22, Vicksburg, Miss., Bu Mines OFR 47-81, Contract No. HO 262064. NTIS (ADA 082317 A12).

Ward, J. C., and Reineck, S. E. 1972. "Water Pollution Potential of Snowfall on Spent Oil Shale Residues," June 1972, Colorado State University, under grant No. G0111280, for Laramie Energy Technology Center, Laramie, Wyo.

Wasko, A. 1982. "Situation Report, Oil Shale's Winding Path," Shale Country, Vol 4, No. 1, January 1982, Mountain Empire Publishing, Denver, Colo.

Weeks, J. B., et al. 1974. "Simulated Effects of Oil-Shale Development on the Hydrology of Piceance Basin, Colorado," Geological Survey Professional Paper 908, U. S. Geological Survey, Alexandria, Va.

White River Shale Oil Corporation. 1981. "White River Shale Project, Detailed Development Plan, Oil Shale Tracts Ua and Ub," Vol I and II, White River Shale Oil Corp., Salt Lake City, Utah.

Wildung, R. E., and Zachara, J. M. 1980. "Geochemistry of Oil Shale Solid Waste Disposal," paper presented at symposium: Oil Shale, the Environmental Challenges, Vail, Colo., 11-14 August 1980, Report PNL-SA-8764, Pacific Northwest Laboratory, Richland, Wash.

Woodward-Clyde Consultants and Development Engineering, Inc. 1976. "Disposal of Retorted Oil Shale from the Paraho Oil Shale Project," Final Report, Dec 1976, Report No. Bu Mines OFR 27-77, Contract No. J0255004, Office of Assistant Director-Mining, Bureau of Mines, U. S. Department of the Interior, Washington, D. C. NTIS (PB 263 793).

Woodward-Clyde Consultants. 1979. "Raw Shale Fill, Anvil Points, Colorado," September 1979, prepared for Development Engineering, Inc., Grand Junction, Colo.

Woodward-Clyde Consultants. 1980. "Conceptual Design Criteria for a Retorted Shale Disposal Facility, Paraho Module Project, Phase I," December 1980, prepared for Paraho Development Corporation, Salt Lake City, Utah.

APPENDIX A: CURRENT TECHNOLOGY ON DISPOSAL
FILLS FOR PROCESSED OR RAW OIL SHALE

A1. A comprehensive review of environmental problems in spent oil shale disposal and current technology for the design of disposal sites has been made by Knight et al. (1981). An analysis of environmental control technology was developed by de Nevers et al. (1978). An Environmental Prospectus has also been published by the EPA (EPA 1980a). Detailed development plans for tracts Ua and Ub (WRSOC 1981), tract Ca demonstration project (RBOSC 1981), and the Parachute Creek Shale Oil Program (Union Oil Company Permit Application, UOC 1982) describe site-specific plans for disposal sites. Pertinent information from these references is summarized in this appendix. Applicable information on lining of waste impoundments and disposal sites (Dekesslan et al. 1980) is also included.

Environmental Problems

A2. The following environmental hazards associated with disposal fills for processed oil shale and storage fills for raw oil shale (such as raw reject shale from the Paraho process) have been identified (de Nevers et al. 1978 and Knight 1981):

- a. Contamination of local surface waters and ground water by water and wind erosion of fill surfaces and by leaching of salts and toxic chemicals from fill materials.
- b. Increased sedimentation of local surface waters from water erosion of fill surfaces, disturbed natural soils, and stock-piled topsoil in the disposal area.
- c. Mass movement of fill materials by water erosion, by collapse or slumping of unstable fills, or by combustion of materials leading to instability.
- d. Transfer of toxic chemicals to covering soil and plants by capillary rise and vegetative uptake.

A3. Measures to minimize these hazards include the following:

- a. Locating disposal sites away from major drainages or large gulches where flash floods or debris flows could impinge on disposal fill slopes.
- b. Selecting disposal fill sites where runoff from natural soil slopes can be controlled and routed around and away from disposal fill slopes.

- c. Selecting disposal fill sites to provide a maximum (1) of impervious foundation depth, (2) quantity of suitable surface soils for impervious cover and surface reclamation and collection ponds or catchment basins, and (3) area for stockpiling these soils.
- d. Cooling spent shale to prevent subsequent autoignition and facilitate reclamation and revegetation of final fill slopes.
- e. Specify sufficient compaction and construction quality control during placement of the fill to decrease permeability and prevent excessive long-term settlement or slumping of fill slopes.
- f. Provide for long-term positive collection and containment or treatment of surface water runoff and internal seepage or leachate from the disposal fill.
- g. Providing positive grades for fill surfaces and collection ditches to prevent ponding of rainfall or snowmelt on disposal fill surfaces and minimize infiltration.
- h. Designing fill slope grades to accommodate long-term reclamation measures and to ensure structural stability.
- i. Specifying proven reclamation measures to minimize long-term erosion of disposal fill surfaces and slopes and disturbed natural soil surfaces.
- j. Provide for long-term monitoring to ensure compliance with environmental objectives and restraints.

Site Selection and Characterization

A4. Potential disposal sites which meet economical criteria such as storage capacity, proximity to retort facilities, accessibility, and feasibility of disposal fill construction must be evaluated to establish that the environmental objectives can be met. The evaluation should be based on the types of information and data outlined in the state of Colorado technical guidelines.

Surface geology

A5. A primary requisite in site selection is data on the type, distribution, thicknesses, quantities, and engineering properties of surficial soils. These data are needed to determine the quantities of suitable soils that could be used for (a) an impermeable base beneath pervious spent shale fill, (b) an impermeable cover to retard infiltration and to support vegetation in reclamation of final fill surfaces and slopes, and (c) construction of containment ponds for runoff and leachate water from the spent shale fill. The origin of surface soils is important in detecting debris flow deposits that could

collapse upon wetting if left under holding ponds. Identification of other hazards such as potential mass movements (unstable rock and soil or debris deposits on steep slopes) is also important. Available U. S. Geological Survey surface geology maps on 7-1/2 minute quadrangle sheets and special topographic maps and geologic reports (Donnell 1969 and Weeks et al. 1974) and soil surveys (Radian Corp. 1981) provide a basic information for planning needed field investigations.

Subsurface geology

A6. Data on the type and permeability and geohydrology of subsurface soil and rock strata is important in assessing the need for special measures to prevent possible migration of disposal fill seepage or leachate into the ground water. Identification of the location and orientation of major fractures, joints, planes of weakness, and faults that could influence disposal fill stability and ground-water movement is essential. Another important need is the location of any large subsurface voids (cavities or mine tunnels) that might collapse under the additional weight and cause subsidence of the disposal fill. Borings and backhoe trenches are the primary means for subsurface investigations.

Hydrology

A7. Characterization and monitoring of precipitation and surface water drainage is necessary to determine the location and size of surface runoff diversion measures. A large-scale topographic map and local precipitation records if available with maximum short duration and 100-year record rainfall can be used in preliminary studies.

Ground water

A8. Identification, characterization, and monitoring of ground-water levels and aquifer properties under the disposal site are needed to assess the potential of disposal fill leachate reaching the ground water. This information impacts on the need for special measures to prevent ground-water contamination.

Base line studies

A9. Data on chemical species and amounts in natural soils and rock strata, surface water runoff, and ground water are needed as background information. These data are used in monitoring potential contamination during and after disposal fill construction.

Site topography

A10. One of the most important considerations in site selection is the topography. Canyon (or gulch) fills have been the major type considered because canyons are the most prominent feature of the Colorado oil shale region. Knight et al. (1981) list several advantages for disposal of spent shale in steep-sided canyons: (a) comparatively small open face to stabilize, (b) some protection from wind erosion, (c) majority of fill hidden from view, and (d) large (deep) disposal volume relative to surface area. However, the major criticism to canyon disposal is that major drainages would be blocked. Special measures to route natural drainage through or around the disposal fill would not be fail safe, nor maintained for the required centuries after completion of the disposal and reclamation operations. Disposal fill placement starting along the side of a wide canyon and isolated from the main drainage or started at the head of canyon and extended down canyon are feasible. However, water-bearing strata exposed in the canyon would be blocked. For significant seepage flows, special subsurface drainage measures would be required to intercept the natural seepage, isolate it from the disposal fill, and carry it along the fill-canyon interface to an outlet below the disposal fill face. Such a drainage system is feasible based on earth and rockfill dam experience where long-term monitoring of piezometers (for the life of the project) certifies adequate performance.

A11. An example of a viable disposal plan (WRSOC 1981, Vol 1) utilizes a side canyon (one of a series of connecting and irregular small canyons) for an initial Phase I disposal site with fill placed on a 5 percent slope advancing down grade with final slopes of 1V or 4H as shown in Figure A1. A retention dam would contain all runoff from the disposal area. In Phase II, the disposal fill would be extended from one side of the Phase I fill out across the central section of the main canyon. A large retention dam at the mouth of the main canyon would contain all runoff. In the final phase, Phase III, the disposal fill would be extended down to the mouth of the main canyon. Impermeable strata underlying the area isolate the disposal fill from a deep aquifer. In the Union plan (UOC 1982) a special rock drain has been designed to pass flow from the East Fork of the Parachute Creek under the disposal fill. The disposal fill will ultimately cover a 2.3-mile segment of the East Fork, with a 10-ft-thick compacted envelope of spent shale encapsulating uncompacted spent shale. Laboratory tests for codisposal designs used simulated waste

Figure A1. Processed shale disposal, Phase I (WRSOC 1981)

water for compaction of test specimens. Collection ditches will carry surface runoff to two ponds at the downstream end for evaporation. Spent shale fill slopes will be 1V on 3.5H with 18-ft-wide benches at 35-ft elevation increments.

Design Concepts

Basic objectives

A12. The basic objectives in the design of spent shale disposal fills are: (a) to prevent contamination of surface water, ground water, and the ecological system, and (b) to insure long-term stability against wind and water erosion, slope movement (creep or slumping), and mass movement (collapse, excessive settlement and landslides). Extensive laboratory and field research (e.g. DOE 1981; EPA 1980a, Garland et al. 1981, 1979; Harbert et al. 1979, Kilkelly et al., 1981; PNL 1981; Stollenwerk and Runnells 1981; Ward and Reinecke 1972; and Wildung and Zachara 1980) have demonstrated that leachate and surface water from spent oil shale and reject raw oil shale contain elevated pH and salt levels and toxic chemical species. Thus, the potential for pollution is well established based on laboratory and small-scale disposal fills and pilot studies. However, no commercial scale spent shale or raw reject shale fills have been constructed. The amount of leachate from a disposal fill and the severity of contamination can be hypothesized, but has not been demonstrated for large fills. The main unknown is the amount of infiltration from rainfall and snowmelt that is free to percolate through the fill (after evaporation) and reach the base or seep out of the fill. Until this unknown is established and can be quantified, design must provide for the monitoring of leachate, collection, containment, and safe disposal. The amount of surface water runoff is also unknown and is dependent on infiltration amounts (depending on the slope angle and revegetation scheme). Consequently, the design must include provisions for runoff collection, containment, and safe disposal.

Fill slopes

A13. The design of spent shale disposal fill slopes to insure long-term stability against erosion and to accommodate revegetation has led to the proposed use of relatively flat slopes of 1V on 4H and 1V on 3.5H (WROSP 1981, RBOSCO 1981, and UOC 1982). These flatter slopes would also satisfy a very

conservative design approach that assumes complete saturation of the fill. Control of slope drainage is accomplished with benches and collection ditches. It is highly unlikely that a significant depth of fill will become saturated under the low levels of precipitation and relatively high evapotranspiration rates in the oil shale region (Knight et al. 1981 and EPA 1980a). In one case (UOC 1982) the disposal fill will be covered by a 10-ft layer of nearly compacted (modified effort) spent shale. However, Fenner et al. (1982) present a scenario based on surplus water (December to mid-February at the 6000-ft elevation) from snowmelt that could infiltrate and lead to an eventual saturation zone in a disposal fill. Slopes as steep as 1V or 1.5H are theoretically stable for the properties of the PARAHO process coarse spent shale (WCC 1980). The exterior shell for this steep a slope would be constructed of moistened and highly compacted spent shale with a 3-ft-thick face of cement-stabilized compacted spent shale. (A suggested alternate was well graded rock riprap or riprap over a filter blanket of rock fines and rock spalls).

