TECHNICAL ASSISTANCE FOR DESIGN REVIEWS

EI PROPOSAL NO. 313

IN RESPONSE TO RFP NO. RS-NMS-82-030

PART I – TECHNICAL PROPOSAL

PREPARED FOR

U.S. NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

NOVEMBER 1981

ENGINEERS INTERNATIONAL, INC.
5107 CHASE [illegible] ERS GROVE, ILLINOIS 60515 • 312/963-3460

TECHNICAL ASSISTANCE FOR DESIGN REVIEWS

EI PROPOSAL NO. 313

IN RESPONSE TO RFP NO. RS-NMS-82-030

PART I - TECHNICAL PROPOSAL

PREPARED FOR

U.S. NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

NOVEMBER 1981

ENGINEERS INTERNATIONAL, INC.
5107 CHASE AVENUE, DOWNERS GROVE, ILLINOIS 60515 • 312/963-3460

TABLE OF CONTENTS

1.0 INTRODUCTION 1-1
1.1 Approach 1-2
1.2 Project Team 1-2
1.3 Project Difficulties 1-2
1.4 Conflicts 1-3
1.5 Exceptions and Deviations 1-3
1.6 Summary 1-3
2.0 TECHNICAL DISCUSSION OF APPROACHES 2-1
2.1 Nuclear Waste 2-1
2.2 Mined Disposal 2-1
2.3 Regulations 2-2
2.4 General Geologic Considerations for Repository Siting. 2-2
2.4.1 General Site Considerations. 2-2
2.4.2 Host Rock Types Under Considerations 2-3
2.4.3 Rock Properties 2-4
2.4.4 Rock Mass Properties 2-4
2.4.5 Hydrogeologic Considerations 2-4
2.4.5.1 Porosity 2-4
2.4.5.2 Permeability 2-5
2.4.5.3 Groundwater Flow 2-6
2.4.5.4 Hydrochemistry 2-7
2.4.6 Radioactive Considerations 2-7
2.4.7 Thermal Properties 2-9
2.4.8 Natural Failure 2-9
2.4.9 Breach of Repository 2-10
2.5 Geologic Approach 2-10
2.5.1 Thorough Understanding of the Geologic Environment . 2-10
2.5.2 Field Relationships 2-11
2.5.3 Determining Structural Domains 2-11
2.5.3.1 Rock Types 2-12
2.5.3.2 Major Faulting 2-12
2.6 Design Considerations 2-13
2.6.1 General Site Location 2-13
2.6.2 Access 2-13
2.6.3 Layout and Plan 2-14
2.6.4 Method of Excavation 2-14
2.6.5 Rock Stabilization 2-14
2.6.6 Permanent Support 2-16
2.6.7 Rock Mass Monitoring 2-16
2.7 Shaft Design 2-17
2.7.1 Intended Use 2-17
2.7.2 Rock Mass Properties and Lining Requirements 2-17
2.7.3 Expected Water Inflows 2-18
2.7.4 In-Situ Stress Field 2-18
2.7.5 Groundwater Chemistry 2-18

