Argonne National Laboratory

Preliminary Feasibility Study

MASTER

Injection of Radioactive Waste by Hydraulic Fracturing at West Valley, New York

Volume 2 - Report

MAY 1978

by
Acres American Incorporated
Buffalo, New York
in association with
Terra Tek Incorporated
Salt Lake City, Utah

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

The information in this document, prepared in support of a study concerning the Western New York Nuclear Service Center, does not present all the data from which conclusions were drawn. The report, TID-28905, Vols. 1 & 2, Western New York Nuclear Service Center Study, was prepared after reviewing and evaluating this and other studies.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Argonne National Laboratory

Preliminary Feasibility Study

**INJECTION OF
RADIOACTIVE WASTE BY
HYDRAULIC FRACTURING AT
WEST VALLEY, NEW YORK**

CONTRACT NO. 31-109-38-4238

✓ **Volume 2 – Text**

May 1978

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

by

Acres American Incorporated
Buffalo, New York
in association with
Terra Tek Incorporated
Salt Lake City, Utah

950 3232

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

149

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the Argonne National Laboratory, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

VOLUME 1 - EXECUTIVE SUMMARY

✓ VOLUME 2 - TEXT

VOLUME 3 - APPENDICES

VOLUME 4 - SUPPLEMENT 1

FOREWORD

This report was prepared by Acres American Incorporated under Contract 31-109-38-4238 to Argonne National Laboratories, dated February 17, 1978. The technical authority at Argonne National Laboratories was Dr. C. Luner, Environmental Input Studies Division. Terra Tek Incorporated of Salt Lake City, Utah, acted as Subconsultants to Acres on this study.

The principal authors of this report were S. N. Thompson, A. S. Burgess, M. A. Mahtab, E. L. Skiba of Acres and A. Abou-Sayed of Terra Tek. R. G. Charlwood of Acres provided general consultation, program planning and review. J. C. Roegiers acted as a Reviewer and Consultant for Acres. Fracture testing was carried out in Terra Tek's laboratories.

Acres wish to acknowledge the assistance and comments from C. Luner; M. Chasanov and N. Beskid of Argonne National Laboratories and H. O. Weeren at Oak Ridge National Laboratories and G. Chase and R. J. Sun of the United States Geological Survey.

C. WILLETT

D. C. Willett
Acres American Incorporated

TABLE OF CONTENTS

LIST OF TABLES
LIST OF FIGURES

<u>VOLUME 2</u>	<u>Page</u>
1 - INTRODUCTION -----	1.1
2 - SUMMARY AND CONCLUSIONS -----	2.1
3 - GEOLOGY -----	3.1
3.1 - Introduction -----	3.1
3.2 - Geologic History -----	3.1
3.3 - Site Geology -----	3.3
3.4 - Seismicity -----	3.4
3.5 - Oil and Gas Production -----	3.4
4 - WEST VALLEY SITE CONDITIONS -----	4.1
4.1 - Introduction -----	4.1
4.2 - Stratigraphy -----	4.1
4.3 - Selection of Horizons for Analysis -----	4.4
4.4 - Rock Mechanics Properties -----	4.6
4.4.1 - Introduction -----	4.6
4.4.2 - Previous Data on Devonian Shales -----	4.6
4.4.3 - Properties of Shale From Well No. CH1 at West Valley -----	4.9
4.5 - In Situ Stresses -----	4.13
4.5.1 - Introduction -----	4.13
4.5.2 - Regional Stress Field -----	4.14
4.5.3 - Relationship Between Stress Fields and Structural Geologic Patterns -----	4.15
4.5.4 - Magnitude of the Vertical Stress -----	4.16
4.5.5 - Magnitude and Orientation of the Horizontal Stress -----	4.16
4.6 - Summary -----	4.18
5 - EVALUATION OF HYDRAULIC FRACTURING IN SHALE AT WEST VALLEY -----	5.1
5.1 - Introduction -----	5.1
5.2 - General Requirements -----	5.2
5.3 - Review of Previous Hydraulic Fracturing Tests at West Valley -----	5.2
5.4 - Horizontal Crack Initiation -----	5.7
5.5 - Analysis of Crack Propagation -----	5.9
5.5.1 - Introduction -----	5.9
5.5.2 - Classical Solution Model -----	5.10
5.5.3 - Finite Element Model -----	5.16
5.6 - Summary -----	5.23

	<u>Page</u>
6 - HYDROLOGICAL ANALYSIS -----	6.1
6.1 - Introduction -----	6.1
6.2 - Surface Water -----	6.1
6.3 - Groundwater -----	6.2
6.3.1 - Modeling -----	6.2
6.3.2 - Regional Geohydrology -----	6.7
6.3.3 - Parameters -----	6.8
6.3.4 - Analyses -----	6.10
6.4 - Summary -----	6.12
7 - PROPOSED WASTE INJECTION CONCEPT -----	7.1
7.1 - Introduction -----	7.1
7.2 - Waste Inventory and Composition of Waste at West Valley -----	7.1
7.3 - Choice of Horizons at West Valley -----	7.6
7.4 - Waste Injection at West Valley - Waste Form -----	7.6
7.4.1 - Estimate of Pumped Volume -----	7.9
7.4.2 - Geometry of Induced Fractures -----	7.10
7.5 - Comparison with ORNL -----	7.13
7.6 - Summary -----	7.17
8 - PRELIMINARY HAZARD ANALYSIS -----	8.1
8.1 - Approach -----	8.1
8.2 - Design Conditions -----	8.1
8.3 - Designed Operations -----	8.10
8.4 - Accidents and Failures -----	8.11
8.5 - Summary -----	8.13
9 - FEASIBILITY DISCUSSION -----	9.1
10 - RESEARCH AND DEVELOPMENT REQUIREMENTS -----	10.1
10.1 - General Program and Objectives -----	10.1
10.2 - Prefeasibility Studies (FY78) -----	10.5
10.3 - Research and Development (FY79) -----	10.6
10.4 - Proof Test and Design (FY80) -----	10.11

LIST OF REFERENCES

VOLUME 3

APPENDIX A - LOG DATA FROM WEST VALLEY

APPENDIX B - DETERMINATION OF ELASTIC CONSTANTS FOR
TRANSVERSELY ISOTROPIC ELASTIC MEDIA BY
ULTRASONIC VELOCITY MEASUREMENTAPPENDIX C - MEASUREMENT OF FRACTURE TOUGHNESS
ANISOTROPY FOR WEST VALLEY SHALE

Table of Contents - 3

APPENDIX D - CRITICAL REVIEW OF IN SITU STRESS
MEASUREMENT TECHNIQUES

APPENDIX E - STRESS MEASUREMENT DATA

APPENDIX F - HYDRAULIC FRACTURING MEASUREMENTS
WEST VALLEY, NEW YORK

APPENDIX G - ENHANCEMENT OF HORIZONTAL CRACK
INITIATION BY JETTING

APPENDIX H - DESCRIPTION OF FINITE ELEMENT PROGRAM
FOR ANALYSIS OF CRACK PROPAGATION

APPENDIX I - WELL DATA

APPENDIX J - DESCRIPTION OF FINITE ELEMENT PROGRAM
FOR GROUNDWATER FLOW ANALYSIS

LIST OF TABLES

<u>Number</u>	<u>Title</u>
4.1	Simplified Log of West Valley Well No. NFS CH1
4.2	Rock Properties - Well No. 20403, West Virginia Laboratory Static Triaxial Test Data From Columbia Gas System Service Corporation
4.3	Dynamic Laboratory Data (Terra Tek, Inc.) and Log Data (Birdwell) on Columbia Gas System Service Corp., Well No. 20403
4.4	Constitutive Relations for Transversely Isotropic Materials
4.5	Elastic Constants and Moduli for Transversely Isotropic Shale - Well No. CH1 - West Valley
4.6	Comparison of In situ and Laboratory Tests for Sonic Velocities and Approximate Isotropic Moduli Well No. CH1 - West Valley
4.7	Input Parameters for Analysis of Crack Propagation
5.1	Comparison of ORNL and West Valley Sites
5.2	Instantaneous Shut-In Pressure, Calculated Overburden Pressure, Tensile Strength and Average Cohesive Strength at Fracture Tip for the West Valley Shale
5.3	Description of Cases Analyzed by Finite Element Model
5.4	Energy Release Rates for a Range of Crack Pressures for the 5 Cases of Table 5.4 (V,H Axes)
5.5	Energy Release Rates for a Range of Crack Pressures for the 5 Cases of Table 5.4 (1,2 Axes)

LIST OF TABLES - 2

<u>Number</u>	<u>Title</u>
6.1	Air and Water Permeabilities ORNL
6.2	Permeability and Porosity Values for Shales in the West Valley Area (Chase, 1978)
7.1(a)	Radioactivity Inventory West Valley Waste Tank ⁽¹⁾
7.1(b)	Estimated Actinide (Transuranium) Content and Activity in 8D2 Waste
7.2	Estimated Composition of Contents of Waste Tank 802 ⁽¹⁾
7.3	Composition of Thorium Bearing Waste Tank 8D4 ⁽¹⁾
7.4	Composition of Dry Mix Used in Cementitious Grout Preparation at ORNL
7.5	Representative Parameters for West Valley Shale Injection
7.6(a)	Neutralized Waste Supernate Activity
7.6(b)	Neutralized Waste Sludge Activity
8.1	Grout Compositions
8.2	Grout Leaching for West Valley
8.3	Relative Velocities in Shale
8.4	Velocity of ⁹⁰ Sr Migration Relative to Groundwater Velocity (v_i/v_w) ⁹⁰ Sr
8.5	Relative Transport Velocities
10.1	Estimated Costs for Fiscal Year 1979

LIST OF FIGURES

<u>Number</u>	<u>Title</u>
3.1	Location Map - West Valley
3.2	Physiographic Map - West Valley
3.3	Geologic Map - West Valley
3.4	Earthquake Epicenters and the Clarendon-Linden Fault System
3.5	Recorded Microseismic Earthquake Events - Western New York - 1970 to 1975
4.1	Generalized Stratigraphic Column for Western New York
4.2	Preglacial Buried Valley
4.3	Devonian Shale Basin of Eastern United States
4.4	Shale Well Locations - Columbia/ERDA Research Programs
4.5	Location Magnitude and Direction of Measured Horizontal Principal Stresses - North Central U. S., Southeast Canada
4.6	Ratio of $\sigma_{\min}$ to σ_{OB} in Sedimentary Rock, North America
4.7	Plot of Measures Values of $\sigma_{H(\min)}$ Versus Depth
4.8	Plot of Measures Values of $\sigma_{H(\max)}$ Versus Depth
5.1	Skewed Crack Under Far Field Stress and Internal Pressure
5.2	Orientation of Propagating Crack Which Maximizes Energy Rates
5.3	Conditions for Crack Propagation
5.4	Finite Element Mesh and Boundary Conditions (Plane Strain Analysis)
5.5	Typical Plots of Energy Release Ratio Versus Hydraulic Pressure in Crack (Finite Element Analysis Results)

LIST OF FIGURES - 2

<u>Number</u>	<u>Title</u>
6.1	Surface Water Drainage Basins
6.2	Plan of Site Area
6.3	Discharge Duration Curve for Cattaraugus Creek at Gowanda
6.4	Water Wells in Site Area
6.5	Groundwater Modeling North-south Section Case 1 - Isotropic
6.6	Groundwater Modeling North-south Section Case 2 - Anisotropic 1 Degree Dip
6.7	Groundwater Modeling North-south Section Case 3 - Anisotropic 2 Degrees Dip
6.8	East-west Section Vertical Groundwater Velocities Beneath Valley Bottom
7.1	Cement-Bentonite-Water Mixes
7.2	Areal Extent of Fracture System, Special Test, Pine Island Field, Louisiana
10.1	Proposed High-Level Radioactive Waste Injection Program at West Valley, New York

1 - INTRODUCTION

This report presents the results of the preliminary study undertaken by Acres American Incorporated, of the technical feasibility of the disposal of radioactive waste by hydraulic fracturing and injection into shale formations below the Nuclear Fuel Services Incorporated site at West Valley, New York. At this time there are approximately 600,000 gallons of high level neutralized Purex waste, including both the supernate (liquid) and sludge, and a further 12,000 gallons of acidic Thorex waste stored in tanks at the West Valley facilities. This study assesses the possibility of combining these wastes in a suitable grout mixture and then injecting them into deep shale formations beneath the West Valley site as a means of permanent disposal.

This study addresses the principal geotechnical factors which need to be considered for assessing the feasibility of injection into shale beds. These factors include the regional and site geology, the mechanics of hydraulic fracturing, the hydrological environment, the development of a waste injection concept and a preliminary hazards analysis.

Following the technical discussions, a summary discussion of the feasibility issues is presented. This leads to a definition of the research and development program required in order to demonstrate the technical adequacy of the scheme. A discussion of the nature of the facilities and equipment which will be required for hydraulic fracturing and waste injection is addressed in Supplement 1 to this report. This includes both the construction and operation phases together with associated schedules and cost estimates.

Since only limited site specific data are available for this feasibility study a safety analysis was not included in the scope of the work. However, prior to acceptance of the concept, an analysis will clearly be required at an early stage in the research and development program.

Hydraulic fracturing experiments were conducted at West Valley by the United States Geologic Survey (USGS) and Oak Ridge National Laboratories (ORNL) from 1969 to 1971 (de Laguna 1972, Sun 1973). Waste injection was not carried out at that time, but these tests have provided useful data for this study.

Hydraulic fracturing and injection of radioactive wastes into shale formations has been done extensively at ORNL since the mid 1960's (de Laguna 1968, Weeren 1976, Moore 1976, R. J. Sun 1976, ERDA 1977, and others). A new hydrofracturing facility at ORNL has been designed and is presently under construction (Lampton et al 1975). Consequently a considerable amount of experience and test data is now available and has been used as a basis for comparison in this assessment of the feasibility of injection at the West Valley site.

The approach adopted for this feasibility assessment relied heavily on parametric studies using analytical techniques. This was necessary due to the shortage of site specific data. The key question of whether fractures would initiate and propagate horizontally was addressed through the use of various fracture mechanics approaches. Fracture toughness tests were performed on several core samples from the previous West Valley test core and the results of these tests were used in the analysis.

In order to define the environment into which the waste might be injected, a preliminary hydrological assessment was made. This hydrological assessment will also provide the preliminary basis for subsequent safety analyses. A brief hazards analysis was made of the principal isolation aspects.

The hydraulic fracturing analyses, hydrological studies and hazards analysis were then used to develop the development program required to confirm and implement the concept.

2 - SUMMARY AND CONCLUSIONS

The feasibility of the disposal of 600,000 gallons of stored high-level neutralized Purex waste and acidic Thorex waste by hydraulic fracturing and injection into the deep shale beds beneath the Nuclear Fuel Services, Incorporated West Valley site was assessed.

The West Valley New York site geology consists of gently dipping Upper Devonian shales which are overlain by Pleistocene glacial deposits. The east and northeast part of the site is underlain by a deep preglacial buried valley which is filled with up to 550 feet of glacially derived sediments.

The terrain possesses moderate relief with northerly drainage provided by Buttermilk and Cattaraugus Creeks. There are no mapped faults or folds within the immediate area of the site and the seismicity appears to be low. Natural gas well drilling has been undertaken throughout the region with some recent interest being expressed in gas production in the Devonian shales of Western New York. Many water supply wells are in operation in this area down to depths of 250 feet.

One test borehole, drilled to a depth of 1,500 feet, was hydraulically fractured at West Valley by the USGS and ORNL from 1969 to 1971. This test data was evaluated and the core examined for this study. Fracture toughness tests were performed on several pieces of core. Other than this site specific data, all other data used for this study were from the general literature. In situ stress parameters were estimated from general regional data. Localized changes in the stress fields that may be caused by the buried valley were not considered for this study.

It is recommended that an extensive field program be initiated to yield site specific data for more detailed studies.

The primary objective of this study was to demonstrate that hydraulic fractures could be initiated, and would propagate horizontally along certain selected shale bedding planes. In addition, a preliminary assessment of the hydrological regime was carried out in order to provide an initial basis for subsequent safety studies.

In view of the lack of site specific data and uncertainties in hydraulic fracturing theories, two analytical approaches were used parametrically to provide a basis for confidence in the prediction of crack propagation direction. These were classical solutions for isotropic material properties and a finite element, linear elastic fracture mechanics computer program for anisotropic materials. For the purpose of this study, two stratigraphic horizons (850 to 1,250 feet below ground surface) were chosen for analysis to confirm their preference for horizontal hydraulic fracturing. These horizons were selected after a review of the physical description of the previous drillhole cores and the associated electric and geophysical logging.

It was shown that fractures could be initiated horizontally at the borehole by the use of jetting techniques to cut a horizontal slot to start the fracture. Utilizing the limited amount of site specific data it was then demonstrated analytically that, once initiated, the cracks would propagate horizontally, even if they encountered local, near vertical fractures.

The preliminary hydrological studies addressed the following processes:

- leach rates of radionuclides from the grout

- groundwater flow paths and velocities,
- retardation of radionuclide within the shale.

The rate of release of radionuclides is determined by the leach rates of the nuclides from the grout. Subsequently, the extent of the transport of the radionuclides is substantially limited by slow groundwater movement and retardation within the shale. Consequently, these three processes provide almost independent mechanisms for isolation of radionuclides.

A review of ORNL reports indicated that grout mixes with low leach rates utilizing readily available material have been previously developed and these appear suitable for the West Valley waste. Using a grout mix similar to that in use at ORNL the total injection volume was estimated. Using multiple injection levels, the areal extent of the grout sheet is likely to be within a radius of 1,200 to 2,000 feet from the injection point. The waste will be heat generating, but based on ORNL experience this is not expected to cause problems.

The groundwater movement in a generalized cross-section of the bedrock at West Valley was simulated using a finite element model. Permeability and porosity values were based on data of similar rock types in northwest New York State. These analyses showed that groundwater movement near a grout sheet would be extremely slow with groundwater passing the injected zone flowing towards Buttermilk Creek. The effects of local wells and the buried valley beneath the site on the groundwater regime were not considered in this analysis. Further studies should include these effects.

Preliminary estimates indicated that retardation of radionuclides in the shale beds due to adsorption and ion-exchange

will be very effective in reducing transport velocities and providing isolation of the waste.

A preliminary hazards analysis was performed to identify the mechanisms of potential concern for subsequent safety analyses. Two accident scenarios were considered: a wellhead rupture causing bleedback, and an unexpected vertical fracture, cutting the injection horizon. It was concluded that adequate safety design and contingency plans based on the ORNL schemes could be applied at West Valley to contain any spills during operation. However, site specific field testing, monitoring and injection procedures must be developed and implemented prior to injection of waste material at West Valley.

In summary, the preliminary feasibility assessment indicated that at the 850 to 1,250 feet horizons, horizontal fracturing and injection could be effectively achieved. However, a detailed safety analysis is required to establish the acceptability of the degree of isolation. The principal concerns regarding isolation are due to existing and possible future water supply developments within the area and the local effects of the buried valley. In addition, possible future natural gas developments are of concern. The definition of an exclusion zone may be appropriate to avoid problems with these developments. The buried valley may require the injections to be limited to the lower horizon depending on the results of further investigations.

A general program for the development, verification and implementation of the injection concept was developed. This includes additional brief prefeasibility studies to include a preliminary safety analysis and an assessment of possible conflicts with future water supply and natural gas developments, in fiscal year 1978; an exploratory field drilling and testing research program in fiscal year 1979; a proof

test and design program for fiscal year 1980; followed by licencing, construction, injection and decommissioning by early 1984. An accelerated program with completion by 1982 was also indicated as a possibility.

The costs of the program are summarized below. These are approximate figures for planning purposes only.

Phase 1	Prefeasibility Studies	\$ 100,000.
Phase 2	Research and Development	\$1,000,000.
Phase 3	Proof Test and Design	\$1,000,000.
Phase 4	Licencing	\$ 250,000.
Phase 5	Construction	see Supplement 1
Phase 6	Injection Operation	see Supplement 1
Phase 7	Decommissioning	<u>\$ 500,000.</u>

Total Estimated Program Cost	<u>\$2,850,000.*</u>
------------------------------	----------------------

* Not including Phases 5 and 6.

3 - GEOLOGY

3.1 - Introduction

West Valley lies approximately 30 miles SSE of Buffalo, New York in the north central portion of Cattaraugus County (Figure 3.1). The town of West Valley is at an approximate elevation of 1,500 feet. The town is bounded by hills to the east and west which rise 400 to 500 feet above the town. The region is drained by Buttermilk Creek which flows north-south and enters Cattaraugus Creek which in turn drains into Lake Erie.

Bedrock consists of gently dipping, relatively undeformed Upper Devonian shales which are overlain by varying thicknesses of Pleistocene glacial deposits.