Compacted fill properties

A14. One important property of compacted spent shale is permeability since this parameter controls infiltration and seepage. Reported values of permeability (EPA 1980a) for Paraho, USBM, and Tosco II retorted shale range from 1.6×10^1 to 6.4×10^4 cm/yr (0.5 to 2 ft/yr or 0.5×10^{-6} to 2×10^{-6} cm/sec). The laboratory permeability of Tosco material (WES 1979) decreased from 1.0 to 0.1 ft/year with increased compaction effort. A summary of comprehensive laboratory and field studies (Appendix B) on Paraho material shows a significant influence of gradation, age, and degree of decarbonization on permeability for comparable compaction efforts. The permeability ranged from 1 to 1000 ft/yr for Paraho samples of different age, gradation, and decarbonization. Consequently, compacted spent shale can range from impervious to very pervious depending on retorted characteristics and subsequent treatment until delivered to the fill. An important finding (Holtz 1981) is the need for water during compaction to achieve low permeabilities. The shear strength and consolidation (or compression) characteristics of compacted spent shale are important in designing mechanically stable slopes and assessing settlement and creep magnitudes. Both the Paraho and Tosco (WES 1979) exhibited high strengths (friction angle, ϕ of 33 deg for Paraho and 37 to 43 deg for Tosco) even at low compaction efforts. Both Paraho and Tosco exhibit self-cementing characteristics (3 to 8 fold strength increase for Paraho

material and 1.5 to 3 fold strength gain for TOSCO material after 28 days). The increase in strength is dependent on retorting time (Bloomfield and Stewart 1981). The compression characteristics of compacted Paraho and Tosco retorted shale samples (WES 1979) are similar to dense rockfill and sands and indicate that large settlements would not occur.

A15. The Lurgi processed oil shale (RBOSC 1981) is a nonplastic, silt size material (90 percent finer than the No. 200 sieve) with a specific gravity (of solids) ranging from 2.61 to 2.68. The dry density under standard effort compaction is 80 pcf and relatively insensitive to water content. The unconfined compressive strength generally increased with increased curing time; molding water content and curing temperature have a significant influence on strength. The drained triaxial shear strength (for specimens formed at 20 percent water content) showed a large increase in cohesion (20 psi to 140 psi) and a decrease in friction angle (30 deg to 12 deg) for zero and 28-day (at 70°F) curing times. The coefficient of permeability decreased from about 4×10^{-4} to 3×10^{-6} cm/sec for curing times of 0 to 28 days. Tests on Lurgi spent shale slurry (60 percent solids, 40 percent water) cured at 70°F indicated the following shear strength and consolidation properties:

(a) effective stress friction angles and cohesion intercepts were respectively 30 deg and 12 psi after 7-day curing and 26 deg and 30 psi after 28-day curing, and (b) a decrease in void ratio of 18 percent occurred for a maximum effective vertical pressure of 15 tsf and a curing time of 14 days. A decrease in void ratio of 25 percent occurred for a maximum vertical pressure of 30 tsf and a curing time of 29 days. For zero curing days the void ratio decrease was 25 percent under a maximum load of 15 tsf. Superior processed shale is similar to Paraho direct heated spent shale and Union B processed shale has a size similar to that of Paraho and is finer than TOSCO II (WRSOC 1981).

A16. Union B process (Union Permit Application 1982) retort shale is nonplastic gravel size material (60 to 70 percent gravel) with 70 percent finer than the No. 200 sieve. The specific gravity of shales ranged from 2.52 to 2.59. Laboratory tests using simulated waste water for compaction on minus 3/4-in. size material indicate the following properties:

- a. The modified effort dry density was 99 pcf at an optimum moisture content of 20.5 but the dry density was relatively insensitive to changes in moisture content. Considerable breakdown of particles occurred during compaction.

- b. The drained triaxial shear strength for 100 and 50 percent of standard effort density indicated a cohesion of 630 psf and ϕ of 38 deg at confining pressures up to 80 psi. Above 80 psi the friction angle decreased to 35 deg and the cohesion intercept was 2350 psf. The strength was more dependent on gradation and confining pressure than on initial density.
- c. The coefficient of saturated permeability decreased from 4.6 ft/yr (4.6×10^{-6} cm/sec) under a vertical pressure of 50 psi to 2.6 ft/yr under 200-psi pressure.
- d. Consolidation tests indicated percent compression (settlement) of 0.7 to 2.7 for vertical pressures of 50 to 200 psi.

A special relationship between in-place density and height of uncompacted fill was developed and indicated an increase in dry density from 62 pcf to about 78 pcf at a depth of 100 ft and 83 pcf at 200 ft. Below 600 ft the increase in density was very small. Very little data are available on Superior and retorted shales from other processes (Knight et al 1981).

Infiltration

A17. A study to estimate infiltration and runoff using a two-dimensional, finite element model (unsteady-unsaturated flow, UNSAT 2) for a hypothetical 300-ft-high, 1880-ft-long disposal fill with a 1V or 2H sloping face shown in Figure A2 has been made (Bloomsberg and Wells 1978) and the results are summarized in Bloomfield and Stewart 1981. Two rainfall cases (100-year 1-hour (0.95 in./hr) and 6-hour (0.25 in./hr) storms) and one case simulating 5 ft of surface ponding for one year were used. The results indicated no runoff from the horizontal surface of the 85 pcf (low density) section and that all rainfall would be held in the upper layer until evaporated (no downward seepage). Significant runoff was determined for the sloping face of the 95 pcf (high density) section. This result indicated the need for erosion-control berms (or benched cross drainage) on the sloping face and diversion channels for runoff control. The results also indicated that no internal leachate would reach the base or slope of the fill. The simulated 1-year ponding indicated saturation to a depth of 40 ft with a deeper zone near the crest as shown in Figure A3. The overall conclusions indicated that no infiltrating water would reach the base or slope of the disposal fill. All infiltration would be removed by evaporation even for high intensity, high yield storms. It was suggested that low density (porous) surface layers could be used to prevent runoff and store rainfall for subsequent evaporation.

FINITE ELEMENT MESH 2-D WASTE SHALE PILE

XSCALE = 200.00

YSCALE =

200.00

Figure A2. Finite element model for disposal fill (Bloomsberg and Wells 1978)

Figure A3. Typical cross-valley fill and simulated saturation zone with 1 year of ponding (Bloomfield and Stewart 1981)

A18. The importance of evaluating unsaturated permeability of spent shales is discussed by Sharma and Asgian (1981). Changes in permeability at shallow depth are likely under wet dry cycles that could induce cementation.

A19. Infiltration from artificially induced snowmelt (Ward and Reinecke 1972) on a 2-ft-deep field plot of TOSCO II retorted shale indicated that percolation and excess seepage water could occur at the 2-ft depth and that surface saturation eliminated the effects of compaction (i.e. loosened the surface material). Observations (reported by Fenner et al. 1982) for the Colony semiworks embankment showed several inches of ponding water from ditch failures had percolated into the TOSCO II material to depths of 3 ft. The softened surface prevented movement of wheeled vehicles.

Fill temperatures

A20. Elevated temperatures will exist for several years in retorted oil shale disposal fills. Temperatures for TOSCO II processed material (Fenner et al. 1982) are expected to vary from 200°F at the conveyor discharge, 140-180°F during placement, to 100°F after placement. The temperature of Paraho processed oil shale at the retort discharge was 400°F during field compaction tests (WCC 1976). It was noted that the hot retorted shale gradually became hotter when left in a dumped pile but when spread out in lifts, the temperature rapidly decreased. Maximum temperatures, several months after placement ranged from 85°F at a depth of 6 in. to 70°F at a depth of 9 ft and stabilized at 60°F at the 9-ft depth. The amount of cooling before placement will depend on type of delivery and time to the disposal site and amount of water added during conveyor delivery or during placement. Figure A4 shows the cooling rate (°C) at a depth of 1 m for Paraho retorted shale compacted in a field lysimeter (Harbert et al. 1979). In the Union Plan (UOC 1982), the spent shale will be moisturized and cooled to 200°F with treated waste water before transport to the disposal site.

Surface water control

A21. Potential surface runoff from disposal fill slopes and from natural soil or rock slopes above or adjacent to a disposal fill need to be collected separately and safely disposed. An accurate topographic contour map at an appropriate scale for the site (e.g., 1:2,400 scale and 20-ft contour intervals for small sites to 1:24,000 and 40-ft contour intervals for large sites) and long-term (100-yr, if possible) weather records (rainfall, snowfall, wind data, and evaporation data) from the closest weather station are essential for

Figure A4. Cooling rates for Paraho retorted shale compacted in a field lysimeter (Harbert et al 1979)

estimating runoff and sizing drainage collection ditches. Applicable hydrologic models (e.g., computer program packages such as HEC-1, 1982) which provide acceptable options for estimating runoff and flow hydrographs from rainfall or snowmelt data, slope and soil drainage flow characteristics, and channel slopes and shapes should be used to estimate the size of ditches and containment ponds. A rainfall-runoff model developed for semiarid rangelands and confirmed for basins in Colorado and Wyoming may be useful for western spent shale projects (Goodwin 1982 and McQuisten 1983). Short duration high intensity rainstorm data should be used for estimating maximum ditch size. The 100-yr, 24-hour rainfall or snowmelt data should be used in estimating storage volume for containment ponds.

A22. Erosion of natural and disturbed slopes can produce large sediment loads. Special collection ponds or retention dams may be needed to prevent unacceptable sediment transport to offsite streams and rivers. Natural erosion in the oil shale region of Colorado averages about 6.7 metric tons/hectare/yr and potential erosion for slopes as flat as 1V on 5H (20 percent) for TOSCO II is estimated at 71.7 tons/hectare/yr for bare slopes to 1.4 tons/hectare/yr for 90 percent vegetative cover (Knight et al. 1981). The Universal Soil Loss Equation (USLE) (Mildner 1982) and computer models (e.g., STORM, HEC 1976) incorporating the USLE option and more comprehensive models (being developed by Battelle, Pacific Northwest Laboratory) can be used to estimate erosion and sediment loads in collection ditches and containment ponds once flow hydrographics are defined. A general reference for hydrology considerations is D'Appolonia (1975). Detailed hydrologic and erosion-sedimentation studies are included in RBOSC (1981), WRSOC (1981), and UOC (1982).

Reclamation

A23. A comprehensive discussion of reclamation technology is presented by Knight et al. (1981). Three main methods identified are direct vegetation, revegetation following surface soil application, and revegetation of an artificial soil profile. Direct vegetation on spent shale generally has not shown satisfactory results. The second method involves placing a layer of soil over the spent shale. The layer thickness needed for capillary barrier and other conditioning requirements are site-dependent and subjects of ongoing research (DOE 1981). The third method involves an artificial profile of relative coarse material (crushed rock or raw shale) to form a capillary barrier and overlain by a subsoil layer and then a layer of surface soil. A fourth method

(WRSOC 1981) for the arid Utah Ua and Ub tracks involves soil ditches contoured into slopes to harvest runoff and support plant growth. A schematic sketch is shown in Figure A5. Stability of back slopes can be achieved using riprap or soil cement (para 13).

Construction

A24. Construction of spent shale disposal fills will generally include:

- (a) site preparation, (b) transporting spent shale to the disposal site,
- (c) emplacement in the fill, (d) compaction to a sufficient density to minimize water infiltration, (e) grading slopes to desired contours, and
- (f) application of soil cover and establishing vegetation or use of other materials to protect slopes against erosion.

Site preparation

A25. Site preparation involves access road construction, stripping, and stockpiling of surface soils (for later use in reclamation as fill is placed) construction of drainage control measures (ditches and retention embankments and ponds to contain runoff), foundation preparation, seepage barriers, and leachate collection drains (if needed). All loose or unstable slope materials should be removed to provide a firm foundation for the fill. Stockpiled surface soils require revegetation or artificial stabilization to protect slopes against erosion. Natural drainage channels which cannot be rerouted around the final disposal fill area will require permanent and maintainable conduits isolated from the base of the pile by an adequate seepage barrier. The conduits should handle maximum anticipated flash flood and debris flows and not deform or separate under final fill loads. A unique rock drain has been designed for one disposal fill (UOC 1982). Instrumentation such as piezometers to monitor foundation seepage can be installed beneath the fill and containment ponds. Additional observation wells upgrade and downgrade of the fill area are also installed, if needed, during site preparation. All access and haul roads should be stabilized for dust control.