2.8 Design 2-18
2.8.1 Rock Mass Properties 2-18
2.8.2 Analysis and Design 2-19
2.8.3 Constructability 2-19
2.8.4 Performance Assessment 2-19
2.8.5 Natural Failure 2-20
2.8.6 Breach of Repository 2-20
2.9 Current Conceptual Repository Layout 2-20
2.10 Repository Facilities 2-21
2.10.1 Disposal Rooms 2-22
2.10.2 Disposal Panels 2-22
2.10.3 Ventilation Considerations 2-22
2.10.4 Mining Equipment 2-23
2.10 5 Radioactive Waste Haulage 2-23
2.11 Waste Package Design 2-23
2.12 Thermal Loading Resulting from HLW Storage 2-24
2.13 Stability Considerations 2-25
2.14 Creep 2-27
2.15 Shaft Hoisting Systems 2-28
2.16 Ventilation 2-30
2.16.1 Long Term Ventilation Planning 2-31
2.16.2 Medium-Term Ventilation Planning 2-31
2.16.3 Short-Term Ventilation Planning 2-31
2.17 Design of Ventilation Systems 2-32
2.17.1 Primary Distribution System 2-32
2.17.2 Fans and Entries 2-33
2.17.3 Face Ventilation 2-33
2.17.4 Ventilation Control Devices 2-34
2.17.5 Ventilation Surveys 2-34
2.18 Cooling of Facility Air 2-34
2.18.1 Vapor-Compression Refrigeration System 2-35
2.18.2 Cooling Towers 2-35
2.18.3 Cooling Coils 2-36
2.18.4 Spray Chambers 2-36
2.18.5 Elements of Typical Heat Exchangers 2-36
2.19 Power Distribution 2-37
2.19.1 Underground Switchgear 2-37
2.19.2 Underground Mine Transformer Stations 2-37
2.19.3 Capacitor Pack 2-37
2.19.4 Distribution Centers 2-38
2.19.5 Grounding Circuits 2-38
2.19.6 Batteries and Battery Charging Stations 2-38
2.20 Electrical Equipment and Machines 2-39
2.20.1 Trailing Cables 2-39
2.20.2 Trolley Wires and Nips 2-39
2.20.3 Electric Motors 2-40
2.20.4 Mining Machines 2-40
2.20.5 Electric Blasting 2-40
2.20.6 Ancillary Electrical Systems 2-41
2.20.6.1 Communication Systems 2-41
2.20.6.2 Lighting Circuits 2-41

2.21 Safety 2-42
2.21.1 Materials Handling 2-42
2.21.2 Human Factors Engineering 2-43
2.21.3 Safety Analyses 2-43
2.21.4 Fires 2-47
2.21.5 Overall Safety Considerations 2-49
2.22 Sealing Requirements and Concepts 2-54
2.22.1 Concept for Los Medanos Shaft Seals 2-54
2.22.2 Borehole Seals 2-55
2.22.3 Grouting 2-56
2.22.4 Shaft Sealing Methods 2-57
2.22.5 Sealing Materials 2-57
2.23 Retrievability 2-58
2.24 Boreholes 2-60
2.24.1 Abandoned Boreholes 2-60
2.24.2 Recent Boreholes 2-60
2.25 Seismic Effects 2-61
2.26 References 2-63
3.0 PROGRAM PLAN 3-1
3.1 Objective 3-2
3.2 Project Responsibility 3-2
3.3 Technical Plan 3-2
3.3.1 Step 1 - NRC Task Order Item 3-4
3.3.2 Step 2 - Review by EI Management 3-4
3.3.3 Step 3 - Subdivision into Various Included Technical Areas 3-4
3.3.4 Step 4 - Summary of Specific Detailed Technical Area of Task Order 3-4
3.3.5 Step 5 - Site Characterization Adequacy 3-5
3.3.6 Step 6 - Operations Area Requirements Adequacy . . 3-5
3.3.7 Step 7 - Repository Requirements Adequacy 3-5
3.3.8 Step 8 - Shaft Requirements Adequacy 3-6
3.3.9 Step 9 - Performance Confirmation Requirements Adequacy 3-6
3.3.10 Step 10- Adequacy Summary 3-7
3.3.11 Step 11- Consolidation and Resolution of Differences 3-7
3.3.12 Step 12- Draft Report 3-7
3.3.13 Step 13- Final Report 3-8
3.4 Support Activities 3-8
3.4.1 Meeting Participation 3-8
3.4.2 Workshops 3-8
3.4.3 Site Visits 3-8
3.5 Task 2 Activities 3-9
3.5.1 Meeting Participation 3-9
3.5.2 Workshops 3-9
3.5.3 Report Reviews 3-9
3.5.4 Site Visits 3-9