Physiographically, West Valley is within the Appalachian Plateau Province, a large physiographic subdivision that extends from New York to Alabama (Figure 3.2). This portion of the province is characterized by dissected Paleozoic sedimentary rocks. The erosion processes have formed a terrain of moderate to high relief.

3.2 - Geologic History

West Valley lies within the northwest portion of the Appalachian Basin, an elongated sedimentary basin which extends from the Canadian Shield in southern Quebec and Ontario southward to Central Alabama. The basin extends laterally from Central Ohio and Kentucky eastward to the Blue Ridge.

The basin is delineated as an eastward dipping segment of the earth's crust which has been filled with a thick sequence of Paleozoic age sediments. Basin subsidence commenced in the late Precambrian and continued intermittently throughout the Paleozoic, with the greatest subsidence occurring along its eastern edge. The source area for the basin sediments was generally from the east and north. Sediment thicknesses range from less than 2,000 feet along the Findlay Arch in Ohio to greater than 35,000 feet along the west flank of the Blue Ridge in West Virginia.

Stratigraphy and sedimentology studies indicate that most of the basin sediments were deposited in a miogeosynclinal environment. The high percentages of carbonates, shales and argillaceous material indicate a shallow water environment where the rate of deposition closely balanced the rate of sea floor subsidence. The stratigraphy, particularly along the western and northern boundary of the basin, is marked by hiatuses where the stratigraphic sequence has been interrupted by periods of nondeposition, evaporation and erosion.

The Appalachian Basin has undergone a number of complex orogenic and tectonic events since the Precambrian.

The major tectonism that occurred during the early and middle Paleozoic had only minor effects in Western New York. These events, which were most strongly felt along the eastern portion of the basin, resulted in regional uplift of the area causing erosion and/or periods of nondeposition. The most intense tectonic activity to affect the basin occurred during the late Paleozoic and early Mesozoic time. This event, referred to as the Appalachian Orogeny, resulted in regional folding and faulting occurring roughly perpendicular to the long axis of the basin. The greatest structural

deformation resulting from the orogeny was felt in the eastern part of the basin where the rocks were folded into closely spaced folds and cut by low-angle thrust faults. Folding and faulting becomes progressively less towards the west with only very low amplitude folding occurring in Western New York.

Since the early Mesozoic, the Western New York region has remained stable with only minor crustal uplifts and subsidences.

3.3 - Site Geology

The West Valley site is underlain by Cambrian through Devonian age sedimentary rocks. As discussed in Section 3.1 this region of the Appalachian Basin has been only slightly effected by tectonic events. A generalized geologic map of West Valley and vicinity is shown in Figure 3.3. The site is situated on a thick series of upper Devonian shales of the Canadaway and Conneaut Groups. The rocks gently dip 2 to 3 degrees to the south. Much of the area is covered by thick glacial deposits which reach nearly 600 feet in depth in the buried valley along the east and north portion of the West Valley site.

The nearest mapped fault to the site is the Clarendon-Linden fault, approximately 25 to 30 miles east of the site.

This fault is considered a major tectonic feature in Western New York. It trends north-south for over 60 miles from Lake Ontario to the New York - Pennsylvania border (Figure 3.4). Detailed mapping based on well log data shows one main fault bordered on the east and west by two subparallel faults. The Clarendon-Linden structure appears as a series of reverse faults with the main fault dipping easterly (Fletcher and Sykes, 1977). Stratigraphic offsets of subsurface units indicate that the major deformation appears to be younger than the most recent rock units in the area (post middle Devonian).

3.4 - Seismicity

Figure 3.4 is a plot of historically occurring macro earthquakes in Western New York from 1857 to 1973. As can be seen from the Figure, a majority of these events (including the 1929 intensity VIII Attica earthquake) occurred in close proximity to the Clarendon-Lindon fault.

Work performed by Fletcher and Sykes (1977) and others indicates induced microseismic activity associated with the Dale brine field in the Attica, New York area. It is their hypothesis that hydraulic fracturing and pumping within the brine field has resulted in the release of stress along the fault system. A plot of the microseismic activities monitored from 1970 to 1975 supports this observation. However, as shown in Figure 3.5, these earthquakes occurred along portions of the Clarendon-Lindon fault. It is expected that lesser microseismic activities would be induced and similarly limited, due to hydraulic fracturing at West Valley.

In conclusion, it may be stated that, with the exception of the seismic activity in the Attica area, the natural seismicity in Western New York as a whole appears to be low to moderate, and the potential for induced seismicity due to hydraulic fracturing at West Valley is limited.

3.5 - Oil and Gas Production

Drilling for natural gas has been extensive throughout Western New York. Gas drilling is most active west of West Valley in Chataugua County and along the shores of Lake Ontario.

The primary producing unit is the Medina Group, a series of Lower Silurian shales, sandstones and siltstones. This unit, which is approximately 3,500 feet below the West Valley site is capped by a thick series of Middle and Upper Silurian shales and carbonates of the Clinton and Lockport Groups, which in turn are overlain by the evaporite series of the Salina Group. West Valley is not presently considered a gas production area. However, the actual potential resources of this area are currently unproven.

Recent electric and geophysical logging performed in wells in Chautaugua and Cattaraugus Counties have shown gas flows and/or porous zones within the Upper Devonian Shales (personal communication). During the course of this study, Acres was informed of a pending proposal submitted by a Western New York gas company to the New York State ERDA, to massively hydrofracture the Upper Devonian Shales in Chautaugua County for gas production. We were informed that if this scheme proved feasible for enhancing gas production then additional hydrofracturing of the Devonian Shales would be performed throughout the area to include Cattaraugus County.

10 0 10 20
SCALE IN MILES

FIG. 3.1

LOCATION - WEST VALLEY

PHYSIOGRAPHIC MAP - WEST VALLEY

FIG. 3.2

LEGEND

Dwf	WEST FALLS GP-SHALE AND SANDSTONE
Dj	JAVA GP-SHALES AND SANDSTONE
Dcy	CANADAWAY GP - SHALES

Dct	CONNEAUT GP-SHALES, SILTSTONES, SANDSTONES
Dco	CONEWANGO GP-SHALE SANDSTONE, CONGLOMERATE

FIG. 3.3

GEOLOGIC MAP - WEST VALLEY

EARTHQUAKE INTENSITY
MODIFIED MERCALLI SCALE

- - V
- - VI
- - VII
- - VIII

FIG. 3.4

EARTHQUAKE EPICENTERS AND THE
CLARENDON-LINDEN FAULT SYSTEM

RECORDED MICROSEISMIC EARTHQUAKE EVENTS
WESTERN NEW YORK—1970-1975

4 - WEST VALLEY SITE CONDITIONS

4.1 - Introduction

This section reviews and analyzes the available geotechnical data at West Valley for the purpose of establishing key site-related parameters for the analytical and numerical models of hydrofracturing and injection which are presented in Section 5 of this report. Unfortunately, site-specific data are very limited. As a result, site data relating to rock mechanic properties and the regional stress conditions have been estimated from regional data by extrapolation, and ranges of values used where major uncertainty exists.

4.2 - Stratigraphy

The West Valley site is underlain by up to 5,000 feet of relatively undeformed Paleozoic age sedimentary carbonates, sandstones, shales and evaporites. Due to rock stress limitations (see Section 4.5), only the upper 1,500 to 2,000 feet of upper Devonian rocks were considered feasible for horizontal hydrofracturing at West Valley. The stratigraphy of these Western New York Devonian shales is complicated by a variety of formation names and time-transgressive units. Dr. L. Rickard of the New York State Geologic Survey has compiled a detailed Devonian correlation chart for all of New York State. Figure 4.1 is a generalized summary of a portion of his work covering the Upper Devonian shales in Western New York.

The generalized site geology map of the West Valley areas (Figure 3.3) shows the Conneaut and Canadaway groups outcropping in the vicinity of the site. The younger Conneaut Group sediments outcrop in the hills on either side of West Valley and to the south, while the older Canadaway Group outcrops in the valleys and to the north.

Work performed by others (Safety Analysis Report NFS Reprocessing Plant, West Valley, New York, Docket No. 50-201) shows that the present Buttermilk Creek, which crosses the site, flows mainly on glacial deposits and recent alluvium. Seismic refraction and borings in the vicinity of the site show the presence of a deep preglacial bedrock valley which trends approximately N25W across the site. Profiles across the valley show the gorge has an average depth of 550 feet below ground surface and slopes northward (Figure 4.2).

The present Buttermilk Creek Valley has been eroding into unconsolidated glacial material since the retreat of the last major glaciation (10,000 - 15,000 years ago). The much larger buried valley, which is incised into the underlying shales was eroded over many millions of years and was probably further deepened by glacial scouring.

A continuous boring was core drilled during the early hydraulic fracturing test program at West Valley (NFS CH1). The boring was drilled to a depth of approximately 1,500 feet, and the hole logged by geophysical methods and the core examined. A summary of pertinent rock characteristics from the core is presented in Appendix A and Table 4.1.

The boring site area was covered by approximately 175 feet of glacial tills and weathered shales. All of the rock drilled was part of the Upper Devonian shales of the Conneaut, Canadaway and West Falls groups. About 100 feet of the rock cored

TABLE 4.1 - SIMPLIFIED LOG OF WEST
VALLEY WELL NO. NFS CH1

4.3

Depth, ft.		Modulus E (10 ⁶ psi)
0	Glacial Drift	
100		
200	Weathered shale	?
300	Silty shale & siltstone mod. fissile to mass., pref. frac. at shale-silt contacts	300
STFIELD SHALE		
400	Silty shale, seams of silt, fissile, some sharpstone	5.5 400
500	Silty shale & shaley siltstone cross-bedded shale & siltstone fractured silty shale	4.5 500
501 ft. long		
600	Shale with thin beds of siltstone, sharpstone cong., mass. individual beds with frac. along contacts.	5.1
CANADAWAY		
635 ft.	Thick beds of shaley siltstone & silty shale, calcareous zone at 635 ft	700
700	Silty shale, slightly calcareous & petroliferous	4.5 760
800	Dunkirk transition zone occasionally calcareous, pyritic & cross-bedded structure	5.5 850
900	Petroliferous & pyritic shale with siltstone layers & frac. parallel to bedding	4.8 910
1000	Interbedded shale and siltstone with sharpstone cong	6.5 1030
1100	Shale interbedded with siltstone with some sharpstone cong.	5.3 1100
1170	Shale with beds of siltstone & pyrite, one 5-ft long vert. frac. with base at 1159 ft	5.5 1170
1200	Shale with silt & pyrite seams & occasional fossils	1250
1300	Shale with fossils, occasionally petroliferous, several vert. joints filled with calcite, 1 vert. frac. 4.7 ft long with base at 1316 ft	4.8
1400	Shale with silt, pyrite & pet. several vertical joints up to 12-in. long	
1500		1500

was a sandy siltstone, partially thick-bedded to massive. The core samples and the electric logs suggest that the siltstone, unlike the shales, may have some limited permeability. Some of the dark shales and black shales penetrated, particularly near the bottom of the well, had a distinct odor of petroleum when freshly broken.

4.3 - Selection of Horizons for Analysis

The depth for hydrofracturing and injection of radioactive wastes is restricted by two primary considerations:

- (a) that the level to be used for injection is sufficiently deep to ensure that there will be no leakage of contaminants into the biosphere, and
- (b) that the depth not exceed the point where $\sigma_V \geq \sigma_H$.

For the purposes of this study, two stratigraphic horizons were chosen for the performance of a classical and a finite element analysis for horizontal hydrofracturing. These horizons were selected after a thorough review of the physical description of the boring log for Well No. NFS CH1 (see Table 4.1 and Appendix A) and the associated electric and geophysical logging data. These horizons were selected for

- (a) their apparent stratigraphic continuance and relative homogeneity,
- (b) the absence of large vertical fractures, and
- (c) their low Young's modulus values which indicate potential weaknesses of the rock along bedding planes.

A brief description of the two horizons is discussed below.

Horizon 1

- Depth - Range 850 to 950 feet, nominal 850 feet
- In situ E - 4.8×10^6 psi (isotropic material assumption)
(dynamic)
- Petrography - petroliferous and pyritic shale with siltstone layers
- Fractures - bedding joints or planes of weakness parallel to bedding. Two vertical joints, one from 879 to 880 feet, and the other from 903 to 905 feet.

Horizon 2

- Depth - Range 1,170 to 1,250 feet, nominal 1,250 feet
- In situ E - 4.8×10^6 psi (isotropic material assumption)
(dynamic)
- Petrography - shale with silt and pyrite seams and occasional fossils, slightly petroliferous
- Fractures - no vertical or horizontal joints identified.

Several other horizons in the ranges of 400 to 500 feet and 700 to 760 feet were also considered potentially suitable for analyses on the basis of low Young's modulus and rock descriptions. However, these horizons were considered too shallow for this investigation. Similarly, horizons below 1,250 feet were not considered suitable on the grounds of $\sigma_{H(\min)}$ may approach σ_v at these depths.

4.4 - Rock Mechanics Properties

4.4.1 - Introduction

As stated in Section 4.1, only a limited amount of rock mechanics properties is available for the Devonian shales at West Valley. As a result, previous rock data on Devonian shales of the Eastern United States were compiled to assist in defining key values required for the analytical and numerical modeling. Nine rock samples were collected at varying depths from boring CH1 drilled at West Valley and tested for fracture toughness and elastic constants. A discussion of the rock mechanics properties utilized in the modeling is addressed in this section.

4.4.2 - Previous Data on Devonian Shales

Several wells have been drilled in the Devonian Shale Basin of the Eastern United States (see Figure 4.3 and 4.4). The mechanical properties of Devonian shale at depths of 3,000 to 4,000 feet in Columbia Gas System Service Corporations Well No. 20403 as determined from laboratory and in situ measurements are given in Tables 4.2 and 4.3.

Static triaxial laboratory tests are given in Table 4.2. The static elastic moduli, E and ν , in Table 4.2 were determined under confining pressures that equal the in situ geostatic σ_v . The shale was assumed to be an isotropic medium.

Table 4.3 gives the results of dynamic laboratory and log tests and calculated dynamic moduli, assuming isotropic material.

TABLE 4.2

ROCK PROPERTIES - WELL NO. 20403, WEST VIRGINIA
LABORATORY STATIC TRIAXIAL TEST DATA FROM
COLUMBIA GAS SYSTEM SERVICE CORPORATION

<u>Type of Shale</u>	<u>Depth (ft)</u>	<u>Conf. Pressure (psi)</u>	<u>Triaxial Compression</u>		<u>Triaxial Tension</u>	
			<u>E (10⁶ psi)</u>	<u>ν</u>	<u>E (10⁶ psi)</u>	<u>ν</u>
Upper Brown	2,981	2,981	4.28	0.21	3.14	0.17
Middle Brown	3,446	3,446	4.79	0.20	3.59	0.18
Lower Gray	3,821	3,821	4.90*	0.25*	3.00	0.20
Lower Brown	3,996	3,996	8.00	0.37	3.60	0.20

*All values are averages of three tests, except those marked with an asterisk
which are averages of four tests

Note: Material is assumed to be isotropic

TABLE 4.3 - DYNAMIC LABORATORY DATA (TERRA TEK, INC.) AND LOG DATA
(BIRDWELL) ON COLUMBIA GAS SYSTEM SERVICE CORP., WELL NO. 20403

4.8

Depth	Orientation	VELOCITIES				MODULI						POISSON'S RATIO		SPECIFIC GRAVITY	
		P-Wave (Ft/Sec)		S-Wave (Ft/Sec)		Young's E (psix10 ⁶)		Bulk K (psix10 ⁶)		Shear G (psix10 ⁶)		v			
		Log	Lab	Log	Lab	Log	Lab	Log	Lab	Log	Lab	Log	Lab	Log	Lab
2880	Parallel	13420	13640	7180	8950	4.81	6.43	4.0	2.84	1.85	2.86	.300	.122	2.67	2.66
2880	Normal	-	16800	-	9500	-	8.26	-	5.74	-	3.27	-	.260	-	2.67
2891	Parallel	13460	13450	7270	8030	4.90	5.75	3.96	3.46	1.89	2.35	.294	.223	2.66	2.71
2891	Normal	-	16920	-	10260	-	9.29	-	5.32	-	3.84	-	.209	-	2.71
3110	Parallel	12490	12900	6830	7560	4.27	5.06	3.34	3.23	1.66	2.04	.287	.239	2.64	2.66
3110	Normal	-	16810	-	9550	-	8.26	-	5.77	-	3.28	-	.261	-	2.67
3365	Parallel	11650	12170	6670	7340	3.89	4.63	2.66	2.70	1.55	1.91	.257	.214	2.58	2.63
3365	Normal	-	16320	-	9260	-	7.66	-	5.38	-	3.03	-	.263	-	2.63
3446	Parallel	12040	12230	6330	7740	3.56	4.69	3.10	2.35	1.36	2.01	.309	.167	2.52	2.50
3446	Normal	-	15750	-	9750	-	7.56	-	4.06	-	3.18	-	.190	-	2.48
3596	Parallel	11200	11740	6080	7400	3.19	4.39	2.55	2.22	1.24	1.87	.291	.170	2.48	2.54
3596	Normal	-	16260	-	9980	-	8.19	-	4.52	-	3.42	-	.198	-	2.55
3675	Parallel	13250	13710	6800	8660	4.31	6.30	4.01	3.16	1.63	2.70	.321	.168	2.61	2.67
3675	Normal	-	16520	-	10240	-	8.96	-	4.79	-	3.77	-	.188	-	2.67
3910	Parallel	12280	10780	6760	6540	4.16	3.47	3.19	1.99	1.62	1.44	.283	.209	2.63	2.49
3910	Normal	-	16080	-	10090	-	8.02	-	4.12	-	3.41	-	.175	-	2.49
4020	Parallel	11880	11670	6600	6970	3.85	4.07	2.87	2.45	1.51	1.66	.276	.223	2.57	2.54
4020	Normal	-	16750	-	9770	-	8.13	-	5.26	-	3.27	-	.242	-	2.54

Note: Material is assumed to be isotropic

Both the moduli generally increase with depth (higher confining pressure), their values being lower in triaxial tension than in compression (e.g. the average ratio for E values is 0.64).

Table 4.3 lists the values of the in situ dynamic moduli for the same well, normal to the bedding and the laboratory-determined dynamic moduli of the shale normal as well as parallel to the bedding. There is no significant difference between the moduli determined from the laboratory and the in situ measurements made perpendicular to the bedding. However, the moduli determined parallel to the bedding are from 1.5 to 2.5 times the moduli normal to the bedding, indicating that the shale is elastically anisotropic, in particular transversely isotropic.

4.4.3 - Properties of Shale From Well No. CH1 at West Valley

The following nine samples of NX-size core from Well No. CH1 at West Valley were tested for fracture toughness and/or elastic constants.

<u>Depth</u> (ft)	<u>Length of Core</u> (in)
546.5	2.5
705.5*	2.0
707.5	3.0
853.0+	3.0
857.5*+	2.5
1,274.0	3.0
1,275.0*	3.5
1,309.0	3.0
1,478.0*	3.0

Those samples from the depths indicated by an asterisk were tested for elastic constants, whereas the samples from depths indicated by a plus sign were tested for fracture toughness.

The techniques for measuring fracture toughness and elastic constants are described in Appendices B and C. The critical fracture toughness K_{IC} was determined for two directions, parallel and normal to the bedding planes. It was only possible to actually record and test specimens obtained from depths of 853 and 857 feet, because of the deteriorated condition of the core.

As noted earlier, the Devonian shale (which includes the shale encountered in Well No. CH1) generally exhibits anisotropic behavior. The dynamic tests performed on the shale samples were analysed to obtain the five independent elastic constants for a transversely isotropic material. The constitutive relations for this material are illustrated in Table 4.4 where the axes 1, 2 are assumed to lie in the bedding plane(s) and the axis of symmetry 3, is normal to the bedding (and along the axis of the vertical wellbore).