A26. Retorted shale. Spent shale can be transported to the disposal fill site by a combination of truck hauling, covered conveyors, and stackers. All three methods have been ranked by Bloomfield and Stewart (1981) and have been proposed for the White River Shale Project (WRSOC 1981). Important considerations during construction are dust control, compaction, drainage

Figure A5. Contouring for revegetation program (WRSOC 1981)

diversion, and collection. Specific considerations are described in the following subparagraphs.

a. Dust control. Field compaction tests for the coarse Paraho direct heated spent shale (WCC 1976) indicated the need for (1) dust collector hoods at the plant loading point, (2) stabilizing haul roads with chemical or raw shale gravel, and (3) use of bottom dumps and moisture addition during placement and compaction. Dust generated in dry placement and compaction quickly settled out of the air. For the Colony Project (Fenner et al. 1982) moisture addition to the spent TOSCO II material is proposed at the retort for dust control along the conveyor route and for subsequent compaction. Additional moisture will be added at the discharge point if dust is a problem. Water trucks will sprinkle the surface after compaction to control dust. The following procedures are proposed for the White River Project (Superior, TOSCO II, and Union B processed shales).

- (1) The processed shale will be moisturized as it leaves the retorts as a first step to control dust, reduce temperatures, and condition the shale for compaction to make the processed shale easier to compact, and to aid in cooling it.
- (2) The entire length of the conveyor will be enclosed to prevent dust emission.
- (3) At the loadout bins, a dust-suppression system using water mixed with a chemical wetting agent will minimize dust as the shale is discharged from the conveyor into the bin and from the bin into the hauling trucks.
- (4) Truck hauling routes will be continuously maintained using conventional road wetting and chemical stabilization techniques.
- (5) As the processed shale is spread and compacted, water will be sprayed on it to stabilize the surface. A chemical wetting agent will be used if it proves, from operating experience, to be effective in reducing water consumption or improving surface stability.

b. Foundation preparation. Construction operations in foundation preparation include clearing and removal of vegetation and large rocks, stockpiling of soils, installation of drains for intercepted springs or seepage strata, and placement of an impermeable base for the disposal fill and drains for seepage and leachate monitoring. For foundations in thick impervious sedimentary rock with no open joints, special measures for an impermeable base may not be necessary. Special measures are not proposed for the White River Project because the depth to an existing aquifer is 600 to 700 ft below the ground surface and compression of the disposal fill will inhibit any vertical seepage. For the Union project (UOC 1982), clearing and stockpiling of topsoil will be followed by installation of the rock

drain with appropriate filter aggregate and then a 10-ft thick layer of heavily compacted spent shale (8-in. lifts) ahead of placement of thick lifts of uncompacted spent shale (150-ft layers). For foundations in permeable or highly jointed sedimentary deposits, a base of compacted impervious soil layers to a thickness of 5 to 10 ft may be necessary depending on the pervious nature of the spent shale after placement. An alternative is placement of an artificial liner (Dakessian et al. 1980) covered with a thick layer of highly compacted, well decarbonized oil shale and suitable monitoring wells. Liners will be required to meet federal regulations, if spent shales are declared a hazardous material.

- c. Placement and compaction. In the Colony Project, TOSCO II material will be placed in windrows by 150-ton bottom dump trucks, spread with dozers into 18-in. lifts, and compacted by self propelled compactors (Fenner 1982). A high degree of compaction and quality control is specified for the cross valley dam and linear materials. Field dry densities of 95 pcf at 12 to 14 percent moisture will be required. For Paraho spent shales, dry densities of 94 to 105 pcf at 18-24 percent moisture (Appendix B) can be obtained. Field compaction tests (WCC 1976) with vibratory rollers on 8-in. lifts achieved 104 percent with no moisture and up to 110 percent of standard effort density with the addition of moisture. For the White River Project, a compacted density of 85 pcf (WRSOC 1981) was selected as a working value for processed shale based on Paraho material tests (WCC 1976) and expected compaction by heavy equipment and by self weight of material as the fill enlarges. The Rio Blanco Oil Shale Demonstration Project (RBOSC 1981) includes test fills to investigate various placement and compaction procedures for the Lurgi processed material. The Union project includes field compaction tests to determine compaction procedures for the 10-ft-thick compacted envelope of spent shales. Because of the above variation in procedures and expected variations in properties of processed oil shale materials, it will be necessary to test and refine field placement and compaction procedures using in-place density and percolation tests as construction of disposal fills proceeds.
- d. Surface drainage. Construction of drainage diversion structures are required prior to full disposal operation. These structures include (1) ditches and culverts to route surface runoff around the fill from natural soil surfaces, (2) separate ditches to collect and route runoff from fill surfaces to containment ponds and (3) settling ponds to contain fill runoff for reuse of water in compaction and dust control or treatment/evaporation before release. Unlined ditches can be used on slopes with a grade less than 5 percent. Paved ditches and energy dissipators should be used on steeper slopes. Ditches and culverts should be large enough to contain maximum flash flood runoff and sediment loads. During construction fill surfaces should be graded to prevent ponding by maintaining a positive slope towards collection ditches. Temporary collection ditches may be required as fill placement progresses.

- e. Final slope contouring and revegetation. Benching during construction and contouring of final slopes to assist in reclamation vegetation is a major construction requirement. In the more arid region of tracts Ua and Ub, use of soil-filled trenches on benches for plants and sealed slopes for water harvest are proposed (WRSOC 1981 and McKell et al. 1978). The Union project includes test plots to verify reclamation development. Combinations of benches, leached spent shale, soil cover thicknesses of 6 to 18 in. have been investigated (Kilkelly et al. 1981; Knight et al. 1981). The availability of topsoil and water for leaching to reduce pH and salt levels and many other factors will dictate the type of final slope preparation for reclamation.
- f. Retention ponds. Construction of ponds to contain runoff from disposal fills and allow settlement of suspended solids requires firm foundations and impervious materials to prevent leakage. Proof rolling and/or ponding may be necessary to consolidate collapsible foundation soils common in alluvial deposits (derived from debris flows) in the western oil shale region. Where natural impervious soils are scarce, highly compacted retorted shale could be used over artificial liners (now required by federal regulations) for pond bases and alternatively under embankments. This concept proved satisfactory in field tests (WCC 1976) until a settlement failure occurred. Ponds constructed with natural soils and artificial liners would provide less risk over the long term. Dakesian et al. (1980) provide comprehensive information on performance, selection, and installation liners and cover materials for waste impoundments and disposal facilities. This reference describes effects of wastes on linings, types of natural and artificial liners, service life and failure mechanisms, installation problems and requirements, costs, and tests for preinstallation and monitoring of service behavior.

A27. Raw reject shale. Construction of fills for raw reject shale fines would be similar to fills for retorted shale. A major consideration would be compaction to prevent wind erosion, reduce possible oxidation, and to prevent a possible fire hazard from hydration heat causing ignition of oil shale particles. Two techniques considered for surface stabilization (WRSOC 1981) were liquid chemical agent and a liquid or emulsified asphalt to seal the fill surface. Construction of a small new fill of old raw shale fines at Anvil Points (WCC 1979) included (1) a 2-ft-thick compacted clay soil lining and starter fill, (2) placement of the raw shale in 8-in. loose lifts with compaction by routing of heavy equipment, (3) a front slope of 1V on 1-1/2H, (4) natural soil cover over the completed fill, and (5) drainage collection ditches to route natural slope runoff around the raw shale fill to an existing pond. An alternative is to include reject fines and collected process dust in

the spent shale stream to the disposal fill (UOC 1982). Dispersion of raw fines in the spent shale, cooled to 200°F, is necessary to prevent pyrolysis and should be verified early in the construction phase.

Monitoring of Disposal Fills

A28. Monitoring of disposal fills is needed to characterize infiltration, runoff, and seepage water and to identify problems in time for corrective action to be effective in preventing contamination of offsite surface water and groundwater. Monitoring activities (EPA 1981) include (a) inventory and characterization of solid waste disposed and manner of disposal, (b) performance of infiltration tests to gage amount of leaching and character of leachate, (c) performance of regular moisture tests to track the seasonal variation of moisture in the fill, (d) regular monitoring of groundwater quality in near-surface alluvium or aquifers at points down gradient and close to the fill boundaries, (e) determination of sediment and pollutant loading in surface runoff, and (f) maintenance of an early warning system for surface runoff. Another important aspect is regular inspection of the condition of fill slopes and integrity of surface drainage structures and collection ponds. The following, extracted from EPA (1980), provides general guidance on monitoring.

The hydrogeologic framework and existing water quality

A29. "The hydrogeologic framework and existing water quality in the vicinity of a disposal site should be adequately described to measure the changes in water quality that might occur as a result of the oil shale activities. Recommended approaches for a more or less typical situation are presented in the following paragraphs.

- a. Characterization of alluvium. Recommended activities for monitoring program development are as follows:
 - (1) Test drilling and geophysical surveys to define the characteristics and boundary condition for the alluvial system (i.e., thickness, subsurface extent).
 - (2) Sampling of water quality of alluvial aquifer.
 - (3) Pump testing of saturated zones identified to determine hydraulic characteristics.
- b. Formation fracturing. Fracturing in the bedrock formations that are in contact with the spent shale may create pathways

for the movement of pollutants from the disposal area to surface waters or to deep aquifers. Identification of the density and character of this fracturing is thus the key to evaluating pollutant mobility and development of the monitoring program. As the materials in the alluvial channels and canyon slopes are cleared for construction of the processed shale pile, visual surveys should be made of the surface of the bedrock formation. Fracturing should be mapped, and the maps used for locating monitoring sites for following mobility in the processed shale disposal area.

c. Testing Green River formation. Testing recommended for the aquifers in the Green River Formation includes:

- (1) Evaluation of water quality sampling procedures at existing and proposed wells to establish suitable sampling methods and sampling frequency.
- (2) Evaluation of existing pumping test data and performance of additional pump testing at existing wells.
- (3) Installation, pump testing, and water quality sampling of new wells where hydrologic assessments indicate they are needed.

Infiltration potential

A30. "Infiltration potential is to be evaluated to examine the water-balance for the processed shale pile and to provide a basis for monitoring pollutant mobility in the processed shale disposal area. The two areas where infiltration should be assessed are the surface of the disposal pile itself and the surface of the underlying formation (i.e., in fractures). For these assessments, it is recommended that double-ring infiltrometers be used as follows:

- a. At various stages of the construction of the processed shale pile including:
 - (1) As shale is spread before compaction.
 - (2) After compaction.
 - (3) After surface is sealed.
 - (4) During revegetation (i.e., in revegetation trenches).
- b. At the surface of cleared areas where the underlying formation is exposed.

A31. "In conjunction with these infiltration tests, monitoring of subsurface mobility should also be employed as presented in the following discussions. Such monitoring offers the opportunity to provide the infiltration assessments, provide estimates of subsurface hydraulic conductivity, test various monitoring equipment (e.g., moisture blocks, suction cup lysimeters,

and neutron probes), and (via sample collection) provide an analysis of leachate formation and composition."

Pollutant mobility

A32. Pollutant mobility monitoring needs in the processed shale disposal area include monitoring (a) in the processed shale pile itself, (b) in alluvium that may be present in the disposal area, and (c) in the bedrock formations.