3.6 Quality Assurance 3-10
3.6.1 Commitment and Organization 3-10
3.6.2 Responsibilities 3-10
3.6.2.1 Project Manager 3-10
3.6.2.2 Quality Assurance Engineer 3-10
3.6.2.3 Project Engineer 3-13
3.6.3 Document Control 3-13
3.6.4 Trained Personnel 3-13
3.6.5 Handling, Storing, Identification, and Control of Test Specimens 3-13
3.6.6 Calibration of Instruments 3-14
3.6.7 Auditing 3-14
3.6.8 Reporting 3-14
3.7 Project Reviews and Presentations 3-15
3.8 Personnel Requirements 3-15
3.9 Equipment and Materials 3-15
3.10 Travel 3-15
3.11 Subcontracts 3-17
3.12 Reports and Delivery Requirements 3-17
3.12.1 Program Plan and Schedule 3-17
3.12.2 Monthly Progress Reports 3-17
3.12.3 Deliverable Items 3-18
4.0 PROJECT SCHEDULE 4-1
5.0 ORGANIZATION 5-1
5.1 Engineers International, Inc. 5-1
5.2 Project Team 5-3
5.3 Responsibilities of Key Project Personnel 5-10
5.3.1 Project Manager 5-10
5.3.2 Project Engineer 5-10
5.4 Project Controls 5-11
5.5 Management System 5-12
5.6 Key Person Involvement 5-12
5.7 Experience 5-12
6.0 PERSONNEL 6-1
6.1 Resumes of EI Staff 6-2
6.2 Consultant Resume 6-44
7.0 FACILITIES 7-1
7.1 General Facilities 7-1
7.2 Regulation Library 7-2
7.3 Laboratories 7-3
7.4 Computational Facilities 7-6
7.5 Field Equipment 7-11
7.6 Specific Project Requirments 7-11
8.0 SUPPORTING DATA 8-1
8.1 Reporting Concurrence 8-1
8.2 Government Contracts 8-1
8.3 Letter from Consultant 8-7
9.0 CONFLICTS 9-1
10.0 CLOSURE 10-1

ENGINEERS INTERNATIONAL, INC.

EI Proposal No. 313

In response to RFP No. RS-NMS-82-030

TECHNICAL ASSISTANCE FOR DESIGN REVIEWS

Part I - Technical Proposal

1.0 INTRODUCTION

Nuclear waste has been generated from military, research, medical, and power generation sources and still continues to be generated, so some method of disposing of this hazardous material is ultimately essential. At the present time, storage facilities are planned in repositories mined underground in various geologic formations, including basalt, tuff, granite, bedded salt, and dome salt. Accordingly, the Nuclear Regulatory Commission (NRC), which has the responsibility for licensing nuclear waste repositories, needs assurance that all proposed repository alternatives are adequate, or the deficiencies are identified at an early date.

The NRC has, therefore, issued this RFP to Engineers International, Inc. (EI), and other organizations, for the purpose of providing assistance for thoroughly reviewing repository designs identifying potential regulatory guidance and needed research.

EI is well-qualified to undertake this work for the NRC since it has specific and pertinent experience in all required fields, including mining, civil, structural, mechanical, electrical, safety, thermomechanical properties of rock, and others. Also, EI has no past or present conflicts that might influence its work on this project.

It is not possible in a concise proposal to fully discuss all of the pertinent technical items in each subject, so EI has decided to not go into detail on nuclear waste isolation technology, but merely to discuss the general problems known, and EI's approaches to such work. It will be seen in the proposal that EI has a thorough grasp of the technical problems involved in the Statement of Work items, and that our approach to this work is well-founded, innovative, efficient, and of a high technical level.

The EI staff have extensive design and research experience in geotechnical and mining technology and civil projects as their resumes will indicate. In fact, EI has been praised by its clients for finding practicable solutions to difficult underground investigation and design projects. A careful reading of the qualifications section of this proposal will demonstrate that EI, despite being a relatively small and new firm, has successfully undertaken several major research and design projects at the forefront of technology.

The personnel, financial, hardware, and physical resources are present at EI to carry out this project for NRC, and we would appreciate the opportunity to do so.

1.1 APPROACH

A project involving an assessment of new or undeveloped technology for underground nuclear waste management requires a blend of research, practical design and operations skills and experience that are seldom found in a single organization. EI, however, is thoroughly involved in mining and geotechnical research, as well as in mine operations, equipment evaluations, safety, ventilation, tunnel design, and field investigations, that gives us the required appropriate approach.