The values of the five independent elastic constants and the corresponding moduli determined from the laboratory tests are given in Table 4.5. It is evident that the moduli parallel to the bedding plane are greater than the moduli in planes normal to the bedding. The average ratio of the moduli is approximately:

$$\frac{E_1}{E_3} = 1.9$$

$$\frac{\nu_{12}}{\nu_{13}} = 3.2$$

TABLE 4.4 - CONSTITUTIVE RELATIONS FOR
TRANSVERSELY ISOTROPIC MATERIALS

3:axis of symmetry

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{23} \\ \tau_{31} \\ \tau_{12} \end{Bmatrix} = \begin{bmatrix} c_{11} & c_{12} & c_{13} & 0 & 0 & 0 \\ c_{12} & c_{11} & c_{13} & 0 & 0 & 0 \\ c_{13} & c_{13} & c_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & c_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & c_{44} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{c_{11}-c_{12}}{2} \end{bmatrix} \begin{Bmatrix} \epsilon_1 \\ \epsilon_2 \\ \epsilon_3 \\ \gamma_{23} \\ \gamma_{31} \\ \gamma_{12} \end{Bmatrix}$$

$$\begin{Bmatrix} \epsilon_1 \\ \epsilon_2 \\ \epsilon_3 \\ \gamma_{23} \\ \gamma_{31} \\ \gamma_{12} \end{Bmatrix} = \begin{bmatrix} \frac{1}{E_1} & -\frac{\nu_{12}}{E_1} & -\frac{\nu_{13}}{E_3} & 0 & 0 & 0 \\ -\frac{\nu_{12}}{E_1} & \frac{1}{E_1} & -\frac{\nu_{13}}{E_3} & 0 & 0 & 0 \\ -\frac{\nu_{13}}{E_3} & -\frac{\nu_{13}}{E_3} & \frac{1}{E_3} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{13}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{13}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{2(1+\nu_{12})}{E_1} \end{bmatrix} \begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{23} \\ \tau_{31} \\ \tau_{12} \end{Bmatrix}$$

Five independent constants

$E_1, E_3, \nu_{12}, \nu_{13}$ and G_{13}

$$G_{12} = \frac{E_1}{2(1+\nu_{12})}$$

TABLE 4.5 - ELASTIC CONSTANTS AND MODULI FOR
TRANSVERSELY ISOTROPIC SHALE - WELL NO. CH1 - WEST VALLEY

Depth, Feet	Elastic Constants ¹ , 10 ³ Mpa (10 ⁶ psi)					Elastic Moduli, 10 ³ Mpa (10 ⁶ psi)					
	C ₁₁	C ₁₂	C ₁₃	C ₃₃	C ₄₄	E ₁	E ₃	v ₁₂	v ₁₃	G ₁₂ ²	G ₁₃ ³
705.5	55.20	12.38	5.90	32.91	13.12	51.76	31.16	0.209	0.087	21.41	13.12
	(8.01)	(1.80)	(0.86)	(4.67)	(1.90)	(7.51)	(4.52)			(3.11)	(1.90)
857.5	62.25	13.05	10.57	44.11	19.69	57.83	41.09	0.175	0.142	24.60	19.69
	(9.03)	(1.89)	(1.55)	(6.40)	(2.86)	(8.39)	(5.96)			(3.57)	(2.86)
1275.0	60.64	13.94	-4.64	26.78	11.79	56.95	26.20	0.220	-0.062	23.35	11.79
	(8.80)	(2.02)	(-0.67)	(3.88)	(1.71)	(8.26)	(3.80)			(3.39)	(1.71)
1478.0	61.44	13.27	1.76	23.74	10.87	58.49	23.66	0.214	0.023	24.08	10.87
	(8.91)	(1.92)	(0.15)	(3.44)	(1.58)	(8.48)	(3.43)			(3.49)	(1.58)

1. Axes No. 1 and 2 define the bedding plane(s) and axis No. 3 defines the axis of symmetry as well as the axis of the well.

$$2. G_{12} = \frac{E_1}{2(1+\nu_{12})}$$

$$3. G_{13} = C_{44}$$

$$\frac{G_{12}}{G_{13}} = 1.8$$

The effect of this elastic anisotropy does not appear to be too significant and is assessed in the analyses of propagation of a hydraulic fracture using these values in Section 5.

In order to compare the new laboratory test data with previous log data for Well CH1, an approximate evaluation of the elastic moduli of the shale has been made in the laboratory by determining E and ν parallel and normal to the bedding, assuming that the material is isotropic. The results of such tests made on the West Valley shale specimens from four depths are presented in Table 4.6. Table 4.6 also lists the values of E and ν normal to the bedding as determined from the in situ tests, again assuming isotropy.

The E values from the laboratory are generally in agreement with the in situ values. However, the ν values were different. It is suspected that this difference is related to drying of the core, which led to microcracking or separation along the bedding planes.

4.5 - In Situ Stresses

4.5.1 - Introduction

In assessing hydraulic fracturing as a possible technique for radioactive waste disposal, the most critical parameters are those which determine the orientation

of the induced fractures. It is essential to be able to demonstrate that the fracture initiate and propagate horizontally within the selected formation.

The direction of fracture initiation may be dictated by the type of packers used and/or preslotting the borehole wall (see Section 5.4). However, the propagation direction is essentially predetermined by the in situ stress field. A simple, and usually reliable rule, is that the fracture will become and remain perpendicular to the least compressive in situ stress component. It is therefore imperative to determine both the magnitudes and directions of the preexisting in situ stress field.

Since no horizontal in situ stress measurements have been performed at West Valley, stress parameters were estimated for this study using the available stress determinations made over a large region of the Northeastern United States and Southeastern Ontario. The in situ stress values thus developed were then reviewed in the terms of the data generated from the previous hydraulic fracturing experiments conducted at West Valley.

The objective of this review is to be able to approximate a realistic estimate of the existing stress fields at West Valley so that these values can be input into the numerical and analytical hydraulic fracturing models presented in Section 5.

4.5.2 - Regional Stress Field

Cataloged in the literature are a number of stress measurements performed in the Northeastern and North-

central United States, and Southeastern Canada. These stress measurements are made at a wide range of depths by several techniques.

The techniques that have been most successfully used in the determination of one or more principal stress components include the borehole deformation meter, borehole strain cells, fault plane solutions, and hydraulic fracturing. A critical review of the principles, merits and limitations of each of these techniques for determining stresses is given in Appendix D.

Appendix E is a documentation of many of the stress measurements made to date.

Ideally, a synthesis of these available stress measurements would reflect geologic features and phenomena that may be characteristics of the West Valley site. Figure 4.5 is a plot of the stress data compiled for this study. This map shows the location of stress measurement sites and the direction and magnitudes of the measured horizontal principal stresses.

4.5.3 - Relationship Between Stress Fields and Structural Geologic Patterns

In most cases, the vertical in situ stress is the geostatic loading. Generally, under a wide range of materials and site conditions, σ_v can be approximated (in psi) as 1.1 times the depth in feet. In areas not subjected to tectonic forces, σ_v is generally the principal stress.

However, the determination of horizontal stresses is more complex, particularly at shallow depths where the in situ σ_H may be considerably larger than the computed

$$\sigma_H = \left(\frac{\nu}{1-\nu}\right) \sigma_v$$

This situation can be related to residual tectonic forces or to glacial unloading when σ_v , but not σ_H , is relieved (see Figure 4.6).

Orientations of σ_{Hmax} in the Appalachian area tend to be grossly parallel to the axes of structural features. It has been suggested that these stresses are remnants of the principal stresses that caused regional folding and faulting of the Appalachians (see Section 3).

With the limited data currently available, it appears that in situ stresses has no apparent specific relation to rock type.

4.5.4 - Magnitude of the Vertical Stress

Since the West Valley area has not been severely deformed (see Section 3.2), σ_v is considered a principal stress. Hydraulic fracturing measurements made to date tend to support this conclusion (see Section 5.2). Thus, for the purpose of this study σ_v is considered geostatic with the gradient being 1.1 psi per foot of depth.

4.5.5 - Magnitude and Orientation of the Horizontal Stress

Hydraulic fracturing at West Valley has horizontally fractured the shales to testing depths of 1,450 feet

TABLE 4.6 - COMPARISON OF IN SITU AND LABORATORY TESTS FOR
SONIC VELOCITIES AND APPROXIMATE ISOTROPIC MODULI
WELL NO. CH1 - WEST VALLEY

Depth Ft.	Direction to Bedding	VELOCITIES				MODULI				SPECIFIC GRAVITY	
		P-WAVE 10 ³ ft/sec		S-WAVE 10 ³ ft/sec		E, 10 ⁶ psi		ν			
		Lab	In Situ	Lab	In Situ	Lab	In Situ	Lab	In Situ	Lab	In Situ
705.5	Normal	12.3	13.3	7.8	6.8	4.4	4.2	0.156	0.326	2.3	2.6
	Parallel	16.1	-	10.0	-	7.3	-	0.183	-		
857.5	Normal	13.5	13.9	9.0	7.2	6.3	4.9	0.097	0.318	2.6	2.7
	Parallel	16.1	-	10.1	-	8.4	-	0.173	-		
1275.0	Normal	10.7	13.2	7.1	7.1	3.8	4.6	0.107	0.296	2.5	2.6
	Parallel	16.2	-	10.0	-	8.0	-	0.187	-		
1478.0	Normal	9.7	12.3	6.6	7.0	3.4	4.4	0.078	0.251	2.7	2.6
	Parallel	15.7	-	9.8	-	8.2	-	0.178	-		

(see Section 5.1), indicating that σ_H is greater than σ_V . The magnitude of σ_H , however, is unknown.

An evaluation of the regional stress data (Appendix E) allows us to assign approximate limits to σ_{Hmin} and σ_{Hmax} at the West Valley site. A plot of the values of both the minimum and maximum measured horizontal stress components as a function of depth (Figures 4.7 and 4.8) shows that most of the data can be plotted within an envelope. Noting that those stress values that plot within the depths being considered for this study (700 to 1,300 feet), a general stress range for $\sigma_{H(max)}$ and $\sigma_{H(min)}$ can be approximated. Based on these data, a $\sigma_{H(max)}$ of 2,000 psi and a $\sigma_{H(min)}$ of 1,500 psi for both testing horizons is considered reasonable for the modeling study.

Similarly, directional plots of principal stress trajectories from locations where stress measurements have been made (Figure 4.5) suggest that $\sigma_{H(max)}$ for West Valley will act in a direction between northeast and east (approximately N60E).

4.6 - Summary

Two horizons have been selected in the Devonian Shale formations at the 850 foot-and 1,250-foot depths. These appear most suitable for the hydraulic fractures to initiate and propagate horizontally.

Rock mechanics properties have been estimated based on previous test data from West Valley, new tests on parts of the core from that test, and general data available for the

Devonian Shale. The shale was shown to be anisotropic, of the particular class referred to as transverse isotropy, with elastic moduli normal to the bedding planes being approximately 60 percent of those parallel to the bedding. The in situ stress field has been estimated since this has a major impact on the orientation of fractures.

The values of the various parameters to be used in the analysis of crack propagation (Section 5) are summarized in Table 4.7. Note that the mechanical properties for Horizons 1 and 2 are assumed to be equal to the properties (in Table 4.6) for depths of 857.5 and 1,275 feet respectively.

TABLE 4.7INPUT PARAMETERS FOR ANALYSIS OF CRACK PROPAGATION

Horizon	Depth (ft)	σ_v (psi)	σ_H (min), psi		Critical Fr. Toughness K, psi (in) ^{1/2}				Mechanical Properties
			Low	High	Perp. to Bedding		Paral. to Bedding		
					Low	High	Low	High	
1	850	935	1,500	2,000	500	1,000	50	100	Table 4.5 Depth: 857.5 ft
2	1,250	1,375	1,500	2,000	500	1,000	50	100	Table 4.5 Depth: 1,275 ft

PREPARED FROM: RICKARD, L.V., 1975
CORRELATION OF THE SILURIAN AND DEVONIAN ROCKS
IN NEW YORK, N.Y. STATE MUSEUM AND SCIENCE
SERVICE MAP AND CHART SERIES NO. 24

GENERALIZED STRATIGRAPHIC COLUMN
FOR WESTERN NEW YORK

FIG. 4.1

PREGLACIAL BURIED VALLEY

FIG. 4.2

LEGEND

UPPER DEVONIAN SHALE FORMATION

BIG SANDY FIELD - HISTORICAL AREA OF
DEVONIAN SHALE PRODUCTION

1000 THICKNESS OF FORMATION IN FEET

DEVONIAN SHALE BASIN
OF EASTERN UNITED STATES

FIG. 4.3

LEGEND

- 13 WELL PROGRAM - SHALE WELLS ONLY (CRYO FRAC)
- ▲ 3 WELL SHALE PROGRAM (MHF)

SHALE WELL LOCATIONS
COLUMBIA / ERDA RESEARCH PROGRAMS

FIG. 4.4

FIG. 4.5
 LOCATION, MAGNITUDE AND DIRECTION OF
 MEASURED HORIZONTAL PRINCIPAL STRESSES.
 NORTH CENTRAL US - SOUTHEAST CANADA

LEGEND

ABOVE 600 METERS (2000 FEET)

□ PALEOZOIC SEDIMENTS

◇ TERTIARY SHALE, SANDSTONE (Sh, Ss)

○ TERTIARY OIL SHALE (Ms)

◄ TERTIARY TUFF (Tf)

► GRANITE, GRANODIORITE, GNEISS

BELOW 600 METERS

□ PALEOZOIC SEDIMENTS

▽ SEDIMENTARY ROCKS

Ss - SALT, Ls - LIMESTONE,

Ss - SANDSTONE, Dol - DOLOMITE

▼ CRYSTALLINE, PRE-CAMBRIAN ROCKS

Qz - QUARTZITE, Gr - GRANITE

REFERENCE

SWOLFS, H.S., 1977

ABOU SAYED, A.S., 1977

FIG. 4.6

RATIO OF $\sigma_{H \text{ MIN.}}$ TO σ_{OB} IN
SEDIMENTARY ROCK NORTH AMERICA

PLOT OF MEASURED VALUES
OF $\sigma_{H \text{ MIN}}$ VERSUS DEPTH

FIG. 4.7

FIG. 4.8
PLOT OF MEASURED VALUES
OF $\sigma_{H \text{ MAX}}$ VERSUS DEPTH

FIG. 4.8

5 - EVALUATION OF HYDRAULIC FRACTURING IN SHALE AT WEST VALLEY

5.1 - Introduction

The concept of hydraulic fracturing and grout injection of radioactive waste material into shale formations was proposed twenty years ago by D. A. Shock (as cited in de Laguna, 1968) and implemented by Oak Ridge National Laboratories (ORNL) during the period 1964 to the present. A total of 1,114,540 gallons of low-medium level radioactive waste has been injected to date at the ORNL facility. The grout used for the injection is designed to provide a very low rate of leaching. The low leach rate coupled with the high ion exchange capacity of the shale formation will provide effective isolation of the waste.

In this study, extensive references were made to the ORNL operation at which both the concept and the detailed technology were developed. Details of the ORNL waste injection operation have not been presented here since reference may be made to the various reports on that subject (Weeren, 1976, de Laguna et al, 1970). A summary description is, however, given in Section 7.5.

This section presents the results of the preliminary studies on the hydraulic fracturing aspects of a proposed waste injection concept at West Valley. The studies were particularly concerned with demonstrating that fractures would initiate and propagate horizontally within certain selected horizons. A preliminary assessment of the degree of isolation provided by such horizontal fractures containing the waste/grout mix is presented in subsequent sections.

5.2 - General Requirements

As briefly discussed in Section 4, the principal requirements for hydraulic fracturing and injection of radioactive waste are:

1. The injection zone should lie within impermeable or nearly impermeable formations within a tectonically stable region.
2. The induced fracture should be initiated and propagate essentially horizontally and/or along bedding planes so that the fractures extend only within desirable zones.
3. The areal extent of the induced fracture and the waste should be well defined and away from any significant groundwater flow paths or possible future drilling sites and mines.

These conditions, which have been met at the ORNL site, are considered to represent the general guidelines for the choice of any future waste isolation site. Table 5.1 summarizes the comparison between the ORNL site and the West Valley site.

5.3 - Review of Previous Hydraulic Fracturing Tests at West Valley

The major question concerning hydraulic fracturing and injection of waste at West Valley is whether horizontal fractures can be induced and maintained within the shale formation. Hydraulic fracture testing to address this question was carried out at West Valley in 1971.

TABLE 5.1 - COMPARISION OF ORNL AND
WEST VALLEY SITES

Feature	ORNL	West Valley
Topography	Dip and Scarp Total relief about 600 feet.	Broad valleys with streams incised in valley bottoms. Total relief about 800 feet.
Rock Type	Conasauga Shale (Cambrian)	Canadaway Group Shales
Structural Geology	Appalachian Valley and Ridge Province Dip at site 15 to 20 degrees	Appalachian Plateau Dip at site 1 to 2 degrees
Tectonics - in situ stress	Not explicitly determined for site	$\sigma_H = 1.0 \text{ to } 1.6 \sigma_V$ (estimated)
seismic hazard	Low	Low to moderate
Geohydrology	No known groundwater movement below 200 feet Conasauga shale contains salt.	Wells to 250 feet depth in bedrock within 5 miles of the site.
Rock Properties		
Strength	Parallel to bedding 3,400 to 4,870 psi. Perpendicular to bedding 3,500 to 7,780 psi.	Not available

Table 5.1 -
Second Page of 2-Page Table - 2

Feature	ORNL	West Valley
Fracture Toughness	Not available	Parallel to bedding 50 to 100 psi $\sqrt{\text{in.}}$. Perpendicular to bedding 500 to 1,00 psi $\sqrt{\text{in.}}$.
Permeability	Parallel to bedding 15 to 576 x 10 ⁻⁶ md. Perpendicular to bedding < 1 to 17 x 10 ⁻⁶ md.	Parallel to bedding 1 to 7 x 10 ⁻⁶ md. Perpendicular to bedding 0.1 to 1 x 10 ⁻⁶ md.
Resource Potential of Area	Not known	Possible natural gas reserves within Canadaway Group
Operation of Facility		
Grout Volume Injected to date	1,822,870 gallons	nil
Grout Volume Injections Planned	Approximately 200,000 gallons/year plus 300,000 gallons/year for 10 years for sludge inventory injection.	3,000,000 total gallons over a 2 to 3 year period.
Grout Waste Description	Approval for 20 Ci/gallon. Transuranics < 10nCi/gm.	Approximately 8 Ci/gallon. Transuranics > 20nCi/gm.

The testing procedure, test results and their interpretations were described by W. de Laguna (1972), R. J. Sun (1973) and R. J. Sun and C. E. Morgon (1974). Table 5.2 is a concise summary of data as prepared by R. J. Sun. More detailed discussions of individual fracturing experiments are outlined in Appendix F.

One method of establishing whether a fracture is initiated horizontally is to compare the instantaneous shut-in pressure with the anticipated value of the overburden stress.

As stated by de Laguna (1972), "It is generally recognized that when a horizontal fracture is formed, the fracturing pressure must be at least equal to the weight of the overburden, but that, for a vertical fracture, it may be, but is not necessarily less than this critical weight... One test of fracture orientation, therefore, is the fracturing pressure, more properly, the instantaneous shut-in pressure. If this pressure is less than the pressure of the overburden, then the fracture must be vertical, and also, at least one horizontal component of the earth stress at the fracturing depth must be less than the pressure of the overburden. If the fracturing pressure is equal to or slightly greater than the weight of the rock cover, the geometry of the fracture is indeterminate. If the fracturing pressure is well above the weight of the rock cover, there is a high probability that the fracture is horizontal. In other words, the pressures associated with a fracturing operation can strongly suggest the orientation of the fracture, but only under favorable circumstances can they prove it."

Therefore, the results shown in Table 5.2 indicate that the fractures formed in the West Valley experiment at the specified depths were horizontal. In addition, using the hypothesis that a fracture will initiate in a direction normal to the minimum principal stress, it is concluded that

TABLE 5.2

INSTANTANEOUS SHUT-IN PRESSURE, CALCULATED OVERBURDEN PRESSURE,
TENSILE STRENGTH AND AVERAGE COHESIVE STRENGTH AT FRACTURE TIP
FOR THE WEST VALLEY SHALE

No.	Date	Depth (ft)	Injection Fluid	Total Injection Volume (gal)	Calculated Overburden Pressure Rate		Instantaneous Shut-In Pressure		Calculated Tensile Strength (psi)	Calculated Average Cohesive Strength f.T at Fracture (psi)	Remarks
					By Specific Gravity (psi)	By Pressure Decay rate (psi)	Observed (psi)	Predicted (psi)			
1	10/9 1969	1,450	Water	114,300	1,580	1,575	1,750	1,735	447 602*	154	Before 45-minute pause
							1,740	1,735	568	154	After 45-minute pause
2	6/26 1970	1,450	Water	112,200	1,580	1,515	1,930	2,204	562	258 162**	
3	8/27 1970	1,226	Water	90,600	1,330	1,375	1,430	1,435	602	106	
4	5/10 1971	1,010	Water	98,700	1,085	1,070	1,170	-	452	84	
5	5/29 1971	500	Water	51,500	510	450	550	563	106	52	
6	7/23 1971	500	Water Grout	2,350 38,650	510	-	-	580	110 to 120	69	

*Calculated on basis of the breakdown pressure at 100 gallons per minute

**Calculated on basis of the actual observed instantaneous shut-in pressure

Average cohesive strength at fracture tip (f.T) is calculated on the basis of regression equations of P and Q. The values of (f.T) calculated on the basis of observed instantaneous shut-in pressures are essentially the same as those based on the regression equations.

the overburden pressure is the least principal stress, i. e. less than the horizontal stresses.