- a. Monitoring in the processed shale disposal pile includes the sensing of changes in moisture content (thus potentially inferring movement of water and solute materials) and the collection and characterization of these solute materials. The monitoring program should be initiated with the infiltration evaluations presented above. Infiltration test sites should be instrumented as follows:
 - (1) Water content (or "soil"-water pressure) sensing:
 - (a) Access well for neutron moisture logging.
 - (b) Soil moisture blocks (at various depths).
 - (2) Suction cup lysimeters for water quality sampling (tensiometers should be used to appropriate suction levels).
- b. As indicated above, a sequence of infiltration tests during the various stages of pile construction is recommended. The initial testing of spent shale before and after compaction forms the basis of initial monitoring of the shale pile. The test sites should be maintained as long as possible during pile construction. As benches are formed in the disposal pile, permanent monitoring sites should be established on them with access (neutron logging) tubes, tensiometers, or other sensors demonstrated to be applicable during infiltration testing.
- c. Monitoring installations in completed segments of the processed shale pile would include (1) selected infiltration test sites as described above, (2) selected sites associated with revegetation trenches such as those depicted in Figure A6. These trench sites are appropriate because water harvesting efforts make these the most likely initial locations of infiltrating water. Access tubes for neutron logging, tensiometers, suction cup lysimeters, or other monitoring devices shown to be suitable during the infiltration testing would extend below the trenches into the processed shale pile itself. Should appreciable pollutant movement be indicated by monitoring within the processed shale pile, monitoring in the natural hydrogeologic realm would be indicated.
- d. Along with the revegetation trenches, an intensive sampling program should also be conducted in the vicinity of the toe of the completed spent shale pile. Lower reaches of the pile may become saturated as a result of leaching for salinity control, or because of subsurface movement of water from trenches. Leachate produced by saturated conditions may flow out of the pile into downstream alluvium, or downward into underlying

Figure A6. Possible monitoring facilities:
soil trenches (EPA 1980)

formations. A possible array of monitoring facilities in the toe of a spent shale pile is illustrated in Figure A7.

Monitoring in the alluvium

A33. Monitoring wells should be drilled in the alluvium in locations where pollution from the spent shale pile is most likely to occur, such as near the toe of the pile. Recommended procedures for constructing these monitoring wells include drilling a 20- to 30-cm (8- to 12-in.) hole to the base of the alluvium. A 10- to 15-cm (4- to 6-in.) diameter PVC casing should be installed to the bottom of the hole. The casing should be perforated opposite the interval from a few meters (several feet) below the static water level to the bottom. Clean pea gravel of known composition should be used to gravel pack the well. The upper few meters (several feet) should be filled with cement to form an annular seal. The wells should be logged by a geologist during drilling and developed by airlifting and/or pumping upon completion. A locking cap should be installed along with a suitable barrier to prevent destruction. The following sampling activities are suggested.

- a. Water samples should be retrieved by installation of suitable submersible pumps for the reasons previously discussed. After well development, a submersible pump should be installed and field tests performed during continuous pumping for several hours or days. Temperature, electrical conductivity, and pH of the discharged water could be measured. After completion of this phase, a determination should be made as to the length of pumping necessary before collection of a water sample. At least two or three well volumes should be pumped before sample collection. This procedure will allow collection of water samples typical of the alluvium near the monitor well.
- b. Sample collection should include field measurement of pH, specific conductance, and Eh. Water samples should be filtered and preserved at the time of collection.
- c. Appropriate sampling frequencies should be developed during the initial sampling program. Initially, depth to water and field measurement of pH, specific conductance, and Eh (or DO) should be monitored on a monthly basis. More detailed chemical analyses should be performed on a quarterly basis unless appreciable water quality changes are noted during the monthly sampling. Sampling frequency should be reevaluated after each sampling year.

Demonstration project example

A34. A detailed test section developed for the Rio Blanco Oil Shale Project (RBOSC 1981) includes compaction, erosion, pond, leachate, and revegetation test segments. These test segments for Lurgi processed shale are shown

Figure A7. Possible monitoring facilities at the toe of the spent shale pile (EPA 1980)

in Figures A8-A10. The test area is contained within protective soil embankments with 1V on 3H slopes.

Figure A8. Plan of Phase I test areas (RBOSC 1981)

Figure A10. Section A-A, Phase I demonstration test area (RBOSC 1981)

APPENDIX B: GEOTECHNICAL PROPERTIES OF PARAHO
AND TOSCO RETORTED OIL SHALE
AND RAW OIL SHALE

PART I: PARAHO RETORTED SHALE

B1. Comprehensive laboratory and field testing of spent shale from the Paraho pilot and semi-works retorts at Anvil Points were performed during 1974-1976 by Woodward Clyde Consultants (WCC 1976) and the Waterways Experiment Station (WES 1979). Test phases of the WCC testing are listed in Table B1. Source of the spent shales tested are summarized in Table B2. Except for sample WCC II, freshly retorted shales were tested. The geotechnical properties of these retorted shales are summarized in this section to assess their variability and possible relationships with retorted characteristics. Emphasis is placed on test results that might be pertinent to future oil shales from the Anvil Points mine retorted by the Paraho process in the semi-works plant and used in a research demonstration fill. The geotechnical properties summarized are not applicable to existing spent shales at the Anvil Points facility because of weathering, thermally induced changes, and the fact that spent shales from other locations, retorted using other processes are mixed in the pile.

Physical Properties

B2. The gradation of the retorted shales tested are summarized in Figure B1. These data illustrate the relatively wide range in gradations of retorted materials produced from the pilot and semi-works retorts. Maximum particle sizes ranged from 3 in. to 3/4 in. with the amount of fines (minus No. 200 sieve, less than 0.074 mm) ranging from 3 to 42 percent. The majority of sample material had maximum particle sizes of 1-1/2 in. to 3 in. (only a small portion of the retorted shale in WCC Phase V had a 3/4-in. maximum size). The retorted shales were classified as nonplastic, poorly graded gravel with a trace of fines (GP) (WES 1979), silty gravel (GM), and silty sand (SM) (WCC 1976).

B3. The retorted shales tested had a low abrasion resistance but exhibited significant breakage (increase in fines) during compaction and

Table B1
Summary of Test Phases Reported in WCC 1976

<u>Phase</u>	<u>Title</u>
I	Test Program Preparation
II	Exploratory Laboratory Tests on Old U.S.B.M. Retorted Shale
III	Laboratory Tests on Retorted Shales from DEI* Pilot Plant
IV	Laboratory Tests on Retorted Shale from the DEI Semi-Works Plant
V	Field Compaction Tests on Retorted Shales from the DEI Semi-Works Plant
VI	Field Infiltration Pond Tests on Retorted Shale from the DEI Semi-Works Plant
VII	Laboratory Tests on Raw Shale

* Development Engineers Incorporated, lease holder for DOE research facility at Anvil Points.

Table B2

Source of Paraho Retorted Shale Samples
Tested by WCC (1976) and WES (1979)

<u>Sample</u>	<u>Source and Date</u>	<u>Remarks</u>
WCC-II	Trench in retorted shale Waste pile to obtain old material (1949-1955)	Coarser after compac- tion (aggregation of particles)
WCC III-1	From pilot plant (1200 deg F) direct heating mode, July 1974	High carbonate decom- position (light)
WCC III-2	Same as WCC III-1	Low carbonate decompo- sition (dark)
WCC IV-1B	Semi-works plant, direct heating mode (1000°F) Feb 1975	Dark shale
WCC IV-1B2	Semi-works plant, direct heating mode, Nov 1975	Additional material to complete tests
WCC IV-1IH	Semi-works plant, indirect heating mode, Feb 1976	Somewhat darker than direct heating mode material
WCC V	Semi-works plant, direct heating mode, mid-1975	Similar to Phase IV material, variable degree of carbonate decomposition, vari- able gradation
WCC VI	Semi-works plant, direct heating mode, late 1975	--
WES	Semi-works plant, direct heating mode, 1976	--

Figure B1. Range in initial gradations of Paraho retorted shale samples tested by WCC (1976) and WES (1979)

consolidation. However, the material was resistant to weathering since the Plasticity Index (minus No. 40 sieve fraction, 0.42 mm) increased from 0 to only 5 after 18 months of soaking. The slake durability index values (1-1/2-in. and 3/4-in. particles) were 90-94 percent, indicating a high to very high durability (WES 1979). The apparent specific gravities (particles coarser than No. 4 sieve, i.e., gravel sizes) were 2.11 for aged material (WCC II), 2.56 to 2.59 for fresh material (WCC III and WCC IV, respectively), and 2.42 for the WES sample. The retorted materials tested had a variable degree of carbonate decomposition and thus a variable hydrocarbon content.

Engineering Properties

B4. The important engineering properties of retorted shales for the design of waste fills include the following for various compaction efforts:

- a. Optimum water content and corresponding maximum dry density.
- b. Dry density of unwetted material.
- c. Permeability.
- d. Consolidation properties.
- e. Shear strength properties.
- f. Earth pressure at rest coefficient (K_0).
- g. Cyclic triaxial compression properties.
- h. Dynamic shear moduli (G), Young's moduli (E), and damping ratios (λ).

B5. Results of tests (WCC 1976 and WES 1979) to determine these engineering properties at three compaction efforts of low (50 or 60 percent of standard effort), standard (ASTM D 698), and modified (ASTM D 1557) are summarized in this part. Only test results for full-scale gradations (1-1/2-in. and 2-in. maximum particle sizes) are summarized since these gradations represent the majority of sampled materials. The effect of aging on self-cementing characteristics and the effects of adding cement or lime are also covered.

Compaction properties

B6. Maximum dry density and optimum water content values are summarized in Table B3. Dry densities with no moisture added are also listed and are significantly lower than maximum values except for samples WCC III-1 and WCC III-2 (standard and modified efforts). A comparison of the range in maximum dry densities is shown in Figure B2. Values for sample WCC III-1 (low

carbonate decomposition) were lower, while values for sample WCC II (aged shale) were higher than for other samples. A trend of increase in density with increase in percentage of gravel (or density decrease with increase in percent fines) is indicated for materials retorted by the direct heating mode, semi-works plant. This trend could be useful for establishing a gradation index for field compaction control for future Paraho, semi-works, direct heating mode, retorted shales. The samples exhibited a significant particle breakage and an increase in percentage of fines after compaction (WCC 1976 and WES 1979). The influence of the increased fines on permeability is discussed subsequently. Compaction tests on modified gradations in 6-in.-diam molds did not produce results comparable with tests on the total material compacted in 12-in.-diam molds (WES 1979).

B7. Also shown in Figure B2 is the dry density for the field compaction of dry material and material compacted in Pond 1 at optimum water content, both by a smooth-drum vibratory roller (WCC 1976). For the field compaction test, the field dry density corresponded to 104 percent of that for standard effort compaction. No comparison was made for Pond 1. However, it is readily apparent that the use of a smooth-drum vibratory roller for compaction can achieve high dry density values for air dry materials. Laboratory vibrated density tests (WES 1979) indicated much lower dry densities (Figure B2). This test method is not applicable for predicting field vibratory compaction.

B8. Results of drop height tests (WES 1979) to simulate air dry retorted shale falling from the end of a conveyor belt indicated low density values. The density increased significantly for a drop height of 5 ft as shown in Figure B3. However, the maximum density achieved was only 86 percent of standard effort density for unwetted material. Consequently, retorted shale dropped from a conveyor belt behind a well-compacted embankment would initially be in a loose condition.