EI recognizes the great importance of this project to the national good, and has accordingly taken a very considered and professional approach to this work, which includes thorough and accurate technical work, quality assurance, lack of conflict, and responsive project management.

1.2 PROJECT TEAM

EI has assigned what we consider to be excellently qualified individuals to this project. The Project Manager is Mr. Francis S. Kendorski, who has managed mining and geotechnical research and design both industrial and federally funded projects as well as the design efforts for major tunnel construction projects. Mr. Leif G. Eriksson will serve as Assistant Project Manager, and he has specific and pertinent high-level nuclear waste respository analysis and design experience in underground storage facilities worldwide. Mr. Michael F. Dunn will be Project Engineer, and he has carried out mine design, tunnel design, ventilation design, equipment evaluations, mining research, safety and rock mechanics projects. EI professional staff include persons with extensive experience in both research and operational projects in mining design, civil design, ventilation, rock mechanics, and geologic investigations. In addition to the existing staff, we have retained the services of Dr. M. Ashraf Mahtab as Rock Mechanics Consultant, and he has pertinent experience in the rock mechanics of nuclear waste repositories. Dr. Madan M. Singh, Principal of EI and Staff Consultant, has managed over 36 federal projects, so can provide the managerial skills to lead to project success.

1.3 PROJECT DIFFICULTIES

The information required to carry out assessments of repository proposals for the numerous alternatives may not be readily available in reports provided by NRC and DOE, due to incompleteness or the fact that much of the repository work is still on-going. However, EI library holdings, abilities to glean the required information from various sources, and experience in telephone inquiries on highly technical items, as well as research and industrial contacts maintained by EI, assure that the project information will be complete in so far as possible and also up-to-date.

Methods of numerically analyzing maany factors in geologic media are not well-developed, but EI's familiarity with these technologies will assure that adequate analyses are carried out and numerical techniques are applied and developed efficiently.

Quick response could be a project difficulty, but EI has proposed an efficient management plan for identifying the particular required review items and assigning them to experienced staff, with careful feedback and responsiveness built in.

1.4 CONFLICTS

The RFP specifically states that an important evaluation criterion for selecting a contractor for this work is the lack of past or present conflicts or apparent conflicts that could influence the contractor's work and assessments. EI is proud to be in a position on this RFP such that we have no conflicts of any sort that might jeopardize our objectivity for the NRC and DOE. EI, while fully qualified in all of the required fields for this project, has not worked on any projects directly or indirectly related to or funded by NRC or DOE geologic nuclear waste repository efforts.

Thus EI can provide on this project without any possibility of conflict or potential conflict in reviewing our own work for NRC and DOE, which, we believe, satisfies a very important contractor selection criterion, and is unusual in a firm in our fields of interest.

1.5 EXCEPTIONS AND DEVIATIONS

EI has not taken any exceptions or deviated in any manner from the requirements of the Statement of Work and RFP.

1.6 SUMMARY

EI has carefully considered and thoroughly planned an approach to this project that includes:

- Strong and effective management
- Evaluation of reports and studies
- Assessments of designs in accordance with 10 CFR 60
- Identification of any inadequate components or systems
- Quality Assurance
- Preparation of comprehensive Task Reports

- Assistance to NRC in meetings, workshops, and report reviews

In order to accomplish this, EI has assembled an experienced and knowledgeable project team, carefully thought out the project requirements or manpower, budget, and schedule, and prepared this detailed and comprehensive proposal for all project elements.

2.0 TECHNICAL DISCUSSION OF APPROACHES

The isolation of nuclear waste is a problem that must be solved, and solved in the near future. The waste presently exists in considerable quantities from both power generation, research, medical, and military sources. These wastes are in temporary storage in various sites around the country and must ultimately be dealt with. Continuing and new nuclear power generation constantly adds to the quantity of waste, so with time, permanent isolation and disposal becomes even more critical.

2.1 NUCLEAR WASTE

Nuclear waste materials are a very diverse group of substances that share two main characteristics; they are radioactive and therefore dangerous to life and ecosystems; and they generate self-heat as a consequence of their radioactivity, thereby complicating their long term isolation. The volume of the waste can be reduced by processing techniques of various kinds that also increase their activity per volume. Current technology would reduce the waste material to a relatively stable configuration that does not interact with the environment except by radioactivity and heat.