Another method of grossly substantiating these results is by analysis of pressure decay after the well has been permanently shut-in. The pressure decay after water injection may yield some information useful in judging whether or not the fracture formed was horizontal. A point of discontinuity on a log-log plot of pressure decay rate versus time would suggest that an induced fracture closes at that particular time. Multiple discontinuities may be caused by:

- (a) flow into different fracture systems (induced or natural),
- (b) changes in formation permeability,
- (c) the fracture not being entirely horizontal (slight bedding plane dip).

Employing this latter method, pressures at the discontinuities on a log-log plot of the pressure decay rate versus time have been determined (de Laguna, 1972, Sun, 1973). The results for each fracturing experiment are cataloged in Appendix E and summarized in Table 5.2.

Within the realm of experimental accuracy and bearing in mind the necessary analytical simplifications of the model, these data show that horizontal or quasi-horizontal fracturing occurred during the West Valley experiment.

5.4 - Horizontal Crack Initiation

Initiation of horizontal hydraulic fractures at shallow depths in a well bore can be enhanced by the jetting technique. The most successful method of accomplishing this enhancement is with the use of sand slurry jetting to perforate casing

and notch formations. The jetting technique consists of pumping a fluid containing an abrasive solid (usually sand) down the tubing string. When pumped through specially designed jets under high differential pressure, the solids-laden fluids cut away through the desired formation as the erosive jet stream impinges against the rock face.

A fracture can be selectively initiated in closed or open holes by obtaining a cut into the formation. To obtain a horizontal cut, the jet is rotated at the same horizon. The horizon cut weakens the particular zone of interest by creating a source of stress concentration at the notch tip. Subsequent pumping, to hydraulically fracture the rock causes the resultant opening stresses to concentrate at an elevated level at the notch tip, making the formation more susceptible to fracturing. In addition, breakdown pressures are generally reduced when the fracture is first initiated by abrasive jetting. This technique is commonly used to initiate horizontal fracture in solution mining of salt. It has also been used as a tool for initiation of horizontal fractures in the ORNL waste disposal program. The use of this technique in the West Valley site represents no new technology and would require only minor modification to existing tools.

The previous tests discussed in Section 5.3 indicate that hydraulic fracturing would initiate horizontal fractures at the depths of interest. However, jetting would ensure horizontal hydraulic fracturing initiation within the shales at West Valley.

Appendix G is a detailed description of the commercially available service for formation notching by abrasive jetting.

5.5 - Analysis of Crack Propagation

5.5.1 - Introduction

Once the crack has been initiated (see Section 5.4) the next step in the hydraulic fracturing process is to define the direction of crack propagation.

This is influenced by the in situ stresses, the material properties (including fracture toughness and anisotropy) and the applied pressure.

Two analytical approaches were used in the study to evaluate crack propagation direction. The first was a classical solution, which handles only isotropic material properties but provides a simple basis for understanding the mechanisms of propagation. To complement the classical method, the finite element method was used with anisotropic material properties. This allowed an evaluation of propagation direction enhancement due to the anisotropic fracture toughness properties. The two methods, used together, provide a sufficiently wide coverage of the problem to include all pertinent determining factors.

To analyze the growth of a crack inclined to the directions of the far-field in situ stresses and subjected to pressure on its faces, this study has used the fracture mechanics concepts presented by Endogan and Sik (1963), Williams and Ewing (1972), Cotterell (1972) and Hussain et al (1974), where linear elasticity is assumed and attention is given to the elevation of stresses near the crack tip. Such analyses are particularly applicable when plastic deformation and other nonlinear effects near the crack tip are confined to a small region within a linear elastic field. The near-tip stress state in such a field is characterized by a single parameter.

Irwin (1960) introduced the stress-intensity factor K as one such parameter-- others include the J-integral (Rick, 1968) and the specific energy-release rate, G (Irwin, 1957). These parameters, which are equivalent in linear elastic fracture mechanics, measure the intensity of the local stress field at the crack tip. They are determined by the applied loading, the crack configuration, and the geometry of the body. A crack is expected to advance if the values of these parameters reach critical values characteristic of the material considered. On the other hand, if the loads acting on the body and its geometry are such that the value of K , J , or G is less than this characteristic material property, then the crack is expected to remain stationary.

5.5.2 - Classical Solution Model

For this study, a pressurized crack oriented at an arbitrary angle α relative to the direction of the horizontal stress σ_H of the far-field stress system, was considered (Figure 5.1). When the crack faces of length $2L$ are subjected to a pressure p , the stress-intensity factors K_I (for the opening mode) and K_{II} (for in-plane shearing mode) for the existing crack are given by (Rice, 1968, eq. 97):

$$K_I = \pi L \{p - \sigma_H \sin^2 \alpha - \sigma_V \cos^2 \alpha\} \quad (5.1)$$

$$K_{II} = \pi L \{1/2(\sigma_H - \sigma_V) \sin 2\alpha\} \quad (5.2)$$

where σ_H and σ_V denote respectively, the horizontal and vertical compressive stresses.

When the existing crack extends in the arbitrary orientation defined by the angle γ shown in Figure 5.1, then the energy-release rate $G(\gamma)$ associated with extension in that direction will be given by the following equation (Hussain, et al, 1974)

$$G(\gamma) = \frac{4(1-\nu^2)}{E} \left(\frac{1}{3 + \cos^2 \gamma} \right)^2 \left(\frac{\pi-\gamma}{\pi+\gamma} \right)^{\gamma/\pi} \left[(1+3\cos^2 \gamma) K_I^2 + 8\sin\gamma\cos \gamma K_I K_{II} + (9-5\cos^2 \gamma) K_{II}^2 \right] \quad (5.3)$$

where K_I and K_{II} are given by Equations (5.1) and (5.2), and E and ν denote the Young's modulus and Poisson's ratio of the material, respectively. If the crack is assumed to advance in the orientation, $\gamma_{\max}$, for which $G(\gamma)$ is a maximum, then the relationship between the orientation of crack advance, $\gamma_{\max}$ and the ratio, (K_{II}/K_I) , is given by Figure 5.2 (Abou-Sayed et al., 1978).

The energy release rate $G(\gamma)$ is a positive definite function of K_I and K_{II} . Furthermore, substitution of equations (5.1) and (5.2) into (5.3) shows that $G(\gamma)$ is proportional to the crack length. Therefore, if cracks advance for a prescribed finite value of $G(\gamma_{\max})$, the only way a sufficiently long open crack can maintain finite value is for K_I and K_{II} to be equal to zero. From equation (5.1) and (5.2) the conditions $K_I = 0$ and $K_{II} = 0$ are satisfied for

$$p = \sigma_H \sin^2 \alpha - \sigma_V \cos^2 \alpha \ll 1 \quad (5.4a)$$

and

$$(\sigma_H - \sigma_V) \sin 2\alpha \ll 1 \quad (5.4b)$$

If σ_H and σ_V are not equal, equation (5.4b) requires that

$$\alpha \cong 0 \text{ or } \alpha \cong \pi/2$$

In the former case, $\alpha \cong 0$, equation (5.4a) requires that the pressure p approximately equal the vertical compressive stress σ_V , whereas in the alternate case where $\alpha = \pi/2$, the pressure p approximately equals the horizontal compressive stress σ_H , showing that sufficiently long open cracks can be stationary only if they are parallel to principal stress directions and if the pressure p is equal to the principal stress perpendicular to the crack face.

Whether the case $\alpha = \pi/2$ or $\alpha = 0$ is more likely to occur can be determined by noting whether an arbitrarily oriented crack tends to rotate to become perpendicular to σ_H or σ_V . Based on Figure 5.2, a crack tending to open by internal pressure (i.e. a crack with $K_I > 0$) will have a maximum energy release rate if it extends in the direction of positive γ for $K_{II} > 0$. Then, for $(\sigma_H - \sigma_V) > 0$, equation (5.2) indicates that for α in the interval $(0, \pi/2)$ the predicted inclination γ of the extending crack is positive whereas γ is negative for α in the interval $(\pi/2, \pi)$. For $(\sigma_H - \sigma_V) < 0$, the predicted inclination γ of the extending crack is positive whereas γ is negative for α in the interval $(-\pi/2, 0)$. In other words, when

$\sigma_H - \sigma_V$ is not zero, the maximum energy release rate hypothesis predicts that the crack tends to extend in a direction which is more nearly perpendicular to the direction of minimum compressive stress rather than along an existing crack. This prediction is consistent with laboratory results (Brace and Bombolakis, 1963; Williams and Ewing, 1972; Ingraffea and Heuze, 1977 and Wu et al, 1977).

Therefore, this analysis shows that if a rock is viewed as a homogeneous, isotropic elastic medium with an isotropic failure criterion, a crack propagating in this medium due to fluid pressure acting on its face, will grow along the path of least resistance (i.e. it will extend in the plane perpendicular to the least compressive in situ principal stress). For a moderately long crack, the pressure required to hold the crack open, but not extend it, will be slightly greater than the far-field stress acting normal to the fracture. Therefore, it follows that the shut-in pressure is approximately equal to the minimum in situ compressive stress.

The incorporation of failure anisotropy in the previous analysis poses no real difficulty as will be discussed below. However, the consideration of elastic anisotropy substantially increases the complexity of the problem. Several authors (cf. Sih et al, 1965; Delale and Endrogan, 1977; Yang and Chou, 1977; Hoenig 1977a and 1977b) have obtained the solution to various problems of single-mode crack in anisotropic bodies. Their studies are based on the work on elastic analysis in anisotropic bodies (Lehknitski, 1963). As in most two-dimensional problems in anisotropic elasticity, the solutions involve the roots of a sixth degree polynomial so that it is necessary to proceed numerically at some

stage in the analysis. Therefore, the problem of mixed mode crack in transversely isotropic media with anisotropic failure criterion has been treated in Section 5.5.3. with the use of the finite element technique. Such an approach avoids some of the complexity inherent in treating the problem analytically while still maintaining the fundamental aspects associated with effect of material anisotropy on mixed mode fracturing.

Preliminary experimental results suggest that the shales at West Valley have pronounced anisotropy with respect to fracture toughness, caused by weak bedding planes. The results show that the fracture toughness of the weakness planes is an order of magnitude lower than the rock matrix fracture toughness. In order to include this failure anisotropy into the previous analysis, the following failure criterion was established.

If $G(\alpha) = G_{HC}$ and $G(\gamma_{max}) < G_{VC}$,
the inclined fracture will take a sharp turn and propagate along the bedding planes. On the other hand, if $G(\gamma_{max}) = G_{VC}$ and $G(\alpha) < G_{HC}$, then the crack extension will be in a direction inclined at angle γ_{max} to its original direction.

As previously discussed, when the overburden stress is less than the minimum horizontal in situ stress, analysis based on the isotropic failure criterion shows that a nearly vertical crack will tend to propagate in a direction γ_{max} such that it finally realigns itself horizontally (normal to the least compressive stress). Intuitively, a material that possesses lower fracture resistance for horizontal fracturing than for vertically advancing cracks, will tend to enhance the trend of crack turning.

It will now be shown analytically that a nearly vertical crack in the West Valley shales will propagate in a direction that is close to the horizontal plane in which crack initiation commenced.

The ratio of $G(\alpha)$ and $G(\gamma_{\max})$ has been calculated for a crack that is initially at an angle of inclination, $\alpha = 88$ degrees, subjected to an almost hydrostatic stress state ($\sigma_V = 0.95\sigma_H$).

The general expressions for K_I , K_{II} and $G(\gamma)$ were normalized as follows:

$$\bar{K}_I = K_I/\sigma_H \quad \pi L = \bar{p} - \sin^2\alpha - \bar{\sigma}_V \cos^2\alpha$$

$$\bar{K}_{II} = K_{II}/\sigma_H \quad \pi L = (1 - \bar{\sigma}_V) \sin\alpha \cos\alpha$$

and

$$\begin{aligned} \bar{G}(\gamma) &= 4G(\gamma)E/\sigma_1^2 \pi L (1 - \nu^2) \\ &= \left(\frac{4}{1 + 3\cos^2\gamma}\right)^2 \left(\frac{\pi - \gamma}{\pi + \gamma}\right)^{\gamma/\pi} [(1 + 3\cos^2\gamma) \bar{K}_I^2 + \\ &\quad 4 \sin 2\gamma \bar{K}_I \bar{K}_{II} + (9 - 5\cos^2\gamma) \bar{K}_{II}^2] \end{aligned}$$

where $\bar{p} = p/\sigma_H$ and $\bar{\sigma}_V = \sigma_V/\sigma_H$. The value of $\gamma_{\max}$ was obtained from Figure 5.2 after the angle

$$\beta = \tan^{-1} \bar{K}_{II}/\bar{K}_I$$

was evaluated.

Conditions for crack propagation are not valid until $\bar{K}_I > 0$. This discussion is restricted to cracks that are forced open as well as sheared along the faces. This condition was established to avoid problems of frictional resistance along the crack faces. The steps of the calculation are given below for illustration.

$$\alpha = 88 \text{ degrees}$$

$$\bar{\sigma}_V = 0.95$$

$$\bar{K}_I = \bar{p} - 0.9988 - 0.00116$$

$$\bar{p} \approx 1, \bar{K}_I = 43 \times 10^{-6}, K_{II} = 1744 \times 10^{-6}$$

$$\beta = \tan^{-1} \bar{K}_{II}/\bar{K}_I = 88.6 \text{ degrees}$$

$$\gamma_{\max} \text{ (from Figure 9) } = 70 \text{ degrees}$$

$$\bar{G}(\alpha) = 28.78 \times 10^{-6}$$

$$G(\gamma_{\max}) = 30.63 \times 10^{-6}$$

Since

$$\bar{G}(\alpha)/\bar{G}(\gamma_{\max}) = 0.94 > G_{HC}/G_{VC} = 0.1, \text{ crack propagation will be along the horizontal direction, } \gamma = \alpha$$

The conditions $\bar{\sigma}_V = 0.95$, $\bar{p} = 1$ and $\alpha = 88$ degrees represent the most unfavorable values for these parameters which may be reasonably expected at West Valley.

5.5.3 - Finite Element Model

The critical energy release rate criterion was also used in the finite element model to analyze crack

propagation. The geometry and loading for an existing crack and the conditions for propagation of the crack are illustrated in Figure 5.3 which differs from Figure 5.1 in that the existing crack runs through the model boundary and that the half length of the crack is undefined, though comparable to L .

The energy release rates required for analysis of crack propagation can be determined when the stress or displacement field for a given crack system is known. Approximate numerical methods, such as the finite element method, are particularly suited for fracture analysis in real situations that involve complex geometries, boundary conditions, and material anisotropy.

A two-dimensional, plane strain finite element model (Figure 5.4) was used for the analysis of this study. The crack for this model is inclined at a slope of 20 degrees to the horizontal. The stress singularity at the crack tip is approximated by moving the mid-side nodes (of the 8-noded isoparametric element) to the quarter points nearer the crack (see Figure 5.4 and Appendix H). The energy release rates are evaluated using the "stiffness derivative" technique of Vanderglas (1977). Details of the finite element program used are given in Appendix H.

The horizontal and vertical axes (see Figure 5.3) are defined as H and V and the major and minor axes of the existing crack are defined as 1 and 2, with axis 1 inclined at angle α to H . The computed energy release rates in the various directions are given by G_H , G_1 , and so on. Two values of critical energy release rates, derived from the results of fracture toughness tests, are:

$$G_{Hc} = (1 - \nu^2) K_{IHc}^2 / E \text{ in the horizontal direction}$$

and

$$G_{Vc} = (1 - \nu^2) K_{IVc}^2 / E \text{ in all other directions,}$$

where E and ν are averages of the moduli in the H and V directions, and where K_{IHc} and K_{IVc} are the minimum and maximum values of K_I of the fracture toughness data obtained from laboratory tests (Appendix C). Assuming that the crack will propagate in a direction that is inclined at an angle γ to axis 1 such that

$$-\pi/2 < \gamma < \pi/2,$$

$$G(\gamma) = (G_1 \cos \gamma - G_2 \sin \gamma = G_H \cos (\alpha - \gamma) + G_V \sin (\alpha - \gamma),$$

$$G(\gamma) = (G_1^2 + G_2^2)^{1/2} = (G_H^2 + G_V^2)^{1/2} \quad \text{and}$$

$$\gamma_{\max} = \tan^{-1} (-G_2/G_1)$$

The criteria for extension of the crack are:

1. $G_H > G_{Hc}$ and $G_1 > 0$; giving extension along H .
2. $G(\gamma) > G_{Vc}$, $G_H < G_{Hc}$, and $G_1 > 0$; giving extension at γ .

Table 5.3 lists four cases of the near-vertical crack of Figure 5.4 that were analyzed. The distinguishing parameters were combinations of two values of vertical

TABLE 5.3 - DESCRIPTION OF CASES ANALYZED
BY FINITE ELEMENT MODEL

Case No.	Depth ft	σ_V psi	σ_H psi	Hyd. Pressure in Crack, p psi	Inclination of Existing Fracture	Comments
1	850	935	1500	800 - 3000 in 200 psi increments	Very vertical	Anisotropic elastic moduli from Table 4.
2	850	935	2000	"	"	"
3	1250	1375	1500	"	"	"
4	1250	1375	2000	"	"	"
5	1250	1375	1500	"	Nearly horizontal	"

in situ stress for the two nominal depths and two values of the minimum horizontal stress (see Table 4.7). The combinations provide ratios of σ_H/σ_V from 1.1 to 2.1, the ratios decreasing with depth. Anisotropic elastic properties were used for the nominal depths (see Table 4.5). A fifth case was run for a nearly horizontal crack by rotating the properties and loads 90 degrees in the existing geometry.

Tests were conducted on each case by increasing the crack pressure from 800 to 3,000 psi in steps of 200 psi. Tables 5.4 and 5.5 present the energy release rates, as previously defined, for values of pressure in the area of interest. This is defined by G_1 going positive (the crack starting to extend). The critical energy release rates are so low that their exact values are not significant. For such a long crack, the energy release rates are very large, and the order in which the rates go positive (the order in which the criteria are satisfied) is most important, since the critical values are exceeded almost immediately. The fracture toughness anisotropy, however, is of importance in giving the preferential cracking in the horizontal direction (along the bedding planes).

A typical plot of the progression of the energy release rates with pressure is shown in Figure 5.5 for the near vertical cracks, cases 1 to 4. G_H turns positive well before G_1 and greatly exceeds G_{Hc} when G_1 goes positive. This would indicate horizontal crack propagation preference. Table 5.5 presents the p values at which the various G's turn positive, for all the cases. A so called "window"

TABLE 5.4 - ENERGY RELEASE RATES FOR A RANGE OF CRACK
PRESSURES FOR THE 5 CASES OF TABLE 5.4 (V,H AXES)

Crack Pressure p, psi*	G_V for Case 1 - 5, psi in.					G_H , psi in.				
	1	2	3	4	5	1	2	3	4	5
1200	-38.24	-121.25	-58.17			-0.01	-0.86	-3.25		
1400	-18.81	- 94.71	-28.34		-1.55	0.90	0.20	-0.93		- 6.04
1600	0.34	-68.45	0.78	-104.87	0.14	1.71	1.10	1.23	-0.39	-22.09
1800	19.24	-42.51	29.25	- 65.02	1.75	2.45	2.04	3.22	1.87	50.60
2000		-16.86		- 25.88			2.82		3.97	
2200		8.51		12.54			3.51		5.91	
2400		33.64		50.29			4.11		7.68	

* Critical crack pressures for failure condition (1), $G_H > G_{HC}$ and $G_V > 0$ (horizontal cracking) are: Case 1: 1,596 psi; Case 2: 2,132 psi; Case 3: 1,594 psi; Case 4: 2,133 psi; and Case 5: 1,443 psi. In all cases, failure condition (1) is reached before failure condition (2), see Figure 5.1.

TABLE 5.5 - ENERGY RELEASE RATES FOR A RANGE OF CRACK
PRESSURES FOR THE 5 CASES OF TABLE 5.4 (1,2 AXES)

Crack Pressure p, psi*	G_1 , psi in.					G_2 , psi in.				
	1	2	3	4	5	1	2	3	4	5
1200	-18.19	-121.14	-58.29			-1.80	-5.20	0.34		
1400	-18.74	- 94.59	-28.35		- 5.95	-1.83	-4.93	-0.49		-1.84
1600	0.42	- 68.33	0.84	-104.75	22.05	-1.69	-4.58	-1.19	-4.84	1.24
1800	19.34	- 42.35	29.37	- 64.85	50.45	1.47	-4.21	-1.75	-5.11	4.27
2000		- 16.70		- 25.65			-3.66		-5.26	
2200		8.68		12.82			-3.08		-5.27	
2400		33.81		50.61			-2.43		-5.16	

* Critical crack pressures for failure condition (1), $G_H > G_{HC}$ and $G_1 > 0$ (horizontal cracking) are: Case 1: 1,596 psi; Case 2: 2,132 psi; Case 3: 1,594 psi; Case 4: 2,133 psi; and Case 5: 1,443 psi. In all cases, failure condition (1) is reached before failure conditions (2), see Figure 5.1.

may be defined between the intercept $G_H = 0$ and $G_L = 0$. It may be seen from Table 5.5 that this window is proportional in width to σ_H/σ_V .