Permeability

B9. An important property of compacted retorted shale is permeability, since it affects the degree of water infiltration and leaching of undesirable chemicals. Saturated permeability values for minus 1-1/2-in. material are summarized in Table B4 for low, standard, and modified compaction efforts. WCC tests were performed on 8-in.-diam permeability specimens and WES tests were performed on 9-in.-diam triaxial specimens. Saturated permeability values from WES tests were significantly higher than those from WCC tests

Table B3
Compaction Properties, Minus 1-1/2-in. Material

Sample	Before Compaction		Compaction Effort*	After Compaction Fines*	Optimum Water Content %	Maximum Dry Density pcf	Dry Density No Water Added
	Gravel %	Fines* %					
WCC II	48	32	L	33	18.5	99.2	93.8
			S	33	15.5	103.2	95.8
			M	33	14.4	108.4	104.2
WCC III-1	79	7	L	18	22.0	77.0	73.6
			S	19	19.8	80.2	79.8
			M	20	22.0	88.8	88.1
WCC III-2	72	12	L	26	22.0	93.0	91.1
			S	36	22.5	96.6	96.1
			M	38	23.0	102.5	102.4
WCC IV-1B	43	31	L	29	23.7	88.0	85.8
			S	29	22.0	92.5	89.9
			M	36	22.0	98.7	96.4
WCC IV-1B2	51	12	L	15	22.0	87.5	86.5
			S	16	22.0	94.8	92.2
			M	17	22.0	98.9	97.6
WCC IV-1IH	68	11	L	13	22.0	93.9	89.0
			S	14	18.0	98.8	94.4
			M	19	18.0	105.8	102.1
WES (2-in. maximum size)	73	3	L	3	23.3	94.6	92.5
			S	8	22.2	97.5	96.3
			M	10	18.4	104.4	103.8

* Minus No. 200 Sieve (0.074 mm)

** L = Low, S = Standard, M = Modified
 L for WCC = 50%S and L for WES = 60%S

LEGEND

— . — TREND FOR SIMILAR RETORTED SAMPLES
(DIRECT HEATING MODE, SEMI-WORKS PLANT)

NOTE: COMPACTION EFFORT: L=LOW, S=STANDARD, M=MODIFIED

1. FIELD COMPACTION, 8-IN. LIFT, NO MOISTURE, 6 PASSES OF SMOOTH DRUM VIBRATORY ROLLER
2. TEST POND 1, 8-IN. LIFT, MOISTURE ADDED, 7 PASSES OF SMOOTH DRUM VIBRATORY ROLLER

Figure B3. Results of drop tests on air dry material (minus 2-in. fraction)

Table B4

Summary of Saturated Permeability Values, 1-1/2-in. Fraction, Paraho Retorted Shale

Sample	As Compacted		Percent Fines After Compaction	Permeability, Feet/Year* Under Vertical Pressure in psi of:										Remarks
	Dry Density pcf	Water Content %		20	40	50	70	80	100	145	160	200	300	
Low Compaction Effort														
WCC III-1	77.0	0	18				2,088			1,016			480	
WCC III-2	93.0	0	26				199			118			76	
WCC IV-1B	88.0	0	29			15			5.5			1.7		
WCC IV-1IH	93.8	0	13			71			52			30		
WES	91 to 95	17 to 23	3**	15,000	10,000			5,800			2,700			Triaxial test specimens
Standard Compaction Effort														
WCC II	103.2	16	35			1.3			1.1			0.9		Average of two tests
WCC III-1	80.2	20	19				157			71			41	Average of two tests
WCC III-1	80.2	22	12				828			307			146	Cured 14 days, 125°F
WCC III-1	80.2	22	12				191			62			41	
WCC III-2	96.6	22	36				168			140			81	Average of two tests
WCC III-2	96.6	24	24+				2.3			1.5			1.4	Cured 14 days, 120°F
WCC IV-1B	92.5	22	29			7.0			1.4			0.8		Gravel content varied
WCC IV-1B	95.5	22	32+			0.8			0.4			0.3		
WCC IV-1B	95.5	22	25+			1.6			0.6			0.4		
WCC IV-1B	92.5	24	29			11.4			10.9			10.0		Cured 28 days, 125°F
WCC IV-1B	92.5	24	29			11.5			8.5			7.3		
WCC IV-1IH	98.8	20	14			3.8			3.7			2.9		
WES	96 to 98	17 to 19	8**	4,600	1,900			520			620			Triaxial test specimens
Modified Compaction Effort														
WCC III-1	88.8	22	20				51			40			16	
WCC III-2	102.5	22	38				2.1			1.8			1.1	
WCC IV-1B	98.7	22	36			1.1			0.6			0.1		Average of two tests
WCC IV-1B2	98.9	22	17			0.3			0.3			0.2		
WCC IV-1B2	98.9	22	17			0.8			0.8			1.7		Cured 28 days, 125°F
WCC IV-1IH	105.8	18	19			2.0			2.5			2.4		
WES	100 to 102	13	10**	590	760			460			570			Triaxial test specimens

* Feet/year $\times 0.97 \times 10^{-6}$ = cm/sec.

** Based on compaction tests on minus 2-in. material.

+ After permeability test.

because of the coarser gradation (small percentage of fines) of the WES re-torted shale sample. WCC tests on cured specimens indicated higher permeabilities than for uncured specimens. A comparison of permeabilities versus percent fines after compaction is shown for the three compaction efforts in Figure B4. Permeabilities decreased with increase in vertical pressure and generally decreased with an increase in the percentage of fines.

B10. At the low compaction effort (Figure B4a) permeabilities ranged over four orders of magnitude, from about 10,000 to 1 ft/year. Specimens of dry compacted material from the pilot plant indicated a significant difference for low and high decarbonated material, but permeabilities were within the range of those for comparable WES and WCC specimens compacted at optimum water content (direct heat mode, semi-works plant). Holtz (1981) reports a value of 42 ft/yr for a dry compacted specimen that probably corresponds to sample WCC IV-1B. The field permeability measured for Pond 2, compacted by hauling and spreading equipment, is in the upper range but lower than the permeability for WES specimens. Seepage classification for this compaction effort would be semipervious to pervious.

B11. For standard effort compaction (Figure B4b), permeabilities ranged from 4500 ft/year for WES tests on coarser material to 1 ft/year for the aged retorted shale (WCC II) with 35 percent fines after compaction. The seepage classification is semipervious to pervious. The permeability from field seepage measurements at Pond 1, compacted by vibratory equipment, was in the lower range of 4 to less than 1 ft/year. Permeabilities of a dry compacted sample reported by Holtz (1981), probably corresponding to WCC IV-1B material, were significantly higher (20 to 45 ft/yr) than for samples compacted at optimum water content. Also shown in Figure B4b are results of large column (7 in. square by 6 ft high) and cell (6-in.-diam) tests by Pacific Northwest Laboratory (PNL 1982). The source of the shale tested by PNL was not given, but the gradation (PNL 1982) was very similar to WCC IV-1B2.

B12. Permeabilities for modified compaction (Figure B4c) ranged from 750 to 0.1 ft/year. This range is an order of magnitude less than that for the low compaction effort. A significant difference, similar to that for the low compaction effort occurred for the low and high decarbonated materials (WCC III). The permeability for dry compacted specimens reported by Holtz (1981) was higher (26 to 40 ft/yr) than those for specimens compacted at optimum water content (WCC IV-1B). Results of PNL tests are also shown in Figure B4c.

LEGEND:

MES Results from 9 inch diameter triaxial tests.
MCC Results from 8 inch diameter consolidation tests.
PML Results from 7 inch square column and 6 inch diameter cell tests.
S-W Seal-works report.
DH Direct heat mode.
PI Indirect heat mode.
pcf Initial sample dry density, lb/cu ft.
% u.c. Initial sample water content, percent of dry weight.
+ 50 psi Range of applied vertical pressures.
+ 200 psi

NOTE: See Table B2 for MES and MCC sample source.

Figure B4. Variation in saturated permeability with percent fines (0.074 mm)

B13. A comparison of permeabilities versus percent fines for the three compaction efforts and 100-psi vertical pressure is shown in Figure B4d. For the wide range in permeabilities, a significant decrease in permeability with increase in percentage of fines is evident. However, a better correlation shown in Figure B5 was found between the saturated permeabilities and the median grain size, termed D_{50} size, of the test material before compaction.

B14. As emphasized in the WCC (1976) final report and by Holtz (1981) water would be required during field compaction to produce low permeabilities. In addition, it may be necessary to require a high compaction effort with equipment that would cause significant particle breakage and produce the amount of fines needed to provide impermeable zones that would prevent infiltration of surface water into a retorted shale fill. However, compaction at water contents as high as optimum can produce free water that could accumulate in the fill. Results of field capacity tests by PNL (1982) indicate that water contents of 15 to 22 percent yielded excess water that drained out of the compacted material.

Consolidation

B15. The WES consolidation tests were performed on 12-in.-diam saturated specimens. In the WCC tests, compression was measured during permeability tests on 8-in.-diam saturated specimens. The most useful consolidation property in assessing settlement for retorted shale fills is percent compression, summarized in Table B5 and Figure B6. Percent compression increased with an increase in vertical pressure with maximum values ranging from 5 to 10 percent. WCC specimens cured before testing, exhibited less compression. The compression for individual test materials decreased with an increase in compaction effort. The range in compression for all materials was greatest for standard effort compaction. The percent compression at this effort varied from about 1.2 to 3.5 percent under a vertical pressure of 100 psi. This pressure corresponds to a hypothetical fill height of about 150 ft (Figure B6b). For this height, total settlement would be approximately 2 to 4 ft for the saturated condition. The results for the retorted shales compare with vertical compression of silty gravels and silty sands in several USBR dams (Sherard, et al. 1967) and with dense uniform gravel (Parkin, 1977) as shown in Figure B6b. The ranking shown in Figure B6 of test sample materials by increasing percent compression indicates that compression increased with increasing values of dry density and with increasing percentage of fines,

CORRELATION OF D 50 SIZE WITH SATURATED PERMEABILITY
AT A VERTICAL PRESSURE OF 100 PSI

CORRELATION OF D 50 SIZE WITH SATURATED PERMEABILITY
AT A VERTICAL PRESSURE OF 200 PSI

Figure B5. Correlation of initial sample D_{50} (median) grain size with saturated permeability

Table R5

Summary of Percent Compression, 1-1/2-in. Fraction, Paraho Retorted Shale

Sample	As Compacted		Percent Fines After Compaction	Percent Compression Under Vertical Pressure, psi, Of:									Remarks	
	Dry Density pcf	Water Content %		50	70	100	145	200	300	400	800	1000		
Low Compaction Effort														
WCC III-1	77.0	0	18		1.6		2.4		2.8					
WCC III-2	93.0	0	26		2.8		3.4		4.4					
WCC IV-1B	88.8	0	29	2.8		3.0		3.2						
WCC IV-1IH	93.8	0	13	2.1		2.7		4.2						
WES	94.6	23	3*			2.5		4.5		7.3	10.2			Consolidation test, minus 2-in. fraction
Standard Effort Compaction														
WCC II	103.2	16	35	1.8		2.2		3.7						Average of two tests
WCC III-1	80.2	20	19		1.1		1.3		1.4			5.3		Cured 14 days, 125°F
WCC III-1	80.2	22	12		0.5		0.8		1.1					
WCC III-1	80.2	22	12		0.3		0.4		1.1					
WCC III-2	96.6	22	36		3.0		4.1		5.5			10.7		Cured 14 days, 120°F
WCC III-2	96.6	24	24		0.4		1.2		1.5					
WCC IV-1B	92.5	22	29	1.4		1.6		1.7						Cured 28 days, 125°F
WCC IV-1B	95.5	22	32	0.2		0.6		0.8						
WCC IV-1B	95.5	22	15	0.1		0.2		0.2						
WCC IV-1B	92.5	24	29	0.8		0.8		0.8						
WCC IV-1B	92.5	24	29	0.7		0.8		0.9						
WCC IV-1IH	98.8	20	14	1.2		2.0		3.8						
WES	97.5	22	8*			2.0		3.5		5.8	7.9			Consolidation test, minus 2-in. fraction
Modified Compaction Effort														
WCC III-1	88.8	22	20		0.4		1.2		1.3					
WCC III-2	102.5	22	38		3.4		3.6		3.9					
WCC IV-1B	98.7	22	36	0.9		1.0		1.1						
WCC IV-1B2	98.9	22	17	0.8		0.9		1.0						
WCC IV-1B2	98.9	22	17	0.15		0.25		0.5						Average of two tests cured 28 days, 125°F
WCC IV-1IH	105.8	18	19	1.0		1.6		2.2						
WES	104.4	18	10*			1.1		1.8		3.0	5.1			Consolidation test, minus 2-in. fraction

* Based on compaction tests.

a. LOW COMPACTION EFFORT

b. STANDARD COMPACTION EFFORT

Direct Heat Mode Samples Ranked by Increasing Percent Compression

Compaction Effort	Sample	Dry Density pcf	After Compaction Fines %
Low	WCC III-1	77	18
	WCC IV-1B	88	29
	WCC III-2	93	26
	WES	95	3
Standard	WCC III-1	80	19
	WCC IV-1B	92	29
	WES	98	8
	WCC III-2	97	36
Modified	WCC III-1	89	20
	WCC IV-1B2	99	17
	WCC IV-1B	99	36
	WES	104	10
	WCC III-2	102	38

c. MODIFIED COMPACTION EFFORT

Figure B6. Percent compression, saturated condition

except for WES material. The different WES test method on larger specimens could have allowed greater particle rearrangements than the WCC test method. The percent compression for the retorted shales in a saturated condition is an upper limit (worst case condition). A smaller amount of compression would be expected for a retorted shale fill designed to prevent saturation. However, increased breakage and lateral deformation under high fill loads could increase compression, settlement, and creep with time.