The waste material would be containerized into manageable packages of some sort that would incorporate physical and chemical stability, shielding, and optimal or minimal heat generation capability.

Regulation 10 CFR 60 requires that nuclear waste repositories be sealed after decommissioning in order to isolate the radioactive material stored therein from the surroundings. To do so requires that all shafts and boreholes in the vicinity be sealed.

2.2 MINED DISPOSAL

Several alternatives have been proposed for disposal of nuclear waste including seabed isolation, ice sheet isolation and deep continental geologic isolation. In the case of the latter, there are a number of alternatives including mined cavities, solution cavities, hydrofracture emplacement and deepwell injection. Currently, the major emphasis is on the use of mined cavities.

These cavities must be sited and designed such that interaction with the global environment is minimized or eliminated. In order to satisfactorily isolate the nuclear waste, a repository must satisfy certain criteria such as

- adequate depth
- suitable rock properties
- tectonic and seismic stability
- suitable hydrologic regime
- no potential for future

resource interest
- multiple material and engineered safety features

and much investigation and research are required to satisfy these criteria for overall planning and suggested sites.

2.3 REGULATIONS

The responsibility for licensing the disposal of high-level radioactive waste (HLW) in geologic repositories lies with the NRC. The criteria for approval of a license application are set forth in 10 CFR Part 60. Under Section 60.130, design of the repository operations area must include provisions for worker protection which comply with the Federal Mine Safety and Health Act of 1977 (30 CFR Part 57). The first draft of 10 CFR Part 60 also required compliance with state regulations.

The technical criteria of 10 CFR Part 60 require that the engineered system be designed so that the wastes are contained within the waste package for the first 1,000 years following emplacement. Following this period the function of the waste package and repository is to control the release of radionuclides from the facility.

2.4 GENERAL GEOLOGIC CONSIDERATIONS FOR REPOSITORY SITING

In any engineered structure, the environment and materials must be considered as well as their behavior over the expected lifetime of the project. In a geologic environment, these requirements are severely handicapped in that the materials are not planned, designed or controlled in any way. We must work with what is available.

2.4.1 General Site Considerations

The environment of the site must be thoroughly understood and its relationship to surrounding areas considered. The sequence and distribution of rock units in the area comprise the geologic setting and any geologic disturbances such as faults, folds, bedding, and joints must be located and their nature determined.

The site must, for many reasons, be remote from large centers of population but at the same time be accessible by normal means of transport. The topography and geomorphology of the site must be studied so that the physical and spatial attributes of the local environment are known. For example, in very rugged or mountainous terrain, the depth of burial of a desirable repository site could vary a great deal, complicating access and isolation; in level terrain, the situation is more workable.

If rock units have been faulted or folded, their distribution is more complicated than if only depositional processes have occurred. However, no matter what the geologic history of a candidate site, it is necessary to have as complete as possible a knowledge of the geologic structure. Since we cannot see into the rocks, we must probe them with drill holes or infer their character indirectly through seismic or other geophysical techniques. Since every part of the rock mass cannot be viewed or inspected, there is always some element of uncertainty even in the most thorough site investigations.

Aside from the geometric distribution of the rock types, other factors must be understood such as stress state, physical properties and water environment.

2.4.2 Host Rock Types Under Consideration

Most schemes for mined disposal envision a single lithologic unit as the repository site. The types of rock under consideration are basalt, tuff, domed/bedded salt and granite. Site investigations and pilot projects are currently being carried out at Hanford, WA (basalt), Los Medanos, NM (bedded salt) and in Nevada (granite tuff) in the United States and at Asse West Germany (domed salt) and Stripa, Sweden (granite) in Europe.

Basalt consists of lava which may have flowed some distance before coming to rest and solidifying. Jointing can be extensive and is often columnar in nature. Basalt commonly exhibits low permeability and high strength. Even at elevated temperatures, basalts remain strong but may expand.