In case 5, G_H and G_L are in nearly parallel directions. G_H goes positive well before G_V indicating a horizontal cracking preference.

5.6 - Summary

A review of the previous hydraulic fracturing tests performed at West Valley indicated that the fractures formed were horizontal.

Hydraulic fracturing may be considered as comprising two stages, firstly, initiation of the fracture and subsequently, its propagation. Horizontal initiation can be achieved using available jetting methods. The direction of propagation however, is a function of the in situ stress conditions and fracture toughness anisotropy. The analytical (isotropic) and finite element (isotropic and anisotropic) results both predict horizontal crack propagation orientations for the assumed stress conditions. Horizontal fracturing was predicted even for isotropic fracture toughness, however, the presence of the toughness anisotropy increases the tendency for horizontal crack propagation.

The elastic anisotropy of the shale also increases the likelihood of horizontal propagation. A comparison may be made of anisotropic case 3 of Table 5.5 and the isotropic results of Case 1 in Appendix H. With anisotropy, horizontal crack extension is predicted for $\sigma_H/\sigma_V = 1.0$, instead of 1.12 as for the isotropic. This point is determined by extrapolating the results and determining the ratio σ_H/σ_V at which G_H and G_L go positive simultaneously.

SKEWED CRACK UNDER FAR FIELD STRESS
AND INTERNAL PRESSURE

FIG. 5.1

REFERENCE

ABOU-SAYED ET AL, 1978

ORIENTATION OF PROPAGATING CRACK
WHICH MAXIMIZES ENERGY RELEASE RATE

FIG. 5.2

b. CRACK TIP DETAIL

FINITE ELEMENT MESH AND BOUNDARY CONDITIONS
(PLANE STRAIN ANALYSIS)

FIG. 5.4

TYPICAL PLOTS OF ENERGY RELEASE RATES
VS. HYDRAULIC PRESSURE IN CRACK
(FINITE ELEMENT ANALYSIS RESULTS)

FIG. 5.5

ACRES

6 - HYDROLOGICAL ANALYSIS

6.1 - Introduction

The transport of any radionuclide from the shale injection facility both during the injection operation and in the subsequent isolation, will be primarily by groundwater and/or surface water flow. A knowledge of the hydrological conditions of the site areas is thus a prerequisite for any safety assessment.

6.2 - Surface Water

The site is located near the southern boundary of the Erie-Niagara basin. The surface water divide is located approximately 5 miles to the south (Figure 6.1). South of this divide, the surface water drains into the Allegheny basin, a subdivision of the Ohio River watershed.

The existing West Valley plant is located at el 1,400 ft about 150 feet above and 1/2 mile west of Buttermilk Creek (Figure 6.2). The site surface water drains into the Buttermilk Creek which flows into the Cattaraugus Creek and then into Lake Erie.

The total drainage basin area for Buttermilk Creek is 29.4 square miles above the gaging station 1 1/4 miles from the creek mouth. At this location, the average discharge is 46.5 cfs, with maximum and minimum discharges of 3,910 and 2.1 cfs respectively (NFS, 1973).

Cattaraugus Creek has a total drainage basin area of 554 square miles. Of this, 244 square miles are above the confluence of Buttermilk Creek. Discharge duration curve for Cattaraugus Creek at Gowanda are shown on Figure 6.3.

As discussed in Section 3.3, topography of the site comprises broad valleys with incised streams. Total relief from hill-top to valley bottom is about 700 feet. The regional morphology indicates that the local creeks and stream have downcut through varied thicknesses of glacial materials and locally incised into the underlying bedrock shales. Cattaraugus Creek has downcut approximately 200 feet into the shale bedrock at the bridge crossing on Highway 219.

Seismic and drillhole data indicate a buried bedrock valley infilled with glacially derived sediments in the eastern and northeastern portions of the site (see Section 4.2).

6.3 - Groundwater

The essence of shale injection as a technique for waste disposal is the fixation of radionuclides in an inactive groundwater environment. By virtue of this requirement, groundwater data on potential sites is limited. In addition, the factors influencing the movement of groundwater in impermeable strata are not completely understood.

6.3.1 - Modeling

In an ideal porous media, groundwater flow is analyzed using Darcy's Law

$$q = KiA$$

TABLE 6.1AIR AND WATER PERMEABILITIES ORNL

<u>Sample Number</u>	<u>Depth (ft)</u>	For Connasauga Shale at Horizontal Permeability (millidarcys)		
		<u>To Air</u>	<u>To Water</u>	<u>Porosity (percent)</u>
1	155	0.030	0.000105	1.3
2	508	3.2*	0.0396*	1.1
3	660	0.020	0.000191	0.46
4	719	0.047	0.000030	1.1
5	801	0.024	0.000253	1.9
6	2,086	0.0062	0.000253	0.49
7	2,701	0.012	0.000273	0.39
8	2,705	0.002	0.000075	0.54
9	2,826	0.001	0.000576	1.5
10	2,852	0.039	0.000552	0.78

*Fracture

Reference De Laguna et al 1968

where q = discharge

K = hydraulic conductivity

i = hydraulic gradient

A = cross sectional area.

The intrinsic permeability of the medium, independent of the fluid, may be employed, thus

$$k = K/\nu$$

where k = intrinsic permeability

ν = viscosity.

In very fine grained materials, however, factors other than the hydraulic gradient become significant. These include osmotic forces, increased viscosity, surface chemistry and bonding forces on the interstitial water (Gast, 1963). The effect and magnitude of these factors are incompletely understood. For fine-grained materials air permeabilities are frequently higher than water permeabilities. Measurements at ORNL (deLaguna et al, 1968) show orders of magnitude difference (Table 6.1). This was attributed by ORNL to incomplete resaturation. However, such differences may also be due, in part to the inadequacy of present theoretical models for fluid flow in fine-grained materials.

For the purposes of this study it has been assumed that Darcy's Law is valid. This will lead to reasonable, although conservative, estimates of travel times. The conservatism arises from the use of laboratory

TABLE 6.2

PERMEABILITY AND POROSITY VALUES FOR
SHALES IN THE WEST VALLEY AREA
(Chase, 1978)

		Vertical Permeability (md)	Horizontal Permeability (md)	Porosity (percent)
Rhinestreet bituminous shale	LeRoy, New York			2.90
Genessee Group	42°10'N76°56'W	$<1.0 \times 10^{-6} *$		4.61
Genessee Group	42°19'N76°50'W	7.72×10^{-6} 2.84×10^{-5}		3.96 2.57
Genessee Group	42°30'N76°49'W	$<1.0 \times 10^{-6}$		8.21
Genessee Group	42°20'N76°50'W	$<1.0 \times 10^{-6}$		4.64
Genessee Group	42°21'N76°50'W	$<1.0 \times 10^{-6}$		6.29
Genessee Group	42°22'N76°50'W	$<1.0 \times 10^{-6}$		3.90
Angola shale (near top)	West Valley CH1-1,245 ft	$2 \times 10^{-7} **$	$4.3 \times 10^{-6} **$	
Rhinestreet bituminous shale	West Valley CH1-1,436 ft	$1.0 \times 10^{-6} **$	$1.0 \times 10^{-6} **$	
Rhinestreet bituminous shale	West Valley CH1-1,438 ft	$1.0 \times 10^{-7} **$	$7.0 \times 10^{-6} **$	

*3,000 ppm NaCl, 1,500 psi confined, 1,000 psi flow pressure

**Distilled water

For the analyses undertaken in this study the buried valley has not been included due to inadequate information. However, the weathered shale immediately below the surficial deposits may be considerably more permeable than the unweathered shale. Field permeability tests are required to determine the nature and extent of this zone. Further analyses, incorporating these data, would then be required.

Information on groundwater in the area of the site has been obtained from well records (La Scala, 1968). The locations of wells are shown on Figure 6.4 and details are given in Appendix I. The majority of wells are in sand and gravel or till. The thickness of these surficial deposits is evidenced by wells up to 360 feet deep (West Valley School 224-836-1). In general, however, wells in the surficial deposits are 10 to 40 feet deep, and are used for domestic, agricultural and dairy farm purposes. Wells in the shale are usually much deeper with typical depths of 50 to 150 feet deep with occasional wells 10 to 250 feet. The increased depth of these wells, as compared with wells in the surficial deposits reflect the much lower permeability of the bedrock. Yields of wells in the shale are poor, typically 5 to 15 gpm. While not in the immediate area of the site, it is worth noting that two wells were drilled to depths of 298 feet and 447.6 feet on the Cattaraugus Seneca Nation of Indians Reserve approximately 15 miles from West Valley. Yields of these wells were reported as being less than 1 gpm even after shooting each well with thirty-nine sticks of dynamite.

permeability measurements made at gradients much higher than occur in the field. As a result, water which might remain "held" under low field gradients, will move under laboratory conditions.

The transport of nuclides in groundwater occurs with overall movement of groundwater (advection) and molecular diffusion. In addition, mechanical dispersion, both laterally and longitudinally takes place. The transport velocity of a particular nuclide is significantly affected by the surface chemistry within the soil particles causing an overall retardation relative to the water transport velocity. These factors will be discussed in more detail in Section 7.

6.3.2 - Regional Geohydrology

The regional geohydrology is controlled by the geology (structure, lithology) and topography of the area. For the purpose of this study, simulations have assumed the groundwater surface to be coincident with the ground surface. As a result, the groundwater basins are coincident in area with the surface water basins.

The lithology of the shale suggests a strongly anisotropic permeability. This is also borne out by limited permeability tests (see Table 6.2). For comparative purposes both isotropic and anisotropic conditions have been analyzed. The anisotropy has been taken coincident with the regional dip of 1 and 2 degrees to the south.

In addition to relatively shallow water wells, several deep wells for the exploration and production of gas have been drilled in the area (see Section 3.5). The existence of gas in commercial quantities in the underlying rocks, and in trace showings within the shales themselves, indicates the general impervious nature of the shale.

For the hydrofracturing test performed at West Valley in 1971 (de Laguna, 1972) four deep holes were drilled.

6.3.3. - Parameters

(a) Permeability and Porosity

No permeability or porosity tests have been undertaken for this study. The results of previously unpublished tests by the USGS on the Rhinestreet, Genessee and Angola shales from New York State are given in Table 6.2. As a comparison, the results of tests on Connasauga shale from ORNL are given in Table 6.1. As can be seen from these tests, the permeabilities of the shales are very low, in general less than 1×10^{-6} md. Limited tests on samples of the Rhinestreet Group from West Valley indicate that the permeability is up to 20 times higher horizontally (i.e. along the bedding) as compared to vertically.

Porosities of the shales from New York State vary from 2.90 to 8.21 percent (Table 6.2). These are somewhat higher than for the Connasauga shale whose values ranged from 0.39 to 1.9 percent. No correlation is apparent between permeability and porosity at either West Valley or ORNL.

Based on the above results, the following porosity and permeability values have been employed in the analyses.

<u>Condition</u>	$\frac{K_H}{(m/s)}$	$\frac{K_V}{(m/s)}$	$\frac{n}{(percent)}$
Isotropic	1×10^{-9}	1×10^{-9}	1.0
Anisotropic	1×10^{-9}	1×10^{-10}	1.0

The porosity value used was purposely lower than the average measured value. This is to take account of the probable lower "flow porosity" compared to the "total porosity." This latter value includes "dead end pores." The reduction is based upon judgement: field and/or laboratory tests would be required for confirmation.

(b) Groundwater Chemistry

No information is available on the groundwater chemistry at depth at West Valley. The results of analyses from wells in the Canadaway Group within about 20 miles of the site are contained in Appendix I. All groundwaters were slightly alkaline, with pH ranging from 7.2 to 8.3. Sulfate contents were all less than 100 ppm.

Chloride contents were generally less than 100 ppm with only occasional samples over 200 ppm. However, 1,000 ppm was recorded in one well (240-826-1).

(c) Bedrock Mineralogy
and Geochemistry

The lithology of the bedrock is described in Section 3.4. Based on the literature reviewed, neither chlorides nor sulfates have been reported in the Canadaway Group. In terms of clay mineralogy, illites are expected to predominate.

6.3.4 - Analyses

Analyses of groundwater flow fields have been made for two-dimensional vertical sections as follows.

<u>Section</u>	<u>Type of Analysis</u>	<u>Permeability Values</u>
North-south	Finite element	Isotropic - $K_H = K_V = 1 \times 10^{-9}$ m/s
		Anisotropic - $K_H = 1 \times 10^{-9}$ m/s
		- $K_V = 1 \times 10^{-10}$ m/s
		- dip 1 degree to south
East-west	Closed form	Anisotropic - $K_H = 1 \times 10^{-9}$ m/s
		- $K_V = 1 \times 10^{-10}$ m/s
		- dip 2 degrees to south
		Isotropic - $K_H = K_V = 1 \times 10^{-9}$ m/s
East-west	Closed form	Anisotropic - $K_H = 1 \times 10^{-9}$ m/s
		- $K_V = 1 \times 10^{-10}$ m/s
		Anisotropic - $K_H = 1 \times 10^{-9}$ m/s
		- $K_V = 1 \times 10^{-11}$ m/s

For all analyses, the medium has been taken as homogeneous, with a porosity of 1 percent. The bedrock and groundwater surfaces have been assumed coincident with the ground surface. The effect of the radioactive heat generation on the groundwater flow convection has not been included. Future studies should include analyses of this effect once the site parameters are better defined.

The two sections selected are taken approximately parallel and perpendicular to the regional dip. Details of the finite element method used are given in Appendix J. The analytical method is based upon Gustafsson (Gustafsson, 1968) in which the ground surface potential distribution is assumed to be sinusoidal with an amplitude "a" (equivalent to half the relief between the hilltops and valley bottom) and a wave length of "b" (equivalent to the distance from hilltop to hilltop, transverse to the valley axis). The vertical and lower boundaries are taken as streamlines. For these analyses, the depth to the lower boundary, h, has been taken as 3,000 feet, the amplitude, a, 300 feet and wave length, b, 5 miles.

For isotropic conditions, the potentials vertically below the valley bottom are given by

$$\psi = a \frac{\cosh \frac{2\pi(h-z)}{b}}{\cosh \frac{2\pi h}{b}} \cos 2\pi$$

For anisotropic conditions, the geometry must be transformed.

$$\text{Thus, } h^* = h\sqrt{K_h/K_z}$$

The results of the finite element analyses of the north-south sections are shown on Figures 6.5, 6.6 and 6.7. The flow vectors derived by the model indicate that the probable discharge point for flow which pass the injected grout sheet, is Buttermilk Creek. Anisotropy affects the magnitude of the vectors, primarily by the reduction in the vertical permeability. The overall flow pattern, however, for all of the north-south section cases remains the same.

The flow vectors have not been plotted for the east-west section, since it is conservatively assumed that the disposal site will be located in the valley bottom where the streamlines are vertical. The magnitude of the vertical velocities for the three cases analyzed are shown on Figure 6.8. As expected, the vertical velocity decreases with increasing anisotropy.

The effect of a well in the vicinity may shorten the seepage path. An increase in the groundwater gradient will occur locally around the well. The extent of a gradient increase is a function of the drawdown within the well, which is not presently defined. For this reason the effects of local wells have not been considered for this model.

6.4 - Summary

Preliminary analyses indicate that groundwater flow velocities at the proposed injection depths are likely to be low, of the order of 0.1 feet per year or less. The flow direction of groundwater which passes the injection zone will be

towards Buttermilk Creek. The effects of thermally induced flow and of water supply wells on the overall groundwater flow pattern must be studied in future analyses, and the extent and affect of the buried valley must be determined.

FIG. 6.1

SURFACE WATER DRAINAGE BASINS

FIG. 6.2

PLAN OF SITE AREA

DISCHARGE - DURATION CURVE FOR
CATTARAUGUS CREEK AT GOWANDA

FIG. 6.3

WATER BEARING FORMATION

- SHALE
- SAND AND GRAVEL
- TILL

WATER WELLS IN SITE AREA

FIG. 6.4

ACRES

GROUNDWATER MODELLING
NORTH-SOUTH SECTION
CASE I ISOTROPIC

GROUNDWATER MODELLING
NORTH-SOUTH SECTION
CASE 2 ANISOTROPIC 1° DIP

GROUNDWATER MODELLING
NORTH-SOUTH SECTION
CASE 3 ANISOTROPIC 2° DIP

LEGEND

- ISOTROPIC $KH = KV = 10^{-9}$ m/s
- · - · - ANISOTROPIC $KH = 10^{-9}$ m/s $KV = 10^{-10}$ m/s
- ANISOTROPIC $KH = 10^{-9}$ m/s $KV = 10^{-11}$ m/s

EAST-WEST SECTION
VERTICAL GROUNDWATER VELOCITIES
BENEATH VALLEY BOTTOM

FIG. 6.8

7 - PROPOSED WASTE INJECTION CONCEPT

7.1 - Introduction

This section provides a general assessment of the proposed waste injection concept for West Valley. Based on estimated waste inventories at West Valley approximate grout mixes and volumes have been estimated with a discussion as to proposed injection horizons and waste extent. These estimates, for the most part, have been based on previous work performed at ORNL.

7.2 - Waste Inventory and Composition of waste at West Valley

The inventory and composition of the radioactive waste at West Valley is based upon information provided by Argonne National Laboratory (letter dated March 20, 1978) which complements or supercedes previous information (Batelle Pacific Northwest Laboratory 1976). The majority of waste is high-level waste from the Purex process which was neutralized prior to storage, and consists of approximately 570,000 gallons of supernate and 30,000 gallons of sludge. The approximate radiochemical content of the supernate and sludge is given in Table 7.1 (a, b) with the estimated composition given in Table 7.2.

Approximately 12,000 gallons of sludge-free acid waste is also stored on the site. The composition and radiochemical content of this material is given in Table 7.3.

For the purpose of this study, it is assumed that all of the waste (neutralized sludge and supernate and acid waste) are

TABLE 7.1(a)

RADIOACTIVITY INVENTORY
WEST VALLEY WASTE TANK⁽¹⁾

	Curies			
	Sludge ⁽³⁾	Percent in Sludge	Supernate	Total
Strontium-90	7.7 x 10 ⁶	99	8.0 x 10 ⁵	7.8 x 10 ⁶
Yttrium-90	7.7 x 10 ⁶	99	8.0 x 10 ⁴	7.8 x 10 ⁶
Cesium-134 ⁽²⁾	-	0	3.9 x 10 ⁵	3.9 x 10 ⁵
Cesium-137	-	0	1.1 x 10 ⁷	1.1 x 10 ⁷
Barium-137m	-	0	1.0 x 10 ⁷	1.0 x 10 ⁷
Ruthenium 106	6.9 x 10 ⁴	99	1.0 x 10 ³	7.0 x 10 ⁴
Rhodium 106	6.9 x 10 ⁴	99	1.0 x 10 ³	7.0 x 10 ⁴
Antimony 125	-	0	8.6 x 10 ⁴	8.6 x 10 ⁴
Tellurium 125m	-	0	3.6 x 10 ⁴	3.6 x 10 ⁴
Total Rare Earths	1.69 x 10 ⁶	99	2.0 x 10 ⁴	1.7 x 10 ⁶
Other Fission Products	2.4 x 10 ³	99.8	-	2.4 x 10 ³
Total Fission Product Activity	1.72 x 10 ⁷		2.18 x 10 ⁷	3.9 x 10 ⁷
Plutonium ⁽⁴⁾ (30 kg)				
239Pu - (19.11 kg)	1.69 x 10 ³	99.9	1.17	1.17 x 10 ³
240Pu - (8.85 kg)	1.998x 10 ³	99.9	2.0	2.00 x 10 ³
241Pu - (2.04 kg) (β)	2.298x 10 ⁵	99.9	2.3 x 10 ²	2.30 x 10 ⁵
Other Actinides ⁽⁵⁾				
Neptunium	2.328x 10 ²	99.9	2.33 x 10 ⁻¹	2.33 x 10 ²
Americium	1.478x 10 ⁴	99.9	1.38 x 10 ¹	1.48 x 10 ⁴
Curium	3.177x 10 ⁴	99.9	3.12 x 10 ¹	3.12 x 10 ⁴
Total Activity, Curies	1.75 x 10 ⁷	-	2.19 x 10 ⁷	3.94 x 10 ⁷

- (1) Assumes 4,000 kg fission products in fuel processed, all nonvolatile reported to waste tank, and distribution of fission product activity is essentially independent of exposure.
- (2) Cs-134 value obtained by ratioing to Cs-137 according to 9/30/77 NFS analytical report.
- (3) Assumes water-free basis on sludge. It appears that the material identified as sludge in the NFS waste tank may be as much as 85 to 90 percent supernate.
- (4) Assumes distribution of plutonium isotopes similar to that for CANDU fuel at a burnup of 8,000 MWD/MTU (239Pu - 63.7 percent, 240Pu - 20.5 percent, 241Pu - 6.8 percent) (EPRI-ND-365, February 1977, "Study of Developmental Status and Operational Features of Heavy Water Reactors") NFS laboratory data also indicate the presence of small quantities of 238Pu (0.3 percent of the total Pu).
- (5) See Table 7.1B for source information.