Shear strength properties

B16. The triaxial compression tests on minus 1-1/2-in. material, reported by WES (1979), were performed on 9-in.-diam saturated specimens and those reported by WCC (1976) were performed on 6-in.-diam specimens. The WCC tests were performed on as-compacted specimens (dry or at optimum water content) except for one saturated specimen of each material. The results are summarized in Table B6. Angles of internal friction, ϕ' , for effective stress conditions ranged from 29 to 38 deg. Cohesion values, c' , ranged from 0.7 to 2.5 kg/cm². The shear strength was not significantly different for low and standard compaction efforts, but higher for the modified compaction effort. The effect of 14-day curing was to reduce the friction angle and increase the cohesion value. Unconfined compression tests (WCC 1976 and WES 1979) indicated a significant increase in strength with curing times up to 28 days (WES 1979). This strength gain is attributed to self-cementing of retorted shale with higher values for freshly retorted material. The WES triaxial tests indicated a contractive response under increasing normal stress. For high fill loads, this response could induce positive pore pressures in saturated zones and also cause increased settlements and deformation.

B17. Large-scale direct shear tests (WES 1979) on 2 ft by 2 ft specimens compacted to equivalent standard effort density indicated curved strength envelopes as shown in Figure B7. Angles of internal friction, ϕ' , decreased from 45 to 28 deg with increase in normal stress from 1.5 to 15 kg/cm² for inundated tests. For a dry condition, ϕ' values decreased from 57 to 32 deg for the same normal stress range. The WES strength envelope from triaxial tests on saturated specimens at equivalent standard effort density agrees with the envelope for the direct shear test on an inundated (wet) specimen. Curved strength envelopes are common for gravels and rockfill materials and indicate that the friction angle decreases with an increase in normal stress (Leps 1970). This trend is evident in Figure B7 for low normal stresses.

Table B6

Summary of Triaxial Compression Shear Strength Test Results, 1-1/2-in. Paraho Materials

Sample	Type of Test*	Initial		Range of Applicable Normal Stresses kg/cm ²	Total Stress		Effective Stress		
		Water Content %	Dry Density pcf		ϕ deg	c kg/cm ²	ϕ' deg	c' kg/cm ²	c' saturated kg/cm ²
<u>Low Compaction Effort</u>									
WCC III-1	S	0	77.0	3 to 12	--	--	36	0.9	0.6
WCC III-2	S	0	93.0	2 to 13	--	--	37	0.9	0.4
WCC IV-1B	S	0	88.0	3 to 12	--	--	35	1.4	1.1
WES	S	17 to 23	89 to 90	2 to 18	--	--	30	0.9	--
<u>Standard Compaction Effort</u>									
WCC II	R	15.5	103.2	2 to 12	34	1.0	--	--	--
WCC III-1	S	19.8	80.2	3 to 12	--	--	35	0.9	0.2
(cured 14 days)	S	(21.8)	(80.2)	2 to 12	--	--	(30)	(3.4)	(2.7)
WCC III-2	S	22.0	96.6	2 to 12	--	--	34	0.7	0.7
(cured 14 days)	S	(24.0)	(96.6)	2 to 12	--	--	(30)	(1.6)	(1.0)
WCC IV-1B	S	22.0	92.5	3 to 12	--	--	34	1.9	1.7
WCC IV-1IH	S	18.0	98.8	2 to 10	--	--	29	1.4	1.4
WES	R, S	17 to 19	95 to 96	1 to 9	14	1.3	33	0.8	--
<u>Modified Effort Compaction</u>									
WCC III-1	S	22.0	88.8	3 to 12	--	--	38	1.0	1.3
WCC III-2	S	23.0	102.5	2 to 12	--	--	43	0.9	0.9
WCC IV-1B	S	22.0	98.7	3 to 10	--	--	35	2.5	2.0
WES	R, S	13.0	100.0	2 to 18	31	0	32	1.9	--

* S = Consolidated drained; R = Consolidated undrained; $\bar{R}$ = Consolidated, undrained with pore water pressures measured. WCC tests were performed on as-compacted specimens with one saturated specimen at the lowest stress range; WES tests were all performed on saturated specimens.

Figure B7. Comparison of effective stress shear strength envelopes, minus 1-1/2-in. material (WES 1979)

However, the strength envelopes for triaxial tests on saturated specimens at equivalent low and modified effort densities (Figure B7) indicate higher strengths than those from direct shear tests at normal stresses greater than 5 kg/cm^2 . The lower shear strength from the direct shear tests at normal stresses greater than 5 kg/cm^2 can be attributed to multistage testing of the two specimens. Larger normal stresses were applied on each specimen after the maximum shear stress was obtained under a lower normal stress. Progressive breaking of particles undoubtedly occurred along the imposed horizontal failure plane during the multistage test. This accumulated breakage would reduce shearing resistance and produce lower shear strengths at high normal stresses. In the triaxial tests, a new specimen was used for each loading condition. Consequently, the triaxial tests are believed to provide a more realistic measure of the shear strength for the minus 1-1/2-in. fraction at the high normal stresses.

B18. The shear strength for low normal stresses (1.2 to 1.3 kg/cm^2) from the WCC saturated specimens falls between the dashed lines shown in Figure B7. This trend confirms the curved envelopes at normal stresses below 2 kg/cm^2 .

B19. Shear strength envelopes for the WES tests on saturated specimens and the WCC tests on as-compacted specimens (no saturation) are compared in Figure B8. As expected, the strengths for an unsaturated condition are greater than for a saturated condition.

B20. The WES (1979) repeated direct shear tests on small samples (3-in. by 3-in.) indicate no loss in strength for large displacements. The residual angle of internal friction, ϕ'_r , was 35.5 deg .

B21. The WCC (1976) Phase III tests included K_o tests on untreated and 1 percent and 3 percent lime- and cement-treated specimens (cured 28 and 60 days) of minus 3/4-in. material. The specimens were compacted to near equivalent standard effort density and water content. After K_o testing, lateral loads were reduced at constant axial strain until failure. The resulting Mohr circles were plotted with Mohr circles from companion unconfined compression tests to obtain values of c' and ϕ' . These shear strength parameters are summarized below:

a. LOW COMPACTION EFFORT

b. STANDARD COMPACTION EFFORT

c. MODIFIED COMPACTION EFFORT

Figure B8. Comparison of WCC and WES effective stress shear strength envelopes from triaxial tests

	Cohesion, c'		Angle of Internal	
	kg/cm^2		Friction, ϕ' , deg	
	30 days	60 days	30 days	60 days
Untreated	1.8	2.7	29	30
Lime-treated				
1 percent	3.2	2.8	30	29
3 percent	2.5	2.6	30	31
Cement Treated				
1 percent	4.1	3.5	28	26
3 percent	3.9	5.3	32	28

Higher cohesion values were obtained for 30-day cured, lime-treated specimens than for untreated specimens, but 60-day cohesion values were unchanged.

Friction angles were 1 to 2 deg higher. For cement-treated specimens, cohesion values were higher but friction angles were generally lower than for untreated specimens.

Static stress-strain properties

B22. Values of coefficient of earth pressure at rest, K_0 ; Poisson's ratio; and constrained modulus, D , determined from special triaxial compression tests (WES 1979 and WCC 1976) are summarized in Figure B9. For the WES tests, K_0 values increased directly with axial stress (equivalent to vertical stress in a fill). No significant difference was apparent for specimens cured 13 months. The K_0 values from WCC tests decreased and then increased with axial stress, and the lower values at equivalent axial stress compared to WES values could be caused by differences in gradation.

B23. The significance of K_0 results is that lateral stresses would increase under higher fill loads and contribute to lateral deformations, settlement, and creep with time. In a zoned fill, settlements in a low density zone could induce high shear stresses in a well compacted high density outer zone because of noncompatible strains with increase in stress. Poisson's ratio, ν , values showed the same trends as K_0 values. This similarity is expected since ν was calculated from $K_0/(1 + K_0)$. The WES values of constrained modulus, D , showed a weakly defined increase with increase in axial stress. The WCC values of D were generally higher than WES values and did not show a definite trend with increase in axial stress. The difference may also be caused by differences in gradation.

Figure B9. Relationship with K_0 , Poisson's ratio, and constrained modulus with axial stress, 1-1/2-in. Paraho material, standard effort compaction, normally consolidated stress condition (WES 1979)

Cyclic shear resistance

B24. Cyclic triaxial tests (WES 1979) on minus 3/4-in. material (modeled Paraho) at the low compaction effort indicated a high resistance to seismically induced ground failure. Only for a much looser condition (60 percent relative density) did the modeled Paraho show a weaker condition than similarly graded granular materials. Seismically induced ground failure of a retorted shale fill was considered unlikely since 100 percent saturation and loose depositing of materials would be very unlikely to occur.

Dynamic properties

B25. The results of special tests (WES 1979) to determine Young's moduli (E), shear moduli (G), and damping ratios (λ) indicated that well-compacted Paraho retorted shale was similar to dense sands and gravels. The results are applicable to seismic evaluation of specific sites and suggest that complex seismic analyses would be required only in high risk zones. The specific values are strain-dependent and the results and discussion are not repeated here. Reference to WES (1979) is required for details.

PART II: TOSCO RETORTED SHALE

B26. The geotechnical properties of TOSCO II retorted shale summarized in this part are based on results published by the Atlantic Richfield Company (ARCO 1974) and by the Waterways Experiment Station (WES 1979). The spent shales tested were from the Colony semiworks plant near Parachute, Colo. The summary of test results is included in this report to provide information needed in designs for possible inclusion of TOSCO II spent shale in a future demonstration research fill at the DOE Anvil Points facility.

Physical Properties

B27. The gradations of the TOSCO II (referred to simply as TOSCO) retorted shales tested are shown in Figure B10. The spent shale material used in the ARCO tests was tested by Dames and Moore and had a wider range in gradation than the material tested at the WES. Also, a finer gradation was apparently used in consolidation tests for ARCO. The specific gravity of solids and apparent specific gravity for the WES material was 2.61 and 2.55, respectively. The apparent specific gravity value for the ARCO material was 2.52 and is close to the WES value. Atterberg limits for the WES material indicated that it was nonplastic without soaking. However, after nine months of soaking the liquid limit was 31 and the plastic limit was 29. Corresponding values for the ARCO material were 30 and 24, apparently with no soaking. The WES results indicate that degradation and softening can occur with time, and the tests for ARCO on perhaps finer material tend to confirm this trend. The TOSCO spent shale is classified as a silty sand (SM) without soaking and as a clayey sand (SC) after long-term soaking.