Tuff consists of volcanic ash and sand. Although the material itself is volcanic, tuff itself is a sedimentary rock. It is variable in its properties but is commonly a low strength, highly permeable rock. Deposits of tuff can have great extent and thickness.

Salt is formed by precipitations from land locked brines and hence is a sedimentary rock. There are two types - domed salt and bedded salt. Domed salt is formed when salt migrates upward through more dense overlying strata. It is more homogeneous that bedded salt and contains fewer fluid inclusions. Salt is commonly a low strength, low permeability material which flows plastically even at low temperatures and pressure. This plastic behavior is advantageous in that any fractures which may develop will readily heal. Salt also has better heat dissipation properties than other rocks.

Granite is formed by the intrusion of magma into a self-formed cavity generally at great depth. It is generally massive but may be well jointed. Like basalt, granite is commonly a high strength, low permeability rock which may exhibit expansion at elevated temperatures.

2.4.3 Rock Properties

The material properties of the rock itself - as distinct from the discontinuities present - must be well understood, in the same fashion as construction materials.

Since excavation in rock results in stress redistribution and deformation in and damage to the rock surrounding that excavation, the strength and deformation properties of the rock must be determined. Since emplacement of radioactive waste will result in heating of the rock, these properties must be known at elevated as well as normal temperatures.

Only by measuring and understanding these properties will we be able to anticipate the behavior of the mined disposal site throughout its lifetime as well as during construction.

2.4.4 Rock Mass Properties

Rock in place has generally been fractured and deformed over time by geologic processes. The distribution and properties of the discontinuities resulting from such processes are, therefore, as important as the properties of the intact rock in determining the behavior of the rock mass. Faults are sites of movement and commonly incorporated crushing and alteration of the rock. Consequently, they can have physical properties of their own.

Conversely, joints, or cracks exhibit little or no movement. Joints occur in groups, patterns, and sets and this feature controls the inhomogenity and anisotropy of the rock mass. The length and spacing of the joints are important for determining the rock mass physical behavior while the number and attitude of the joint sets controls the directional behavior. Other properties such as roughness, curvature, fillings and termination must also be known as they also influence rock mass behavior.

2.4.5 Hydrogeologic Considerations

It must be assumed that any repository host rock contains water at depth and that the rock will be saturated. Further, even though the permeability of the host rock may be so small as to be negligible for engineering purposes, groundwater movement will be occurring throughout the disposal period. During the selection of a suitable repository site, its hydrogeologic properties will be determined through direct and indirect investigation methods. These properties are discussed below.

2.4.5.1 Porosity

The amount of void space or pores within plutonic igneous rocks is very low. In the case of granites, pores typically account for only one to three percent of the rock's volume (Krynine and Judd, 1957).

Laboratory measurements of porosity are performed on relatively small rock specimens and do not reflect the volume of fractures or small cracks contained within the total rock mass.

Extrusive igneous rocks, such as flow basalts generally contain numerous vessicles formed by gases which were entrapped during flow. Often these vessicles are later filled by zeolite minerals, but basalt porosities are commonly between 10 and 50 percent. (Davis & DeWiest, 1966).

Pyroclastic rocks, in this case tuff, are generally quite porous. Variation of porosity depends on the amount of "welding" that occurs between the individual grains after deposition. Keller (1960) reports that within tuffs of the Oak Spring Formation, Nevada, porosities ranged between 14 and 40 percent.

Rock salt tends to be massive in structure and have low porosity. Fluid-filled inclusions are often present but these isolated voids would not provide avenues for water transport. In bedded salt deposits, dessicated layers of clay or gypsum, anhydrite, and limestone layers are sometimes present. These beds would contribute to the porosity of the rock salt mass but are not water bearing in their natural state.

2.4.5.2 Permeability

Rock permeability is of much greater importance in hydrogeologic investigations than is porosity because permeability is a measure of the rate at which water can flow through the rock. Permeability is controlled not only by the amount of open spaces and their size, shape and interconnection, but also by the density and viscosity of the water itself.

Permeability in rock of the types considered for nuclear waste repositories is generally controlled by fractures and other discontinuities rather than the pores themselves.