TABLE 7.1(b)

ESTIMATED ACTINIDE (TRANSURANIUM) CONTENT
AND ACTIVITY IN 8D2 WASTE

Isotope	Concentration (g/MTHM)	Based on Total MWD of ⁽¹⁾			
		<u>1,278,505 ⁽⁵⁾</u>		<u>2,372,019 ⁽⁶⁾</u>	
		Weight (g)	Activity (Ci)	Weight (g)	Activity (Ci)
Neptunium-237 ⁽²⁾	161.0	8,554	2.33×10^2	15,875	4.32×10^2
Americium-241 ⁽³⁾	75.7	4,022	1.43×10^4		
-242,	0.65	35	6.84×10^2		
242m					
-243	44.4	2,359	4.71×10^2		
Total Americium	120.75	6,416	1.55×10^4	11,905	2.65×10^4
Curium-243	0.02	1	3.37×10^2 ⁽⁴⁾		
-244	7.16	380	3.03×10^4		
-245	2.78	148	2.7×10^1		
-246	0.26	14	4.4×10^0		
Total Curium	10.22	543	3.12×10^4	1,018	5.78×10^4
TOTALS	-	15,513	4.69×10^4	28,798	8.473×10^4

Notes:

- (1) The first set of values presented is based on including the fuel with total MWD exposures in excess of 15,000 MWD/MTHM as the basis for calculation, ignoring the contribution of fuel with lesser burnup. The second set of figures includes all fuel with exposures in excess of 10,000 MWD/MTHM, ignoring the contribution of fuel with lesser burnup. Both sets of values were calculated from the actinide yield tables (ORIGEN Code) for fuel exposed to 24,062 MWD/MTHM. It is probable that the true values for the transuranium actinide concentrations in 8D2 waste lie between these two sets of values, most likely nearer to the higher ones.
- (2) Assumes that 50 percent of the neptunium reported to 8D2. (Personal communication from P. Burn, NFS) Activity includes contribution from ²³⁹Np.
- (3) ²⁴¹Am grows in from ²⁴¹Pu decay; processing at 365 days out of reactor was assumed and the ²⁴¹Am content was taken to be the amount present at that time. Calculation of activity level was done in similar fashion. Both ignored the approximately 1.5-percent loss by decay in 10 years.
- (4) Includes contribution from ²⁴²Cm.
- (5) Fuel included is 33.6 percent of total equivalent MWD in fuel processed, or 9.9 percent by weight of fuel processed.
- (6) Fuel included represents 62.3 percent total MWD in fuel processed, or 25.5 percent by weight of fuel processed.

TABLE 7.2

ESTIMATED COMPOSITION OF CONTENTS
OF WASTE TANK 802(1)

Compound	MW	In Sludge		In Solution	
		Moles (000's)	Kilograms	Moles (000's)	Kilograms
(Na,K) ₂ SO ₄	142.08	-	-	632.1	89,800
(Na,K) NO ₃ /NO ₂	85.01	-	-	11,000	935,110
(Na,K) OH	40.01	-	-	385.9	15,400
(Na,K) Cl	58.46	-	-	8.4	500
Fe(OH) ₃	106.85	463.0	49,500	-	-
Fe PO ₄	150.82	188.9	28,500	8.3	1,250
Cr (OH) ₃ (2)	103.00 (2)	37.6	3,811	20.8	2,100
Ni (OH) ₂ (2)	92.71 (2)	17.6	1,632	<8.3	<750
Al (OH) ₃	77.98	10.7	830	-	-
Al F ₃	83.98			<18.7	<1,570
Rare Earth (M(OH) ₃) (3)	194.9	10.0	1,950	-	-
Fission Products Remainder				2.9 (4)	550
(M'SO ₄)	224.26	6.67	1,500	-	-
(M'(OH) ₄)	165.29	11.54	1,900	-	-
(M ₂ O ₃)	296.59)	.86	250	1.16 (5)	215
(MO _x ⁻¹)	185.99)				
Mo, as Na phosphomolybdate (Na ₃ PO ₄ -12MoO ₃)	1,507.94	7.8	980	4.2	500
Mn, as MnO ₂ (estimated)	86.94	25	2,175	-	-
Pu, as PuO ₂	-	-	34	-	-
U, as Na ₂ U ₂ O ₇	633.98	21.0	6,657	-	-
Actinides, Total as oxides	-	-	19	-	-
TOTAL			99,152		1,047,745
			≈7,400 gallons at assumed dry density of 3.5 g/cc		500 g/l

(1) Based on composite of information from NFS (J. P. Duckworth, private communication), the NFS Waste Surveillance Report No. 9, and calculations based on total MWD burnup in fuel processed at NFS

(2) Assuming ration of chromium to nickel to be 19:9, the ratio in which it occurs in 304 stainless steel

(3) Average atomic weight - 143.9

(4) (Rb,Cs)NO₃, average MW = 189.52

(5) Technicium as NaTcO₄. It is considered very doubtful that this is present. The Tc is most likely to be present as a Ba pertechnetate, coprecipitated with BaSO₄ (Martin and Niles, "Chemical Processing of Nuclear Fuels", Academic Press 1958, page 77

TABLE 7.3

COMPOSITION OF THORIUM BEARING WASTE
TANK 8D4(1)

Component	Molarity	Quantity, kg	Calculated as	Radioactivity, Ci
Thorium	1.46	31,955	Th(NO ₃) ₄	3.55
Alumium	0.35	3,399	Al(NO ₃) ₃	-
Fluorine	0.10	191	NaF	-
Nitric acid	1.03	2,959	HNO ₃	-
Phosphorus	0.04	195	HPO ₃	-
Boron	0.15 ⁽²⁾	423	H ₃ BO ₃	-
Chromium, nickel, iron	See Note (3)		Fe, Cr, Ni nitrates	-
Total fission products	(~227 kg)	520	M(NO ₃) _x	2.43 x 10 ⁶
Cesium	(19.3 kg)	28.2	CsNO ₃	7.47 x 10 ⁵
Strontium	(6.2 kg)	14.8	Sr(NO ₃) ₂	4.83 x 10 ⁵
Uranium (loss)	(10 kg)	17	UO ₂ (NO ₃) ₂	-
Volume, gallons (litres)		12,047 (45,598)		
Teperature, F		100 - 200		
Specific gravity		1.8		
Solids content, g/l (estimated)		875 - 1,019 ⁽⁴⁾		

(1) Based on data in NFS revised Safety Analysis Report, and data recorded during surveillance of the thorium fuel processing campaign

(2) Estimated from data in NFS original Safety Analysis Report

(3) Observations recorded during the surveillance of the thorium fuel processing campaign indicate that substantial quantities of stainless steel hull material dissolved in the fuel dissolution operation, owing to the presence of variable concentrations of fluorides during processing; these same conditions resulted in enhanced corrosion rates on the dissolver vessel. Thus chromium, nickel and iron have been added in an undetermined quantity to the waste stream. It is not possible to determine precisely how much stainless steel dissolved, but evidence in the surveillance report suggests that possibly as much as 2,696 kg of expected hull material was not recovered. It was also reported that the corrosion coupon in the dissolver showed an 8 percent loss following the first dissolution in the campaign. The quantity of corrosion products present in 8D4 is indeterminate from presently available data.

(4) The higher figure includes an estimate for the corrosion products

to be disposed of by shale injection.

7.3 - Choice of Horizons at West Valley

The establishment of the testing parameters and the selection of the two depths (850 ft and 1250 ft) for numerical and analytical modeling are discussed in detail in Sections 4 and 5. Briefly, these sections were selected on the basis of their general homogeneous nature, thickness of shale, absence of vertical fracturing and low Young's Modulus values.

It is expected that other borings drilled at alternative locations at the West Valley facility would provide similar suitable zones for hydrofracturing and injection. However, the extent of the buried valley must be determined to enable the final selection of depth to be made.

7.4 - Waste Injection at West Valley - Waste Form

The radioactive waste will be combined with a clay-cement grout mix, which will be pumped into the selected disposal horizon under high pressure. Upon completion of the injection, the equipment will be washed of contaminants and a final, nonradionuclide containing mix injected to seal the drill hole.

The design of ternary grout mixes (cement-clay-water) may be based upon Figure 7.1. Cement may be replaced in part by fly ash for cost reduction. This would result in minor changes in viscosity and final strength.

The mix used for shale injection waste disposal at ORNL is given in Table 7.4.

TABLE 7.4COMPOSITION OF DRY MIX USED IN
CEMENTITIOUS GROUT PREPARATION AT ORNL

<u>Constituent</u>	<u>Recipe</u> (parts by weight)	<u>Composition</u> (weight percent)
Cement	2.5	38.5
Fly ash	2.5	38.5
Attapulgate-150	1.0	15.4
Grundite	0.5	7.7

The cement used at ORNL was a Portland cement Type 1 and fly ash obtained from a coal fired steam plant. The cement was mixed with Attapulgate - 150 (palygorskite clay group) and grundite (illite clay).

Laboratory tests were conducted for dry mix/waste ratios of 5.5 to 7 lb/gallon. A mixture of 6 lb/gallon produced a wet mixture that handled easily and hardened into acceptable solid. This represents a cement-fly ash/clay/water ratio by weight of 33 percent/10 percent/57 percent.

At ORNL fly ash was used to improve the retention of strontium. Grundite proved beneficial since it has a high affinity for cesium. A retarder CFR-1, delta glucanolactone, was added to the mix 0.003 parts by weight.

Leach rates of cesium, strontium, plutonium and curium from cement grouts at ORNL have been determined (Moore et al 1975) by using tap water as the leachate which was changed (usually daily).

Leaching of radionuclides from the grout samples is essentially a diffusion phenomena. Retardation by surface sorption and ion exchange results in effective diffusion coefficients up to several orders of magnitude lower than diffusion coefficients of common ions in water. Based on the results of ORNL tests (ERDA 1977) the following effective diffusion coefficients, D_e , were measured.

^{90}Sr	7.2×10^{-12}	cm^2/sec
^{137}Cs	1×10^{-14}	cm^2/sec
^{244}Cm	1×10^{-16}	cm^2/sec
^{239}Pu	1×10^{-17}	cm^2/sec

Tests undertaken with cesium using a different clay type

showed the strongest retardation occurred with ground Conasauga Shale, which is available locally at ORNL. The diffusion coefficient value used in this study, however, was based on the use of pottery clay, which would be available in large quantities for West Valley and possesses high retardation qualities.

The quantity of radionuclide leached from the grout sheet may be calculated from

$$A_o = \frac{2 s}{v} \left(\frac{D_e t}{\pi} \right)^{1/2}$$

when A_o = fraction of radionuclide leached
 v = grout sheet volume
 s = grout sheet surface area
 D_e = effective diffusion coefficient
 t = time since start of leaching

7.4.1 - Estimate of Pumped Volume

The total grout volume to be injected at West Valley is estimated at about 3 million gallons, based on the following.

<u>Waste Type</u>	<u>Dilution</u>	<u>Volume after Dilution</u> (gallons)
Neutralized supernate	2 x	1,140,000
Neutralized sludge	20 x	630,000
Acid	8 x	108,000
TOTAL		<u>1,878,000</u>

Using a mix ratio of 6-lb solids to 1 gallon of diluted waste, the volume of grout will be approximately 1.4 times the volume of diluted waste. Adding to this the volume of clean-up waste water which will be incorporated into the grout, brings the total estimated volume of grout to about 3 million gallons.

It should be noted however that these dilution values are only preliminary estimates and that further research will be needed to determine the dilution requirements consistent with operating costs and efficiency, leach rates and thermal effects.

7.4.2 - Geometry of Induced Fractures

The size of hydraulically induced horizontal fractures underground has been estimated by Sun (Sun, 1969) for an idealized medium. Based on elastic analysis of a penny shaped fracture parallel to the surface in a half space, Sun derived the following relationship between the fracture volume Q , the fracture radius α , the distance between the fracture plane and the surface h , the overburden stress γh (where γ is the specific weight for the medium) the pressure inside the fracture, p , and the Young's modulus and Poisson's ratio medium, E and ν respectively.

$$a^1 = a/\alpha = \left(\frac{3EQ}{16 (1-\nu^2) \alpha^5 (p_o - \gamma h)} \right)^{1/3} \quad (7.1)$$

The parameter α is given by the equation

$$(1-\alpha^2)^{1/2} = (p_o - \gamma h)/p_o \quad (7.2)$$

In the present case study, the average values of the parameters in equation (7.1) for the West Valley shales are indicated in Table 7.5.

The total estimated volume of injected grout at the site has been given in the previous section and amounts to approximately

$$Q = 3 \times 10^6 \text{ gal}$$

Substitution of the above values into equation 7.1 leads to the following projected fracture sizes for illustration purposes.

Possible Injection Schemes:

1. Case of single horizon fracture

Horizon depth, ft	850	or	1250
fracture radius, ft	1700		1220

2. Case of single fracture in each horizon

Horizon depth, ft	850	and	1250
fracture radius, ft	1350		970
No. Fracture/horizon	1		1

3. Case of multiple fractures in each horizon

Horizon depth, ft	850	and	1250
Fracture radius, ft	935		770
No. Fracture/horizon	3		2

The above schemes represent some of the most likely arrangements for the injection of the waste at West Valley. Any different combination of multiple fractures at both horizons is feasible and the calculation of the resulting fractures radii can be obtained as outlined

TABLE 7.5REPRESENTATIVE PARAMETERS FOR
WEST VALLEY SHALE INJECTION

Injection depth, h	850 ft	1,250 ft
Overburden stress, h	935 psi	1,375 psi
Down hole pressure, p_o	1,055 psi	1,620 psi
Young's Modulus, E	7.3×10^6 psi	5.6×10^6 psi
Poisson's ratio, ν	0.15	0.16

above. The fracture radius should be limited to a maximum of between 600 and 1,000 feet to suit the relief observed at the site and the existence of the buried valley. Deviations of fracture geometry from a circular shape and located to one side of the injection well have been observed in previous grout injection work (Sun, 1969) as well as some work done in the oil and gas industry (Figure 7.2).

The final selection of the injection scheme and grout sheet extent may be determined by operational constraints, (e.g. maximum batch size).

7.5 - Comparison with ORNL

A comparison of the radionuclide contents and concentrations for ORNL and West Valley neutralized wastes is given in Tables 7.6 (a, b). In the supernate, fission product concentrations (^{90}Sr , ^{137}Cs) at West Valley are approximately 10 times higher than at ORNL. The actinide concentrations, however, are similar. At ORNL, the present sludge inventory is 400,000 gallons, compared to 30,000 gallons at West Valley. However, the fission product activity (e.g. ^{90}Sr , ^{90}Y) is about 100 times higher at West Valley compared to ORNL. Actinide activity (e.g., ^{239}Pu , ^{244}Cm) is 25 to 30 times higher at West Valley compared with ORNL.

Since it is anticipated that any shale fracturing facility at West Valley would be basically similar to that presently employed at ORNL, it is instructive to examine this latter operational facility. Intermediate level waste (ILW) solutions (specific activity of 1.5×10^{-6} to 2 Ci/gal) are discharged to the ILW collection system. After evaporation, the wastes are neutralized and stored in tanks. Periodically, the

TABLE 7.6 (a)NEUTRALIZED WASTE SUPERNATE ACTIVITY

	ORNL		West Valley
	<u>Average</u>	<u>Maximum</u>	<u>(Ci/gal)</u>
	(Ci/gal)	(Ci/gal)	
^{90}Sr	.0316	.11	1.404
^{137}Cs	.48	1.12	19.298
^{106}Ru	6.3×10^{-3}	0.035	1.754×10^{-3}
^{244}Cm	5.2×10^{-4}	1.97×10^{-3}	5.316×10^{-2}
^{239}Pu	7.5×10^{-6}	2.1×10^{-5}	2.053×10^{-6}
^{60}Co	1.2×10^{-3}	2.5×10^{-3}	-

ORNL data from Weeren 1976, Table 5

NFS data based on 540,000 gallons and inventory given in
ANL letter March 20, 1978

TABLE 7.6 (b)NEUTRALIZED WASTE SLUDGE ACTIVITY

	<u>ORNL</u> <u>(Ci/gal)</u>	<u>Total</u> <u>(Ci)</u>	<u>West Valley</u> <u>(Ci/gal)</u>	<u>Total</u> <u>(Ci)</u>
^{90}Sr	1.25-3.75	$0.5-1.5 \times 10^6$	257	7.7×10^6
^{90}Y	NA	NA	257	7.7×10^6
^{106}Ru	NA	NA	25.6	6.9×10^4
^{106}Rh	NA	NA	25.6	6.9×10^4
^{239}Pu	6.25×10^{-4} -7.75×10^{-4}	250-310	5.63×10^{-2}	1.69×10^3
^{244}Cm	3×10^{-2}	12×10^3	1.06	3.177×10^4

Present inventories - ORNL 400,000 gal
 - NFS 30,000 gal

ORNL data from Weeren 1976

NFS data based on 30,000 gal and inventory given in ANL
 letter March 30, 1978

supernate is mixed with cement and clay and injected into horizons in the Conasauga shale at depths between 800 and 1,000 feet. It should be noted that, to date, no sludge has been disposed of in this way. In the new ORNL facility plans, do include the agitation and mixing of the sludge with the supernate prior to injection. In addition, the existing inventory of sludge will be injected. Details of the new facility are given in Environmental Impact Statement (ERDA, 1977).

In the years 1964 to 1975, 1,822,870 gallons of grout were injected at ORNL. This represents about $.037 \times 10^6$ Ci ^{90}Sr and $.523 \times 10^6$ Ci ^{137}Cs (Weeren 1976). In comparison, injection of supernate, sludge and acid wastes at West Valley are estimated to require about 3 million gallons of grout. The total activity of ^{90}Sr and ^{137}Cs contained would be 8.3×10^6 and 12×10^6 Ci, respectively.

Calculations have been made of the temperature rise at the injection level for the new ORNL facility (op. cit. Appendix C). For computational simplicity, the injections are assumed to be simultaneous, with a total injection of 14×10^6 gallons spread over a 250 feet deep cylindrical zone, 870 feet in diameter. At the time of injection, the total heat generation would be 1.893×10^6 Btu/hr. The maximum temperature rise at the center of the injection zone was estimated to be 64 degrees F and to occur after about 40 years.

The total present heat generation rate for the West Valley waste is estimated as 3.5×10^5 Btu/hr. If this waste is distributed uniformly throughout a zone 100 feet in thickness in grout sheets 1,200 feet in diameter, the resulting average heat generation rate per unit volume of

the zone at West Valley would be approximately 20 percent of the ORNL value. It may be acceptable from the thermal point of view to only inject into a smaller zone. The final selection of the injection scheme should take this into account based on thermal stress analyses of the actual concept.

7.6 - Summary

The waste inventory at West Valley has been reviewed and compared with the waste produced at ORNL which has been or is to be disposed of by shale injection. In its present form, the West Valley supernate waste has an activity (measured as Curies per gallon) an order of magnitude higher than that injected at ORNL. The activity of the sludge at West Valley is two orders of magnitude higher than at ORNL. However, in view of much larger volumes of existing sludge and future waste production at ORNL compared to the West Valley volumes, the total heat generation of the existing West Valley waste is comparable to the total heat generation approved for the ORNL injection facility.

Based on an elastic analyses, the thickness and extent of grout injections at West Valley have been estimated. The grout sheet should be located within a radius of between 1,200 and 2,000 feet from the injection well. This must be reviewed following delineation of the buried valley and choice of injection location and depths.

STRENGTHS ARE FOR COMPRESSION
TESTS ON 2 INCH BY 2 INCH CYLINDERS
AFTER JONES 1963 AND TALOBRE 1967

FIG. 7.1

CEMENT- BENTONITE - WATER MIXES

AREAL EXTENT OF FRATURE SYSTEM,
SPECIAL TESTS, PINE ISLAND FIELD, La.

FIG. 7.2

8 - PRELIMINARY HAZARDS ANALYSIS

8.1 - Approach

The safety of shale injection for the disposal of the waste must be considered for the designed isolation and operation conditions and also allow for accident or failure conditions. The object of this section is to identify the principal potential hazards associated with these conditions. These estimates are intended to provide a preliminary basis for subsequent safety analyses and give an initial indication of the technical feasibility of the concept. This analysis also forms the partial basis for definition of the required research and development program.