Engineering Properties

Compaction

B28. Results of compaction tests are summarized in Table B7. For the WES tests, the optimum water content decreased from 21 to 18 percent and maximum dry densities increased from 97 to 104 pcf with increasing compaction effort. Results of ARCO tests indicated similar values for standard effort compaction, but a lower optimum water content of 18 percent and a higher dry

Figure B10. Gradation range of TOSCO retorted shales tested for gradation properties

Table B7
Summary of Engineering Properties for IOSCO Retorted Shale

Source and Type of Test	Gradation				Compaction Effort	Optimum Water Content %	Maximum Dry Density pcf	As Compacted		After Compac- tion Fines %	Permeability		Compression		Shear Strength			
	Bravel Fines D50 D60							Water Content	Dry Density		Applied Pressure psi	t ft/yr	Applied Pressure psi	%	Normal Stress psf kg/cm2	Total Stress		Effective Stress psf kg/cm2
	%	%	mm	mm												0 deg	c kg/cm2	
WES Sample [†] Gradation	9 to 18	28 to 36	2.3 to 3.9	5.5 to 8.3														
ARCO Sample ^{††} Gradation	2 to 19	17 to 47	0.8 to 1.5	0.2 to 2.1														
WES Compaction	Same as WES above				60% Stand. Standard Modified	21 19 18	97 99 104	20 & 26 0 & 20 11 & 20		8 & 27 34 & 9 4 & 2								
ARCO Compaction	Same as ARCO above				Standard 60% Modif. Modified	19 17 16	96 (Average of 12 tests) 107 (Average of 2 tests) 108 (Average of 2 tests)											
WES Triaxial Compression, Saturated Specimens	Same as WES above				60% Stand.			18.5 to 20.7	96		20 40 80 80 160	5.1 3.0 2.8 2.2 1.3			1.4 to 11.0	20	0.3	37 0.1
					Standard			18.4 to 19.1	96 to 98		20 40 40 80 160	3.5 2.8 2.4 2.4 2.0			1.4 to 11.0	18	0.3	33 0.1
					Modified			17.3 to 19.3	103 to 105		20 20 40 80 160	0.75 0.91 0.70 0.60 0.70			1.4 to 11.0	24	1.4	43 0
ARCO Triaxial Compression	Not stated				Lower Densities for Lique- faction Study			5-20 5-20 10 Saturated	85 90 95 85-90						0.98 and 2.4	35 35 35	0.4 0.9 1.4	20 0
WES Direct Shear, Moist	Same as WES above				Standard			20	93						1.0 to 14.0			36 1.0
WES Direct Shear, Inundated	Same as WES above				Standard			20-21	92-93						1.0 to 14.0			34 0
								20	93						1.0 to 14.0			34 0.2
WES Direct Shear, Residual	Same as WES above				Standard			20	93						1.0 to 14.0			34 0
WES Consolidation, Saturated Specimens	Same as WES above				60% Stand.			21	97				100 200 400 800	3.0 5.2 6.9 8.7				
					Standard			19	99				100 200 400 800	1.5 2.4 4.3 6.7				
					Modified			18	104				100 200 400 800	1.3 1.8 2.9 4.7				

(Continued)

* < 0.075 mm

** Confining pressure for triaxial tests

† Colony development sealworks retort (WES 1979)

†† Colony development sealworks retort (WES 1979, Appendix A)

Table B7 (Concluded)

Source and Type of Test	Gradation				Compaction Effort	Optimum Water Content %	Maximum Dry Density pcf	As Compacted		After Compac- tion Finest %	Permeability Applied Pressure psi	ft/yr	Compression Applied Pressure psi	Shear Strength		
	Gravel	Fines	D50	D60				Water Content %	Dry Density pcf					Normal Stress psi	Total Stress psi	Effective Stress psi
	%	%	mm	mm				%	pcf					kg/cm ²	kg/cm ²	kg/cm ²
ARCO Consolidation, Lower Densities for Lique- faction Study	0	53		0.1	Modified	17	100	0	56(32)‡	Saturated at 0.7 psi			0.7 15.3			
													100 30.5			
													400 34.0			
								0	65(32)‡	Saturated at 0.7 psi			0.7 10.3			
													100 26.5			
													700 35.0			
								0	71(63)‡	Tested dry			0.7 0.3			
													100 10.3			
													700 21.3			
								0	87(86)‡	Saturated at 0.7 psi			0.7 0.0			
													100 6.3			
													700 16.0			

‡ Relative (vibrated) density shown by (32)

density of 108 pcf for modified effort compaction. The WES tests showed a sharp peak in the compaction curve, indicating that small changes in water content have a significant effect on compacted density. For example, a water content increase of 4 percentage points caused an increase in dry density of 5 pcf. The gradation after compaction indicated an unexpected random decrease in percent fines for the WES tests as shown in Table B7 (i.e., the material was coarser after compaction). An apparent agglomeration of particles occurred even with extra efforts to disaggregate the compacted material. This anomaly suggests some self-cementing of fines (WES 1979), since they were found to be nonplastic without long-term soaking and should have readily disaggregated. Further studies to explain this condition are needed.

B29. Results of drop tests by WES to determine the increase in density with height of drop such as from the end of a conveyor indicated an increase in air dry density of 77 to 86 pcf for drop heights up to 16 ft. However, the density values were questionable for drop heights above 8 ft because of excessive segregation of fines.

Permeability

B30. WES permeability tests on 6-in.-diam triaxial specimens at three compaction efforts indicated low permeabilities of 0.6 to 5.1 ft/yr (Table B7). The permeability values generally decreased with an increase in applied pressure, although the trend was not consistent. Permeability values did decrease consistently with increased compaction effort. The seepage classification was semipervious for low and standard effort compaction and impervious for modified compaction. Thus, heavy compaction near optimum water content would be required to obtain an impervious layer or zone.

Consolidation

B31. Results in Table B7 of WES consolidation tests on 12-in.-diam saturated specimens indicated that the percent compression increased with an increase in vertical pressure and decreased with increased compaction effort. Postconsolidation gradations indicated that the fines content increased from 32 percent to 61 and 76 percent, respectively, for standard effort and 60 percent standard effort (low) compaction. This increase in fines was in contrast to agglomeration of fines that occurred after impact compaction. Thus, the different effects of compaction and compression on bonding needs further study. The compression values corresponded to those for dense gravel (see Figure B6, Part I).

B32. Application of the compressed values to a spent shale fill would overestimate total settlements, since complete saturation of a spent shale fill is unlikely. However, if excess compaction water or precipitation percolated downward during fill construction, compression saturation of material at the base of the fill could occur. For example, at standard effort compaction, an increase in the water content from 19 to 22 percent under a vertical pressure of 400 psi (equivalent to a fill height of 580 ft) could cause an increase in saturation from 77 to 100 percent. If drainage of water was prevented by the impervious nature of the fill, excess pore water pressures could occur and decrease the mechanical stability of the fill.

B33. Consolidation tests for the ARCO studies (Table B7) were performed on relatively loose and dense specimens of a finer gradation of the TOSCO spent shale (Figure B10). Dry density values ranged from 56 to 87 percent and the percent compression ranged from 10 to 23 percent for the looser specimens and from 0 to 2 percent for the denser specimens. The compression values increased with an increase in vertical pressure. Thus, the finer gradation exhibited less compression than the coarser gradation in the WES tests.

Shear strength

B34. Results of WES consolidated undrained triaxial compression tests on saturated specimens with pore pressure measurements (R tests) are shown in Table B7. Total stress strengths increased with increased compaction effort, while effective stress strengths increased only for modified compaction effort. Results of ARCO unconsolidated undrained (Q) triaxial compression tests (Table B7) on specimens as compacted (no saturation) indicated considerably higher strengths for the total stress condition and lower densities compared to WES test results. An undrained triaxial compression (R) test on low density saturated specimens of the ARCO test material indicated a slightly lower strength compared to total stress strengths from WES tests. The WES tests included direct shear drained (S) tests on 3-in. square specimens molded to standard effort densities. The results compare closely with results from the triaxial compression effective stress strengths. The strength envelopes from the WES tests were linear.

B35. Results of WES unconfined compression tests on specimens cured up to 28 days showed a 1.5 to 3 fold gain in strength within three days. This gain in strength was believed to be caused by particle bonding (cementing) (WES 1979) since soaking overnight did not reduce strengths but caused a

slight increase in strength. Thus, the gain in strength was not due to capillary moisture tension (effective cohesion). Thus, aging of three days without disturbance by heavy equipment after compaction could produce increased strengths.

B36. Lime-stabilization tests were also performed by WES. The results indicated that the TOSCO spent shale had a low reaction and did not meet recommended criteria (WES 1979) for stabilization with lime. Consequently, compaction at the modified effort and aging without disturbance are the primary methods for increasing the strength and thus mechanical stability.

Static stress-strain properties

B37. Values of earth pressure at rest, K_o , Poisson's ratio, ν , and constrained modulus, D , determined from triaxial compression tests on saturated specimens (WES 1979) generally increased with an increase in axial stress. However, specimens cured 9 and 18 months bracketed the range of values for all tests. The K_o values ranged from 0.31 to 0.44. Poisson's ratio values ranged from 0.24 to 0.30. Constrained modulus values ranged from 340 to 2900 kg/cm² with one value as high as 5900 kg/cm².

Dynamic tests

B38. Cyclic triaxial tests and other tests to determine dynamic soil properties of the TOSCO spent shale were not performed in the WES or ARCO investigations. These tests would be needed for evaluation of mechanical stability for a spent shale fill located in a high-risk seismic zone. However, these tests are not critical for the Anvil Points facility because it is located in a low-risk seismic zone (Appendix C).

PART III: RAW OIL SHALE, ANVIL POINTS

B39. Tests by WCC (1976) to determine the physical and engineering properties of raw shale from Anvil Points provide the only information for the design of raw shale storage piles at this site. Limited tests by WES (1979) provide supplementary data. These properties are summarized in this part.

Physical Properties

B40. A sample (WCC VII-1) of the crushed raw shale for the Anvil Points semi-works plant obtained in February 1975 was used for the WCC tests. The raw shale feed stock gradation is shown by curve A in Figure B11. Gradations shown by curves B, C, and D were prepared during the WCC tests to simulate crushed raw shale, feed shale, and reject shale. The raw shale is a nonplastic, durable carbonate rock. The apparent specific gravity was 2.11 for the 3-in. to 1-1/2-in. sizes, 2.15 for the 1-1/2-in. to 3/8-in. sizes and 2.12 for the minus 3/8-in. fraction. The apparent specific gravity from WES tests (1979) on gravel sizes was of 2.19. According to the Unified Soil Classification System, the minus 3-in. and minus 1-1/2-in. to 3/8-in. fractions classify as poorly graded gravels (GP), the minus 1-1/2-in. to No. 200 sieve fraction as a sandy gravel (CW), and the minus 3/8-in. fraction as silty, gravelly sand (SW-SM).

Engineering Properties

B41. The engineering properties of compacted raw shale from the WCC tests are summarized in Table B8. These properties, as they apply to temporary storage fills for run-of-the-mine shale and crushed shale and to waste fills for reject shale, are discussed below.

Compaction properties

B42. Compaction of the hard durable raw shale particles caused very little breakage. Optimum water contents and maximum dry densities for the crushed raw shale (curve C, Figure B11) and feed shale (curve B) showed a small increase for low and standard compaction efforts. However, the coarser grading of the feed shale caused significantly lower values. The finer graded reject shale would be expected to have somewhat higher values of optimum water

Table B8

Engineering Properties of Compacted Raw Shale, Sample VII-1 (WCC 1976)

Property	Crushed Raw Shale: Minus 1-1/2-in. to No. 200 Sieve Fraction		Feed Shale: Minus 1-1/2-in. to 3/8-in. Fraction		Reject Shale: Minus 3/8-in. Fraction
	Low	CW Standard	Low	GP Standard	SW-SM
Classification					
Compaction Effort, ft-lb/ft ³	6200	12,375	6200	12,375	--
Optimum Water Content, %	6.0	8.3	1.0	1.0	--
Maximum Dry Density, pcf	88.3	90.3	77.5	80.1	--
Settlement, % Under Vertical Pressure of:					
50 psi	--	--	1.0	2.0	--
100 psi	--	--	2.0	3.0	--
200 psi	--	--	4.5	6.0	--
Shear Strength:					
Angle of Internal Friction, Ø', deg	35	39	--	--	--
Cohesion, c' unsaturated, kg/cm ²	1.6	1.4	--	--	--
Cohesion, c' saturated, kg/cm ²	1.1	1.0	--	--	--
Permeability, ft/year, loose condition	14,500 (1.4 x 10 ⁻² cm/sec)		--		10,500 (1 x 10 ⁻² cm/sec)
Initial Dry Density, pcf	81				79
Vertical Pressure, psi	4				4

were pervious, as would be expected. The permeability in a denser state was determined in the WES tests on modeled Paraho at equivalent standard effort density. The gradation (3/4-in. maximum size and 8 percent fines) was similar to the raw reject shale and permeabilities ranged from 5 to 52 ft/year. The raw reject shale compacted to standard effort density would be classified as semipervious.

content and maximum dry density than those for the crushed raw shale. The expected higher values tend to be confirmed by WES tests on modeled Paraho, since the after-compaction gradation was similar to the reject shale and maximum dry densities were 92 and 96 pcf, respectively, for low and standard compaction efforts. Corresponding optimum water contents were 27 and 25 percent. For run-of-the-mine shale, compaction properties are irrelevant. This material with rock sizes in excess of 1 ft would be stable in a loose state (as dumped) with steep slopes.