The experience at ORNL has been used extensively as a reference datum, particularly with regard to operational aspects. From a radiological safety standpoint, the main differences between ORNL and West Valley are the higher concentrations of actinides in the grout mix proposed for West Valley.

8.2 - Design Conditions

Under the design conditions approximately 3,000,000 gallons of the grout-waste mixture will be injected into the shale in a set of grout sheets at the preferred horizons. The preferred injection depth from the presently available data may be at either 850 or 1,250 feet below the ground surface. The thickness of each grout sheet after injection is completed has been assumed to be 3/8 inch (ERDA, 1977). The radius of each grout sheet will depend upon the injection batch size determined to be most suitable. It should be noted that a limited number of large injections would be cheaper than many smaller injections, since the preparation and cleanup costs would be reduced.

However, a wellhead rupture near to the end of the injection of a large batch of waste would result in a greater hazard potential and associated cleanup costs. A practical limit of 2,000 feet diameter is considered appropriate for the grout sheets.

Total activity and activity per gallon of grout for ^{90}Sr , ^{137}Cs , ^{244}Cm and ^{239}Pu are given below at the time of injection.

TABLE 8.1 - GROUT COMPOSITIONS

Isotope <u>Isotope</u>	<u>West Valley</u>			<u>ORNL</u>	
	<u>Neutralized Waste Ci</u>	<u>Acid Waste Ci</u>	<u>Total Ci</u>	<u>Concentration in Grout Ci/Gal</u>	<u>Concentration in Grout Ci/Gal</u>
^{90}Sr	7.8×10^6	4.83×10^5	8.3×10^6	2.77	3.6
^{137}Cs	1.1×10^7	7.47×10^5	1.2×10^7	4.00	3.6
^{244}Cm	2.03×10^4	-	3.03×10^4	1.01×10^{-2}	1.8×10^{-2}
^{239}Pu	1.17×10^3	-	1.17×10^3	3.90×10^{-4}	7.1×10^{-5}

The above West Valley concentrations are based on 3×10^6 gallons of grout. The ORNL data is for the proposed new injection facility (ERDA 1977). From this table it is apparent that apart from the higher concentration of ^{239}Pu , the proposed radionuclide content of the West Valley grout is similar to that for the proposed ORNL facility. It should be noted however that consideration is being given to limiting the concentration of long lived α -emitters to less than 10 n ci/g for nonretrievable wastes. The above West Valley grout composition contains approximately 69 n ci/g of ^{239}Pu .

Isolation of nuclides following grout injection is most likely to be achieved in the shale beds due to

- slow leach rates of radionuclides from the grout,
- very slow groundwater movement,
- retardation of radionuclides within the shale.

The leach rates for grout have been discussed in Section 7.4. Leaching is essentially a diffusion process. The effective diffusion coefficient, however, includes the effects of retardation and the relationship between the mobile and immobile phases of the radionuclide in the grout. It thus varies depending upon the composition of the grout and, in particular, with the type of clay used. Estimates of the cumulative fractions leached at increasing times for ^{90}Sr , ^{137}Cs and ^{239}Pu are given in Table 8.2.

Groundwater velocities predicted by Darcy flow using simplified two-dimensional vertical sections have been calculated (Section 6.3). A conservative upper bound on vertical velocity through the grout sheet appears to be 1-foot per year. This value is based upon isotropic conditions. For anisotropic conditions, which are considered more probable, the maximum vertical groundwater velocity may be 0.05 feet per year. Actual velocities may be much lower than those predicted by Darcy flow due to particle surface effects, and may be almost zero. Advection of radionuclides by groundwater flow may thus be very low.

For very low or zero groundwater velocities, molecular diffusion must be taken into account in transport predictions. One dimensional diffusion is described by Fick's Law

$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2}$$

For the boundary and initial conditions:

$$C(o,t) = 0 \text{ for } t < 0$$

$$C(o,t) = C_o, \text{ for } t \geq 0,$$

the solution is

$$C(x,t) = 1/2C_o \operatorname{erfc} \left(\frac{x}{2 \sqrt{Dt}} \right)$$

where $C(x,t)$ = concentration at distance x and time t
and D = diffusion coefficient.

Considering diffusion alone, it would take 10,000 years for the concentration at a point 700 feet from the source to reach a concentration of 7 percent of the source concentration, and 100,000 years to reach a concentration of 18 percent of the source concentration. The values are based on a diffusion coefficient of 10^{-5} cm/s. This value is typical of common cations and anions in water, and isotopes such as ^3H , ^{18}O and D. Retardation effects, if present, would reduce these concentration values.

Retardation of radionuclides relative to the groundwater velocity and molecular diffusion predicted by Fick's Law takes place due to sorption and ion exchange effects with the rock mineral constituents (Burkholder, 1976). The distribution coefficient for a nuclide is defined as

$$K_D = \frac{\text{moles/gm of solid phase}}{\text{moles/ml of liquid phase}}$$

TABLE 8.2 - GROUT LEACHING FOR WEST VALLEY

<u>Isotope</u>	<u>Concen- tration in Grout Ci/Gal</u>	<u>De cm/sec</u>	<u>t yrs</u>	<u>Cumulative Fraction Leached</u>	<u>Cumulative Ci in Leachate per Gal of Grout</u>
^{90}Sr	2.77	7.2×10^{-12}	1	1.785×10^{-2}	4.82×10^{-12}
			10	5.645×10^{-2}	1.22×10^{-1}
			100	1.785×10^{-1}	4.16×10^{-2}
			1000	5.645×10^{-1}	2.77×10^{-11}
^{137}Cs	4.00	1×10^{-14}	1	6.653×10^{-4}	2.600×10^{-3}
			10	2.104×10^{-3}	6.68×10^{-3}
			100	6.653×10^{-3}	2.64×10^{-3}
			1000	2.104×10^{-2}	7.78×10^{-10}
^{239}Pu	3.90×10^{-4}	1×10^{-7}	1	2.104×10^{-5}	8.21×10^{-9}
			10	6.653×10^{-5}	2.59×10^{-8}
			1000	2.104×10^{-4}	8.18×10^{-8}
			10000	6.653×10^{-4}	2.52×10^{-7}
			100000	2.104×10^{-3}	6.17×10^{-7}
			1000000	6.653×10^{-3}	1.51×10^{-7}
			10000000	2.104×10^{-2}	3.56×10^{-18}

For granular media, the distribution coefficient may be used directly to determine the relative velocity of radionuclide to the water velocity by

$$v_i/v_w = \frac{1}{1 + \frac{K_D \gamma}{n}}$$

where v_i = average radionuclide velocity

v_w = average water velocity

γ = bulk dry density (gm/ml)

K_D = distribution coefficient (ml/gm)

n = porosity

For fractured rock, however, the distribution coefficient must be expressed relative to the surface area available for sorption.

Thus

$$K_A (\text{ml/cm}^2) = K_D (\text{ml/gm}) / A (\text{cm}^2/\text{gm})$$

where A is the surface area per unit weight of rock

If it is assumed that K_D values are obtained from tests on granular media comprising uniform spheres, of radius r , then

$$K_A = \frac{K_D \times r \times G}{3}$$

where G is the specific weight of the soil particles

For most rock $G \approx 2.65$ and thus the relationship may be approximated by

$$K_A = 0.9 \times r \times K_D$$

The relative velocity of nuclide migration may then be rewritten as

$$V_i/V_w = \frac{1}{1 + K_A R_p}$$

where R_p is the surface to volume ratio of the pore spaces through which flow takes place.

When considering shale the flow may be characterized as flowing through tubular pathways of circular cross section in which case

$$R_p = 2/r_p$$

where r_p is the pore radius

Thus

$$V_i/V_w = \frac{1}{1 + (2K_A/r_p)}$$

The distribution coefficient for a given radionuclide is a function of the oxidation state of the radionuclide, the pH and presence of other competing ionic species in the liquid, temperature and contact time. The results of tests undertaken by ORNL in their studies of sorption phenomena are reported by Tamura, (Tamura, 1972). Similar studies were undertaken on behalf of the Swedish Nuclear Fuel Safety (KBS) organization (Allard *et al* 1977).

Distribution coefficients for strontium have been measured for the outwash sands and gravels, till and shale from West Valley. K_D varied from 19 to 60 ml/gm for tap water and demineralized water, and from 51 to 77 ml/gm for New York well water (NFS, 1973). Tests at ORNL using natural water and pH of 7.5 gave K_D values between 48 and 117 ml/gm for the clay minerals and micas, except montmorillonite for which K_D was 506 ml/gm. With increasing sodium ion content, however, the K_D value for montmorillonite decreases rapidly, a value of 4 ml/gm being measured for a 0.5N sodium nitrate solution at pH 7.0. In tests carried out by KBS, K_D values for strontium, using a 10 percent bentonite-90 percent sand mixture, varied between 31 and 63 ml/gm. The K_D values at 65 degrees C were slightly higher than those at 25 degrees C.

Distribution coefficients have been determined for cesium and a similar range to that measured for strontium has been observed. Distribution coefficients for the transuranic elements have been less widely researched. The results available to date indicate that plutonium may be more strongly sorbed than strontium. The mechanism, however, is not completely understood, and may be due to "scavenging" by oxide and hydroxide precipitates, (Tamura, 1972). In addition, the K_D value is likely to be strongly dependent upon the oxidation state of plutonium ion, and the nature of any complexes, particularly organic, with which it may be associated. K_D values for plutonium of between 129 and 630 ml/gm have been reported by Tamura for illite, kaolinite and montmorillonite. A K_D value of 4,370 ml/gm was recorded by attapulgite. Research for KBS (Allard et al 1977) on plutonium sorption gave K_D values between 250 and 25,000 ml/gm.

The values of K_D and K_A used in this study are given below. The K_A values are based upon an assumed grain diameter of $1\mu\text{m}$ for the material tested. The ratio of radionuclide velocity to water velocity (v_i/v_w) is based upon pore diameters, d_p , of $2\mu\text{m}$ and $20\mu\text{m}$.

TABLE 8.3 - RELATIVE VELOCITIES IN SHALE

Element	K_D	K_A	v_i/v_w	
	mL/gm	cm^2/gm	$d_p = 2\mu\text{m}$	$d_p = 20\mu\text{m}$
Strontium	50	.00225	1.96×10^{-2}	1.82×10^{-1}
Cesium	50	.00225	1.96×10^{-2}	1.82×10^{-1}
Plutonium	120	.0054	9.17×10^{-3}	8.47×10^{-2}

It should be noted that based on the porosity and permeability values measured for the shale, pore diameter values are anticipated to be closer to $2\mu\text{m}$ than $20\mu\text{m}$. The smaller value is also more probable from a consideration of the mineralogical constituents (clay minerals and fine-grained silicates).

Tests on the retention of plutonium and americium in simulated rock fractures gave values of v_i/v_w of 1×10^{-4} and 5×10^{-4} respectively (Fried et al 1977). The values given above thus appear to be extremely conservative. Measurements of strontium transport velocities relative to groundwater velocity have been made at a number of locations. The results are summarized in Table 8.4.

In summary, for the design condition, safety analyses may be conservatively based upon the following parameters

- depth to injection 850 feet and 1,250 feet
- upward groundwater velocity 0.01 feet/year
- relative transport velocities as given in Table 8.5

TABLE 8.4

Velocity of ^{90}Sr Migration
Relative to Groundwater
Velocity (v_i/v_w) ^{90}Sr

<u>Site</u>	<u>Soil/Rock Type</u>	<u>$(v_i/v_w)^{90}\text{Sr}$</u>	<u>Reference</u>
NRTS, Idaho	Snake River Basalt	0.3	Robertson and Barraclough, 1973
AECL Chalk River, Canada	Shallow Sands	0.03	Parsons, 1961
Studsvik Sweden	Fracture in Granite	0.15	Häggblom, 1977

TABLE 8.5 - Relative Transport Velocities

<u>Nuclide</u>	<u>Concentration in Grout (Ci/gal)</u>	<u>Leach Rate (ci/yr gal)</u>	<u>Relative Transport Velocity (v_i/v_w)</u>
^{90}Sr	2.77	4.82×10^{-2}	1×10^{-1}
^{137}Cs	4.00	2.60×10^{-3}	1×10^{-1}
^{239}Pu	3.90×10^{-4}	8.21×10^{-9}	1×10^{-2}

8.3 - Designed Operations

Safety analyses of operating conditions of the proposed shale injection facility should take account of the following:

- excavation for waste pipelines, tanks, etc in soil which may, in the past, have been contaminated by spills or other incidents

- installation into existing waste tanks of equipment for agitating and slurrying the sludge
- operation and routine maintenance of the injection facility
- phase separation from grout during injection
- decommissioning of existing waste tanks
- decommissioning of waste injection facility.

8.4 - Accidents and Failures

A full safety analysis of all aspects of the waste disposal concept must be undertaken in the next phase of this study. At this time, we will briefly consider only a wellhead rupture and rock failure by a vertical discontinuity. These are possibly the two most severe incidents which must be considered. It must be noted that analyses made for this study indicate that horizontal hydrofracturing will occur for the probable site conditions. Despite this conclusion, the vertical fracture failure condition, however unlikely, must be included in any safety analysis.

A wellhead rupture would result in bleedback of some of the grout already injected. Tests on ORNL with water show a bleedback of about 50 percent. With grout, however, it is anticipated that this would be much reduced. Test injections under these conditions should be undertaken as part of the site proving. In the meantime, it is recommended that a value of 25 percent of the injected volume be used as the estimate of the bleedback. At the existing ORNL facility the bleedback grout would be discharged to a surface ditch. The new facility at ORNL, however, will include storage tanks for this condition. It is anticipated that a similar arrangement would be required at West Valley. Ultimately this grout would have to be disposed of by reinjection or removal from the site. Methods for treatment

and handling this waste grout must be considered in a conceptual design. If the waste grout were required to be transported off-site the 50,000-gallon bleedback from a 200,000-gallon injection would require approximately 18 truck loads at 20 tons per truck. An optimum balance between large, and hence cheaper, injections and possible costs from a wellhead rupture must be determined.

The rock and fracture mechanics part of this study has been directed at showing that the fracture propagation direction will be horizontal under all conditions, for the rock and stress parameters assumed. The results indicate that this fundamental criterion will very likely be met. However, further analytical, field and laboratory testing is required to confirm this. In the meantime, the effect of a vertical hydrofracture extending to rock surface must be considered. This occurrence would, in some respects be similar to a wellhead rupture, since it would allow fluid grout from the horizontal part of the grout sheet to bleedback to the rock surface. Assuming an injection of 200,000 gallons of grout, 50,000 gallons could thus bleedback to the rock surface. It is assumed that, at the rock surface, the grout would form a horizontal layer immediately below the surficial deposits.

A potentially severe condition from a safety analysis aspect, may occur if the vertical hydrofracture occurred in the immediate vicinity of a surface watercourse. One of the criteria for injection well location may thus require that the well be located at about twice the estimated grout sheet radius from a surface watercourse. However, safety analyses may need to assume that the vertical hydrofracture occurs in the vicinity of a surface watercourse. The direct discharge of fluid grout into a watercourse is considered unlikely since as far as can be

ascertained, watercourses in the site area flow within the surficial deposits.

'Dose to man' estimates may be made based on the leach rates and nuclide retardation values given in Section 8.2. The permeability of the near surface shale has been measured at 3.5×10^{-5} m/s. The permeabilities of the surficial till and outwash deposits are within the range 10^{-7} to 10^{-9} m/s (NFS, 1973). The hydraulic gradients in the vicinity of a watercourse will be high due to the steep sided incised valleys. In the absence of definitive field data, a value of 0.4 may be appropriate. Safety analyses of these phenomena will need to consider the actual injection location and local topography and groundwater systems.

8.5 - Summary

The radionuclide concentrations in the preliminary grout mix proposed for West Valley is shown to be similar to that approved for ORNL, except for the higher content of long-lived α - emitters. Leach rates and retardation values for key radionuclides have been estimated based on limited data available in the literature.

The key hydrogeological and waste transport data required for subsequent safety analyses of the isolation provided by injection into selected formations has been presented. In addition various possible, but low probability, operational failures and accidents have been identified, and safety provisions based on ORNL plans have been discussed.

9 - FEASIBILITY DISCUSSION

The preliminary technical studies reported in the above chapters yielded the following conclusions regarding the feasibility of waste injection at West Valley.

- (a) Based on the available, although very limited, site data at West Valley, it appears highly probable that horizontal fractures can be achieved in the shale beds at the analyzed depths of approximately 850 feet and 1,250 feet. Deeper horizons may also be found suitable with the acquisition of additional information regarding the stratigraphy and stress conditions. This conclusion was reached using state-of-the-art analytical techniques based on linear elastic fracture mechanics as applicable to the shale beds. This conclusion was found to be generally consistent with previous experience with hydraulic fracturing at West Valley.
- (b) A total of 3 million gallons of waste and grout has been estimated to be injected at West Valley. Multiple injections will probably be required at the selected horizon(s) to dispose of the 600,000 gallons of liquid waste. Depending on the injection scheme, the areal extent of these fractures will likely be within a radius of 2,000 feet from the borehole.
- (c) The studies in this report were based on the stratigraphy at the location of the previous drillhole on the east edge of the site. The presence of a buried valley filled with glacial sediments located beneath Buttermilk Creek and centrally through the West Valley site, may have locally modified the stress field reducing the probability of horizontal fracturing at shallower depths. Extensive

geotechnical studies will be required to delimit the effects of this valley and locate a preferred injection site.

- (d) The surface hydrological system consists of several creeks in the immediate vicinity of the site which flow northwards toward Lake Erie. These creeks are incised into the glacial till overburden and, in some isolated areas, penetrate the upper shale beds. The general deep groundwater system in the shale beds involve very low permeability materials, low hydraulic gradients and, consequently, very low groundwater velocities. The influence upon the local groundwater regime caused by the buried valley remains to be assessed. Local effects such as topography and the buried valley may cause near surface groundwater discharging into surface water courses causing most of the leached radionuclides to be discharged from the groundwater system into a single creek. Extensive work must be done to accurately define the groundwater regime.
- (e) The composition of the West Valley liquid is generally similar to that being injected at ORNL with the exception that the West Valley waste has approximately seven times the percentage of certain actinides. The technology for designing a suitable grout mixture has been proven at ORNL and should be applicable (as far as mechanical aspects are concerned) to the West Valley site.
- (f) The estimated 3 million gallons of waste/grout mixture to be injected at West Valley is compared with a total volume of waste/grout mixture injected to date at ORNL

of 1.8 million gallons, and an even larger quantity projected to be injected in the future in the new ORNL facility.

- (g) Shale offers potentially excellent isolation properties for the retention of injected radionuclides. This is due to the very low leach rates which would apply to the grout mixture, the low permeability of the shales, low groundwater gradients which would cause only very low groundwater velocities, and, the apparent properties of the shale for the radionuclides. Preliminary analyses indicate that if very strong retardation can be demonstrated then it can be expected that satisfactory isolation of both fission products and the long-lived actinides can be achieved. If only limited retardation can be demonstrated then it will still probably provide effective isolation for the lifetime of the fission products although the complete isolation of the long-life actinides may be questionable. A safety analysis is required to quantitatively assess the isolation potential of the shale.
- (h) In the past a large number of water supply wells have been drilled in the West Valley area. To date these wells have not penetrated below a depth of 250 feet in the immediate area of the West Valley site. Several of these wells, which have penetrated the shale have very low yields. Consequently there is little apparent benefit for future wells to be drilled deeper into the shale beds, and therefore closer to the horizons of interest for waste injection. Detailed safety analyses will be required to confirm that the existing wells would not be contaminated to an unacceptable degree by waste injection at the chosen injection horizons.

- (i) There have been expressions of interest in the recovery of natural gas from the Devonian shales in the Western New York region by the method of massive hydraulic fracturing. This activity will impact substantially on the groundwater system in the area fractured. It will therefore be necessary to assess the potential change to the hydrogeological system and its effect on isolation should hydraulic fracturing be allowed in various locations around the waste injection site. It may be possible to eliminate the interference by defining an exclusion zone of sufficient radius around the injection site.

In summary, it appears technically feasible to hydraulically fracture and inject radioactive liquid waste at the West Valley site. However, a detailed site investigation, laboratory and analysis program will be required to confirm the safety of the concept using site specific data. The principal problems which could interfere with the long-term isolation of the injected waste appear to arise from the potential conflict with gas and water supply interest in the area, and possible effects of the deep buried valley on the local groundwater and stress regimes. Consequently, it would appear appropriate to address these potential conflicts initially and then, if these can be resolved, commence an extensive research and development program to address the safety assessment issues. The details of a suitable research and development program and the probable facility and equipment requirements are outlined in the following sections.

PROPOSED HIGH - LEVEL RADIOACTIVE WASTE INJECTION PROGRAM
AT WEST VALLEY, NEW YORK

10 - RESEARCH AND DEVELOPMENT REQUIREMENTS

10.1 - General Program and Objectives

A general program from prefeasibility studies through to injection and facility decommissioning is shown in seven phases in Figure 10.1. Proposed High Level Waste Injection Program at West Valley, New York. The phases and their principal objectives are

Phase 1 - Prefeasibility Studies (FY78)

Objective - Determination of the general feasibility of the West Valley area for hydraulic fracturing for injection based on general data and experience elsewhere to a level of detail and reliability for overall program planning.

Duration - 9 months

Cost - \$60,000 for additional studies described in Section 10.2

Phase 2 - Research and Development (FY79)

Objective - Field, laboratory and analytical studies to confirm the feasibility of the concept using site specific data and provide the information required for design and location of the proof test and injection facility

Duration - 12 months

Cost - \$1,000,000 approximately. Details of the scope of work and cost estimates are given in Section 10.3.

Phase 3 - Proof Test and Design (FY80)

Objective - A hydraulic fracturing and grout injection test in the designated facility configuration to verify the acceptability of the facility location and injection operations. To prepare the detailed design for the production injection facility, and its decommissioning including bid packages. The test is scheduled for warm weather operation.

Duration - 12 months

Cost - \$1,000,000 approximately. A general discussion of the scope of this phase is given in Section 10.4

Phase 4 - Licencing

Objective - Obtain licence from regulatory agencies for handling and injection of radioactive materials based on PSAR, EIS etc. The requirements for licencing have not been clearly defined at this stage and consequently this phase will be subject to major review.

Duration - Unknown (Assumed 20 months in program)

Cost - \$250,000 (unsubstantiated estimate)

Phase 5 - Injection Facility Construction

Objective - To assemble the necessary batch storage tanks, pumps, piping, grout and water supplies, standby facilities, operating crews training and general preparation prior to FSAR and production injection.

Duration - 9 months. (Depends on mobilization time and awaits spring season).

Cost - Details provided in Supplement No. 1.

Phase 6 - Injection Operation

Objective - Injection of 630,000 gallons of waste in a grout mixture involving a total injection volume of approximately 3 million gallons.

Duration - Two summer seasons. This schedule is based on the injection of approximately 200,000 gallon batches at monthly intervals. This schedule is based on the ORNL schedule for the new facility. It may prove possible to compress this schedule to a more continuous type of operation at West Valley. However, in order to provide a conservative basis for planning, the proven ORNL schedule is suggested.

Cost - Details provided in Supplement No. 1.

Phase 7 - Decommissioning

Objective - To restore the surface site to as close as possible

to its initial state in requiring only minimal monitoring and security. This will involve disposal of pumps, tanks and other surface equipment together with permanent sealing of drill tubes.

Duration - 9 months (approximately, but this may be coordinated with other site decommissioning activities)

Cost - \$500,000 (unsubstantiated)

The above general program assumes that a time span of approximately 5 years is available prior to completion of the injection program. This program provides an orderly development with minimal financial and safety risks applying previously proven techniques, largely from ORNL.

The phases in which time could possibly be saved if necessary are - Phase 4 - Licencing, depending on regulatory requirements; Phase 5 - Construction if this was to be carried out in parallel with the proof test; Phase 6 - Injection, if a more continuous injection program could be justified. If all of these compressions could be made thus it may be possible to complete injection and decommissioning by early 1972, a savings of two years off the basic program.

The cost estimates are based on general consulting and contractor rates applicable in spring 1978. The prices are not firm quotation or offers of services, but are intended for planning purposes only.

10.2 - Prefeasibility Studies (FY78)

Task 1.1 - Following the studies presented in this report, additional tasks should be implemented immediately.

Task 1.2 - Preliminary Safety Analyses. "Dose to Man" predictions could be made based on the preliminary design concept and the preliminary hazards analysis presented in this report. These analyses could only use very limited site data but useful results could still be achieved in terms of design condition concentrations in the surface water system. It is expected that these could be very low, but they need to be quantified as far as possible. Cost - \$20,000 approximately.

Task 1.3 - Gas Survey. A survey should be made of the possible extent, value and commercial and/or governmental interest in the gas reserves in the Devonian Shales in the West Valley area. Areas that may be in ambient hydraulic fracturing to increase gas recovery should be identified to determine how they would impart on the injection zone groundwater system and the preliminary safety analyses. The loss of opportunity costs associated with an exclusion zone should be established. Cost - \$20,000 approximately.

Task 1.4 - Water Supply Survey. Water supply wells have been in operation in the area for many years. A survey of operating and drilling experience and future water supply requirements and plans should be made to determine the potential conflict with the injection zone. The possibility and costs of

providing water from other sources should be established.

Cost - \$20,000 approximately.

10.3 - Research and Development (FY79)

10.3.1 - Introduction

This section contains a summary discussion of the scope and estimated costs for the proposed R and D program for FY 1979. This scope of work is based on the obvious assumption that those problematic areas addressed in task 1.1 - 1.4 have been resolved.

The objective of this proposed program is to

- locate a site on the West Valley facility for hydrofracturing
- conduct geotechnical studies to confirm horizontal fracturing and propagation at West Valley
- perform special studies
- perform a safety assessment for hydrofracturing and injection.

The proposed work for FY 1979 has been divided into three major tasks

2.1 - Safety Analysis

2.2 - Geotechnical Studies and Field Work

2.3 - Special Studies.

The immediate aim for FY 1979 is to obtain sufficient site specific data to substantiate the preliminary findings arrived at in this report. Once this has

been determined, then a decision as to whether to proceed with the scheme must be made.

A generalized cost estimate and schedule for these recommended activities are presented in Table 10.1 and Figure 10.1.

Geotechnical Studies

An extensive geotechnical program is recommended to obtain sufficient baseline data to substantiate the modelling thus far performed and to provide accurate and detailed information for further safety assessment analyses.

The proposed geotechnical program has been divided into three general activities:

- I - Site Selection
- II - Site Deep Drilling and Testing
- III - Laboratory Testing

I - Site Selection

The primary objective of this activity is to select a suitable site for hydrofracturing within the West Valley facility. This will entail a combination of both office and field work. All previous reports concerning subsurface condition would be collected and analysed. Field reconnaissance and geologic mapping would be performed in and around the West Valley facility to define areas of bedrock exposure and regional joint patterns and spacing. Efforts would be made to locate and map any fault(s) within the area. Concurrent

with this field work would be the collection and analysis of all available subsurface data for this area. This would require the acquisition and analysis of all exploratory gas well logs throughout this section of Western New York to accurately define the stratigraphy and to ensure that there are no vertical discontinuities present within the area.

Seismic refraction surveys and drilling would be undertaken to enhance the previous work done to accurately define the configuration and stratigraphy of the deep buried valley beneath the site. Part of this program would involve a detailed hydrologic study of the buried valley as it effects the regional hydrologic model.

II - Site Deep Drilling and Testing

Once a suitable site has been found out for hydraulic fracturing a deep drilling program would be undertaken. To obtain sufficient data for the analyses, it is recommended that two 4-inch diameter borings be continuous cored to a depth of 2,000 feet. These holes can be arrayed so that they can be utilized for either injection and/or observation wells for the actual injection program. The drilling program would be monitored by geotechnical engineers who would log sample, and package selected core specimens for subsequent rock testing.

Once the holes have been completed, a variety of in-hole tests would be performed. As a minimum, each hole could be logged for

- mechanical 3-dimensional properties
- formation density
- caliper
- electric log
- gamma radiation
- neutron
- temperature
- seisviewer
- gyroinclinometer
- porosity
- permeability
- induction.

Hydrofracturing would be performed at a minimum of four horizons to define the in situ stresses and to assure horizontal fracturing. Similarly, in situ permeability measurements would be performed at varying levels within these holes.

III - Laboratory Testing

This activity would involve testing of rock samples taken during the deep drilling program. These tests would include

- static and dynamic moduli tests,
- fracture toughness tests at confining pressure,
- permeability tests,
- physical tests.

Safety Analysis

The general task involves the reanalyses and safety assessment of hydrofracturing and injection based on

the data collected during the geotechnical investigation. This would involve a more detailed modeling of the West Valley site based on site specific data. Programs used in this study would be updated to reflect actual site parameters and condition. In addition, more extensive hydrological modeling would be performed to better reflect the local and regional hydrology.

Special Studies

Several areas requiring additional study were noted during the course of this project. Those items that require the most immediate attention and should be undertaken in FY79, are an assessment of

- grout mix and leaching rates,
- retardation in the overburned and shale beds,
- sludge mixing,
- hydrology.

It is difficult to establish a cost and time estimate for these studies. Several of the items, such as the leaching rates, may require long-term laboratory testing. For this reason it is recommended that these studies be undertaken at an early stage of the project so they will not pose a potential delaying factor in the final safety analysis. Those prices quoted for the study in Table 10.1 are only approximated and reflect only estimated costs for FY 1979. It must be emphasized that it is not expected that the finding of any of these studies would adversely affect the scheme of hydrofracturing and injection, but rather provide detailed data required for the final safety analysis.

10.4 - Proof Test and Design (FY80)

Following satisfactory results from the research and development program in FY79 the detailed design of the facility should be completed. This should include determination of optimum injection batch sizes and hence equipment requirements. The general facility plant, enclosures, storage tanks, pumps, piping and transportation system should be developed.

The proof test may be similar to the ORNL test (Weeren et al, 1974) in which an injection well and four observation wells were drilled. Injections with a grout tagged with a radioactive tracer may be used to confirm the location, extent and orientation of the initial fractures. The drill holes may incorporate holes drilled previously to the R and D program condition of the holes.

The cost estimate of \$3,000,000 is based on the following

Drilling - 5 holes to 850 feet	\$ 700,000
Equipment charges	
Operation, Labour (48 man-months)	150,000
Analysis and reports (12 man-months)	50,000
Facility design (24 man-months)	100,000
Bid packages (provided in Supplement 1)	<u> </u>
Total Estimated Cost	<u>\$1,000,000*</u>

* Bid packages not included in total estimated cost.

TABLE 10.1 - ESTIMATED COSTS FOR
FISCAL YEAR 1979

Geotechnical Studies	Estimated Contract Cost (\$)	Estimated Engineering Cost (\$)
I - Site Selection		
(a) Geologic mapping and data collection and analysis		60,000.
(b) Seismic refraction survey	30,000.	
(c) Shallow borings	20,000.	10,000.
II - Site Deep Drilling and Testing		
(a) Drilling two 4-inch diameter boring to 2,000 feet	210,000.	20,000.
(b) Geophysical logging	30,000.	5,000.
(c) Hydrofracturing and permeability testing (4 horizons per hole)	290,000.	
III - Laboratory Testing		
(a) Static and dynamic moduli tests	30,000.	
(b) Fracture toughness tests at confining pressure	40,000.	
(c) Permeability tests	25,000.	
(d) Physical properties	20,000.	
SAFETY ANALYSIS		60,000.
SPECIAL STUDIES		50,000.
Hydrology		50,000.
Grout Mix and Leaching Rates		50,000.
Retardation		50,000.
Sludge Mixing		50,000.
	\$705,000.	\$355,000.

LIST OF REFERENCES

LIST OF REFERENCES

- Allard, B., H. Kipatshi, and J. Rydberg, 1977. "Sorption av langlivade radionuklider i lera och berg" (Sorption of Longlived Radionuclides on Clay and Rock). KBS Technical Report 55, Kärnbränslesäkerhet, Stockholm.
- Abou-Sayed, A. C., C. B. Brechtel, and R. J. Clifton, 1978. "In Situ Stress Determination by Hydrofracturing - A Fracture Mechanics Approach." Journal of Geophysical Research, in press.
- Abou-Sayed, A. S., A. H. Jones, and E. R. Simonson, 1977, on the stimulation of geothermal reservoir by downward hydraulic fracturing, ASME, Eng. Tech. Conf. Houston, Texas, September 18 - 22, 1977.
- Battelle Northwest Pacific Laboratory, 1976. "Alternative Process for Managing Existing Commercial High-Level Radioactive Wastes." Battelle Pacific Northwest Laboratory NUREG-0043 prepared under ERDA contract E(15-1)-1330 for U.S. Nuclear Regulatory Commission.
- Brace, F. F. and E. G. Bombolakis, 1963. "Anisotropy of Brittle Crack Growth of Compression." Journal of Geophysical Research, Vol. 68, pp 3709 to 3713.
- Burkholder, H. C., 1976. "Methods of Data for Predicting Nuclide Migration in Geologic Media." International Symposium on Management of Wastes from the LWR Fuel Cycle, Denver, Colorado.
- Chase, G., 1978. Personal communication of unpublished porosity and permeability values for Upper Devonian Shales.
- Cotterell, B., 1972. "Brittle Fracture in Compression." International Journal of Fracture, Vol. 8, pp 197 to 208.
- Da Shock, as cited on de Laguna, 1968.
- De Laguna, W., T. Tamura, H. O. Weeren, E. G. Struxness W. C. McClain and R. C. Sexton, 1968. "Engineering Development of Hydraulic Fracturing as a Method for Permanent Disposal of Radioactive Wastes." Oak Ridge National Laboratory Report ORNL-4259.
- De Laguna, W., 1972. "Hydraulic Fracturing Test at West Valley, New York." Oak Ridge National Laboratory ORNL-4827.
- Delale, F., and F. Endagan, 1977. "The Problem of Internal and Edge Cracks in an Orthotropic Strip." Journal of Applied Mechanics, pp 237 to 242.
- Endogan, F. and G. C. Sik, 1963. "Crack Extension in Plates Under Plane Loading and Transverse Shear." Journal of Basic Engineering, Transaction ASME, Vol. 85, pp 519 to 527.

Endogan, F., and G. C. Sik, 1963. "Crack Extension in Plates Under Plane Loading and Transverse Shear,." Journal of Basic Engineering, Transaction ASME, Vol 85, pp 519 to 527.

Energy Research and Development Administration, 1977. "Management of Intermediate Level Radioactive Waste." Oak Ridge National Laboratory, Oak Ridge, Tennessee. "Final Environmental Impact Statement." U. S. Government Printing Office, Washington ERDA-1553.

Fletcher, J. B. and L. R. Sykes, 1977. "Earthquakes Related to Hydro Mining and National Seismic Activity in Western New York State." Journal of Geophysical Research, Vol. 82, No. 26, pp 3767 to 3778.

Fried, S., A. M. Friedman, R. Atcher and J. Hines, 1977. "Retention of Plutonium and Americium by Rock." Science Vol. 196, pp 1087 to 1089.

Gast, R. G., 1963. "Relative Effects of Tortuosity, Electrostatic Attraction and Increased Viscosity on Self-Diffusion Rates of Cations in Bentonite-water Systems." Procurement 1963 International Clay Conference, Pergamon, New York pp 251 to 259.

Gustafsson, Y., 1968. "The Influence of Topography on Groundwater Formation; in Groundwater Problems" editors E. Eriksson, Y. Gustafsson, and K. Nilson, Pergamon Press pp 3 to 21.

Hoenig, A, 1977 a. "Asymptotic Semi-infinite Crack Tip Analysis in a Plane Anisotropic Elastic Body." Division of Applied Science, Harvard University, Mech-4.

Hoenig, A., 1977 b. "The Behaviour of a Flat Elliptical Crack in an Anisotropic Elastic Body, Division of Applied Science, Harvard University, Mech-5.

Haggblom, H., 1977. "Calculations of Nuclide Migration in Rock and Porous Media, Penetrated by Water." KBS Technical Report 52 Kärnbränslesäkerhet, Stockholm.

Irwin, G. R., 1957. "Analysis of Stresses and Strains Near the End of a Crack Transversing a Plate." Journal of Applied Mechanics, Vol. 24, pp 361 to 364.

Irwin, G. R., 1960. "Fracture Mechanics, in Structural Mechanics." Editors J. N. Goodier and N. J. Hoff, Pergamon Press., New York, pp 557 to 594.

Ingraffea, A. R. F. E. Henze, H. Y. Ko and K. Gerstle, 1977. "An Analysis of Discrete Fracture Propagations in Rock Loaded in Compression." 18th U. S. Symposium on Rock Mechanics, pp A21 to 7.

Jones, G. K., 1963. "Chemistry and Flow Properties of Bentonite in Grouts and Drilling Muds, in Engineering Practice." Butterworth and Company, London, pp 22 to 28.

La Sala, A. M., 1968. "Groundwater Resources of the Erie-Niagara Basin, New York Conservation Department Water Resources Commission." Basin Planning Report ENB-3.

Moore, J. G., H. W. Godbee, A. H. Kibbey and D. S. Joy, 1976. "Development of Cementitious Grouts for the Incorporation of Radioactive Wastes." Part 1 Leach Studies, Oak Ridge National Laboratory ORNL-4692.

Moore, J. G., 1976. "Development of Cementitious Grouts for the Incorporation of Radioactive Wastes. Part 2: A Continuation of Cesium and Strontium Leach Studies." Oak Ridge National Laboratory ORNL-5142.

NFS Reprocessing Plant. West Valley, 1973, Docket No. 50 - 201.

Parsons, 1961. "Movement of Radioactive Waste Through Soil." Atomic Energy of Canada Limited, Chalk River Environmental Research. Report 1018 p 46.

Rice, J. R., 1968. "Mathematical Analysis in the Mechanics of Fracture, in Treatise of Fracture." Editor H. Liebowitz, Vol. 2, Ch. 3, Academic Press, pp 191 to 311.

Richard, L. V., 1975. "Correlation of the Silurian and Devonian Rocks in New York State." New York State Museum and Science Service, Map and Chart Series Number 24.

Robertson, J. B. and J. T. Barraclough, 1973. "Radioactive and Chemical Waste Transport in Groundwater at National Reactor Testing Station, Idaho: 20 Year History and Digital Model." 2nd International Symposium Underground Waste Management and Artificial Recharge, American Association of Petroleum Geologists, Vol. 1, pp 291 to 322.

Sih, G. C., P. C. Paris, and G. R. Irwin, 1965. "Cracks in Rectilinearly Anisotropic Body." International Journal of Fracture Mechanics, Vol 1, pp 189 to 203.

Simpson, E. R., A. S. Abou-Sayed, and R. J. Clifton, 1978. "Containment of Massive Hydrofractures." Journal Society of Petroleum Engineers.

Sun, R. J., 1969. "Theoretical Size of Hydraulically Induced Horizontal Fractures and Corresponding Surface Uplift in an Idealized Medium." Journal of Geophysical Research, Vol. 74, No. 25, pp 5995 to 6011.

Sun, R. J., 1973. "Hydraulic Fracturing as a Tool for Disposal of Wastes in Shale; Under Waste Management and Artificial Recharge." Vol. 1.

Sun, R. J. and C. K. Morgan, 1974. "Hydraulic Fracturing in Shale at West Valley, New York, A Study of Bedding Plane Fractures Induced in Shale for Waste Disposal." USGS: Open File Report pp 74 to 365.

Sun, R. J., 1976. "Geohydrologic Evaluation of a Site for Disposal of Radioactive Wastes by Grout Injection and Hydraulic Fracturing at Holifield National Laboratory (formerly Oak Ridge National Laboratory)." Oak Ridge, Tennessee, U. S. Geological Survey Open File Report 75-671, p 77.

Swolfs, H. S., 1977. Unpublished data presented at Conference on In situ stress, Durham, England, August 1977; Sedimentary data from Abou-Sayed, et al.

Talobre, J. A., 1967. "La Mecanique des Roches et Ses Applications." Dunod, Paris.

Tamura, T., 1971. "Sorption Phenomena Significant in Radioactive Waste Disposal." Editor T. D. Cook, Underground Waste Management and Environmental Implications, American Association of Petroleum Geologists Mem. 18, pp 318 to 330.

Vanderglao, M. L., 1977. "Finite Element Analysis of Two and Three Dimensional Elastic Cracks." Master's Applied Science Thesis, University of Waterloo, Waterloo, Ontario.

Weeren, H. O., G. D. Brunton, W. De Laguna, and J. G. Moore. 1974. "Hydrofracture Site Proof Study at Oak Ridge National Laboratory." Oak Ridge National Laboratory ORNL-TM-4713.

Weeren, H. O., 1976. "An Evaluation of Waste Disposal by Shale Fracturing." Oak Ridge National Laboratory ORNL-TM-5209.

Williams, J. G. and P. D. Ewing, 1972. "Fracture Under Complex Stress - The Angled Crack Problem." International Journal of Fracture, Vol. 8, pp 441 to 447.

Wo, H. C., R. F. Yao, and M. C. Yip, 1977. "Experimental Investigation of the Angled Elliptical Notch Problem on Tension." Journal of Applied Mechanics, pp 455 to 461.

Yang, H. C., and Y. T. Chou, 1977. "Antiplane Problem of an Elliptic Inclusion in an Anisotropic Medium." Journal of Applied Mechanics, pp 433 to 441.