Settlement

B43. Compression of the feed shale, determined in the WCC tests, ranged from 1 to 6 percent under vertical pressures of 100 to 200 psi. Compression of the crushed shale and reject shale are expected to be less because these finer, well-graded materials would have a more stable grain structure. For example, well-graded gravel exhibits less compression than uniformly graded gravel (WES 1979).

Shear strength properties

B44. The unsaturated triaxial compression test results on the crushed raw shale indicated effective stress shear-strength parameters of 35 and 39 deg for ϕ' and 1.6 and 1.4 kg/cm² for c' , respectively, for low and standard effort compaction. These results are similar to those for the retorted shale (Table B6) with varying gradations. Since gradation or retorting did not appear to have a significant effect on as-compacted shear strengths, the values of ϕ' and c' for crushed raw shale are appropriate for the feed shale and reject shale. For run-of-the-mine shale, curve A for 3-in. to 3/8-in. sizes can be considered a modeled gradation. Angle-of-repose tests (WCC 1976) on this 3-in. maximum size material indicated slope angles for a loose, dumped pile of 38 to 42 deg with an average of 40 deg. The slope angle is equivalent to ϕ' at low normal stresses. Considering the summaries of rockfill shear strengths and trends in decrease of friction angles with increase in normal stresses reported by Leps (1970) and Wilson and Marsal (1979), a conservative ϕ' value of 35 deg for dumped run-of-the-mine shale appears reasonable.

Permeability

B45. The permeability (Table B8) was determined only for loose specimens of crushed raw and reject shale, since these materials were to be used as a drainage blanket for Ponds 1 and 2. These materials in a loose condition

Seismic Hazards

C1. Table C1 from the Environmental Data Service (1973, 1979) is a tabulation of all felt earthquakes in Colorado up to May 1981. The severest is Modified Mercalli (MM) Intensity VII. Table C2 describes the MM Intensity scale. MM VII is not of concern to well-built structures; MM VIII is the threshold of possible damage to such structures. Thus, Colorado is an area of moderate to low seismicity.

C2. Figure C1 from the Environmental Data Service (1973) shows the distribution of earthquakes of MM Intensity V or greater in the United States. Locations (May 1981) are shown in Figure C2 for all earthquakes around the Anvil Points site. The closest area of severe earthquakes in a state bordering Colorado is central Utah. The recorded earthquake occurred in Elsinore, Utah, 1 October 1921, with a MM Intensity of VIII. Elsinore is approximately 200 miles or 320 km from Rifle. Attenuation for this distance may be estimated from the chart by Krinitzsky and Chang (1977) shown as Figure C3. At 320 km, even the severest earthquake ($M = 7.5$) would attenuate to something under MM Intensity VI. MM Intensity VIII (probably $M = 6.0$) is off the chart for the distance involved.

C3. For the above reasons, Colorado is carried in Figure C4 as Zone I (Corps of Engineers 1977).

Earthquake Motions

C4. The earthquake motions that are proper for the site must be specified in accordance with the analyses that are to be performed. The structure is an earth embankment situated on bedrock. There are no unconsolidated, granular, water-saturated soils in either the embankment or the foundation. Thus, there is no danger of liquefaction and, for such a site in Zone I, no dynamic analyses are needed. It is sufficient to perform a pseudostatic analysis.

Table C1
Historic Earthquakes in Colorado^a

<u>Year</u>	<u>Date</u>	<u>Time (MST)</u>	<u>Locality</u>	<u>N. Lat. Degrees</u>	<u>W. Long. Degrees</u>	<u>Area Sq. mi.</u>	<u>Intensity</u>
1882	Nov 7	18:30	Colo.	40	105	11,000	V
1895	Mar 22		Colo.			1,500	V
1901	Nov 15	am	Colo.	38.8	106.2	(²)	VI-VII
1913	Nov 11	14:55 15:18 16:45	Southwestern Colo.	38.2	107.7	7,500	V
1928	Apr 20- May 10	Various	Creede, Colo.	37.8	107.0	(²)	IV-V
1944	Sep 8	21:12*	Western Colo.	39.0	107.5	3,000	VI
1955	Feb 10	10:30*	Northwestern Colo.	40.5	107.0		V
	Aug 2	23:40	Southwestern Colo.	38	107	2,000	VI
1960	Oct 11	01:06*	Southwestern Colo.	38.3	107.6	10,000	VI
	Oct 17	09:00	Aspen, Colo.	39.2	106.9	(²)	V
1962	Feb 5	07:46*	Southwestern Colo.	38.2	107.6		V
	Dec 4	10:50*	Northeast of Denver, Colo.	39.8	104.7		VI
	Dec 5	06:48*	North-central Colo.	39.9	104.6	6,000	VI
1963	May 25	03:45*	Northeastern Colo.	39.8	104.7	900	V
1965	Feb 16	15:22*	Denver, Colo., area	39.9	105.0	300	VI
	Jul 18	14:41*	Denver, Colo. area	39.8	104.8		V
	Jul 31	06:42*	Denver, Colo., area	39.7	104.9		V
	Sep 13	02:58*	Denver, Colo., area	39.8	104.8		V

(Continued)

^a See footnotes at end of table.

Table C1 (Continued)

<u>Year</u>	<u>Date</u>	<u>Time (MST)</u>	<u>Locality</u>	<u>N. Lat. Degrees</u>	<u>W. Long. Degrees</u>	<u>Area Sq. mi.</u>	<u>Intensity</u>
1965	Sep 14	15:46*	Denver, Colo., area	39.9	104.6		VI
	Sep 29	12:00*	Denver, Colo., area	39.8	105.1		VI
	Nov 20	21:02*	Denver, Colo., area	39.8	104.8	3,000	VI
1966	Jan 4	17:37*	Denver, Colo., area	39.8	104.7		V
	Jan 22	18:57*	New Mexico- Colo. border region	37.0	107.0	15,000	VII
	Oct 2	19:26*	Southeastern Colo.	37.4	104.1	15,000	VI
	Nov 14	13:03*	Denver, Colo., area	39.9	104.7		VI
1967	Apr 10	12:00*	Commerce City- Denver, Colo., area	39.9	104.8	6,500	VI
	Apr 27	10:25*	Denver, Colo., area	39.9	104.7		VI
	Aug 9	06:25*	Denver, Colo., area	39.9	104.7	15,000	VII
	Nov 15	00:10*	Denver, Colo., area	39.9	104.6		V
	Nov 26	22:09*	Denver, Colo., area	40.0	104.7	17,000	VI
1968	Jul 15	11:33*	North-central Colo.	39.9	104.8		V
1969	May 23	02:01	Commerce City, Colo.	39.9	105.1		V
1970	Apr 21	01:54*	Rangely, Colo.	40.1	108.9		V
1971	Jan 4	07:39*	Colo.	39.5	107.3	(²)	V
	Mar 18	09:09*	Colo.	40.7	107.0	(²)	V
1975	Jan 30	14:49*	Colo.	39.3	108.7		V

(Continued)

(Sheet 2 of 3)

Table C1 (Concluded)

<u>Year</u>	<u>Date</u>	<u>Time (MST)</u>	<u>Locality</u>	<u>N. Lat. Degrees</u>	<u>W. Long. Degrees</u>	<u>Area Sq. mi.</u>	<u>Intensity</u>
1977	Sep 30	10:19	Colo.	40.5	110.5		VI
	Oct 11	07:56	Colo.	40.5	110.5		V
	Nov 28	02:23	Colo.	41.4	111.7		V
1978	Jun 10	20:57	Colo.	39.8	104.9		IV
1979	Jan 6	01:58	Colo.	39.0	105.2		VI
	Mar 19	14:59	Colo.	40.2	108.9		IV
1980	May 24	10:03	Colo.	40.0	112.0		V
	Sep 11	17:34	Colo.	36.5	105.1		V
1981	Apr 2	16:10	Colo.	39.9	105.0		VI
	May 14	05:11	Colo.	39.5	111.1		V

* Instrumental origin time and epicenter.

² Local earthquake.

^a Environmental Data and Information Service, NOAA, 1981.

Table C2

MODIFIED MERCALLI INTENSITY (DAMAGE) SCALE OF 1931^a
(abridged)

-
- I. Not felt except by a very few under especially favorable circumstances.
(I Rossi-Forel Scale.)
 - II. Felt only by a few persons at rest, especially on upper floors of buildings.
Delicately suspended objects may swing. (I to II Rossi-Forel Scale.)
 - III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing truck. Duration estimated.
(III Rossi-Forel Scale.)
 - IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, and doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably. (IV to V Rossi-Forel Scale.)
 - V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel Scale.)
 - VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
(VI to VII Rossi-Forel Scale.)
 - VII. Everybody runs outdoors. Damage *negligible* in buildings of good design and construction; *slight to moderate* in well-built ordinary structures; *considerable* in poorly built or badly designed structures. Some chimneys broken. Noticed by persons driving motorcars. (VII- Rossi-Forel Scale.)
 - VIII. Damage *slight* in specially designed structures; *considerable* in ordinary substantial buildings, with partial collapse; *great* in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed. (VIII+ to IX Rossi-Forel Scale.)
 - IX. Damage *considerable* in specially designed structures; well-designed frame structures thrown out of plumb; *great* in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX+ Rossi-Forel Scale.)
 - X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks. (X Rossi-Forel Scale.)
 - XI. Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
 - XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.
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^a Environmental Data and Information Service, NOAA, 1981

Figure C1. Seismicity in the United States, Modified Mercalli Intensity of V or greater (Environmental Data and Information Service, NOAA, 1973)

Figure C2. Location of earthquakes around Anvil Points through May 1981
 (Environmental Data and Information Service, NOAA, 1981)

Figure C3. Attenuation in western United States (Krinitzsky and Chang, 1977)

Figure C4. Seismic zones in the United States with coefficients for earth embankments (U. S. Army Corps of Engineers, ER 1110-2-1806, April 1977)

Seismic Analysis Criteria

C5. A pseudostatic analysis treats the earthquake loading as an inertial force that is applied statically to the embankment, or a segment, at the center of the mass. The analysis determines the ability of the structure to sustain that additional load. In Figure C4, the seismic coefficient for an embankment dam is given as 0.025.

APPENDIX D: PRELIMINARY COST AND TIME ESTIMATE
FOR CONSTRUCTION OF RELOCATION FILL

D1. A preliminary construction cost estimate, including preparation of plans and specifications, contract advertising and awarding, supervision and administration, and engineering and design (for modification during construction) was obtained from the U. S. Army Corps of Engineers Albuquerque District. This District has considerable experience in construction contracting and was considered the best source for an estimate and as a potential agency for accomplishing the construction contracting, supervision and administration for the relocation fill.

D2. The resulting cost estimate is summarized in Table D1. The time estimate in months is given below:

a. Lead time (5.5 months).

(1) Prepare plans and specifications	3.0
(2) Preadvertise	0.5
(3) Advertise	1.0
(4) Award contract	1.0

b. Construction duration, 10 months.

Table D1
Preliminary Estimate of Cost and Time for
Construction of Relocation Fill

Item	Cost in Dollars
Preparation of Plans and Specifications	\$ 47,000
Construction Supervision and Contract Administration	115,000
Construction Engineering and Design (for modifications during construction)	<u>30,000</u>
Subtotal	\$ 192,000
Direct Construction Cost:	
Haul roads, lump sum	75,000
Foundation preparation 200,000 sq yd at \$1.25/sq yd	250,000
Excavation, raking, and hauling 200,000 cu yd at \$5.95/cu yd (Note 1)	1,190,000
Grading ditches and dikes, 1600 linear feet at \$1.00/ft	1,600
Compacted soil layers (behind benches), 14,000 cu yd at \$4.75/cu yd	66,500
Two observation wells, 30 ft at \$50/ft	1,500
Two observation and instrumentation wells, 200 ft at \$100/ft	20,000
Collection ponds, 17,000 cu yd at \$4.95/cu yd	<u>84,150</u>
Subtotal	<u>\$1,688,750</u>
Total Cost, no contingency (Note 2)	\$1,880,750
Total Cost, 25 percent contingency on direct construction cost (Note 2)	\$2,302,938

Note 1. Quantity includes contaminated soil beneath and around pile.

Note 2. Cost does not include maintenance and monitoring.

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