At depth in granitic rocks, the included fractures are generally tightly closed and permeability is very low. Weathering of granites increases their permeability nearer the surface and such permeable weathered zones may extend to depths up to about 300 ft in tropical climates.

In basalts, flow-induced elongation and interconnection of vessicles may produce a very highly permeable rock mass. Also cooling fractures or relic soil horizons between successive flows may produce zones of high lateral permeability. In massive basalts, or where vessicles are not connected, permeabilities may be low.

Because of the lack of interconnection of pore spaces, tuff generally exhibits low permeabilities. Keller (1960) reported permeabilities of 4×10^{-5} and 2.3×10^{-4} cm/sec for bedded and welded tuffs respectively. Again, zones of alteration or fracturing between successive tuff layers may produce highly anisotropic permeabilities in thick tuff formations.

Rock salt is, by nature, highly impermeable. Below about 1,000 ft depth, fractures in salt tend to seal themselves through plastic flowage and fracture permeability is thereby eliminated. However, because of its solubility, water-carrying channels may develop along the contact between the salt and any overlying aquifers. In the case of bedded salt deposits, anhydrite, carbonate, or clay layers may provide some avenue of lateral permeability to the salt mass.

Barring the presence of high angle faults or fracture systems, the rocks previously described tend to exhibit more consistent permeability in the horizontal direction than in the vertical direction. This is due to the tendency of these rocks to be more homogeneous laterally than vertically. Zones of weathering, buried surficial cooling fractures and natural bedding are examples of laterally extensive permeable zones.

By introducing a shaft or borehole into rock having lateral-trending permeability, an avenue for vertical movement of subsurface fluids is created. Increased vertical permeability is produced not only by the borehole or shaft itself, but also by their annulus of disturbed rock. This is particularly true for shafts excavated by drilling and blasting.

Measurements of permeability or "hydraulic conductivity" are performed both in the laboratory and in the field. Laboratory permeability tests are performed on small (less than 2 in. diameter core) rock specimens which are held in triaxial compression while differential hydraulic pressures are used to force water through the specimens. Daemen (1979) Describes three types of apparatus for permeability tests. In the field, the permeability of "tight" formations can be determined through pumping tests in packed off sections of boreholes or injection of air into those sections. Trace ejector tests, where a radioactive isotope tracer is injected into a borehole and later identified on geophysical logs is used in some cases. Other borehole geophysical logging techniques are also utilized by the petroleum industry to provide an indication of rock permeability.

2.4.5.3 Groundwater Flow

The rate of groundwater flow between two points is dependent upon the hydraulic conductivity of the rock mass, the density and viscosity of the groundwater, and the difference in hydrostatic head between the points. This flow has a specific direction which will necessarily be from the area of highest energy potential to lowest potential. Under the conditions present at a suitable nuclear waste disposal zone, the rate of groundwater flow may be so low as to be nonexistent for practical purposes.

The introduction of a mined nuclear waste repository and the attendant boreholes and shafts present the hazard of increased permeability of the rock mass surrounding those structures and would thereby increase the potential for groundwater flow toward them as well as vertically through them.

Convection of the groundwater created by heat from the repository and altered specific gravity and viscosity of the ground water caused by increased mineral solubilities would introduce further changes in groundwater flow. In addition, changes in hydraulic conductivity through fracture plugging or expansion in the vicinity of the shafts and boreholes present more complications to the flow regime.

Theoretical methods of modeling the groundwater flow response to a high level nuclear waste repository have been performed in the absence of in situ measurements of host rock flow regimes. Methods pertaining to homogeneous, porous rock and inhomogeneous, fractured rock are described by Runchal and Maini (1980).

2.4.5.4 Hydrochemisty

Dissolved solids and gases are present in all groundwater to various degrees. In brine solutions found at depth, dissolved solids may be as high as 300,000 ppm. Dissolved gases are considered to amount to as much as 100 ppm in most groundwater and greater in some situations (Davis and DeWiest, 1960).

The chemical constituents of groundwater are not only important to its density and viscosity, but also to its reactivity with constituents of metal casings and grout materials used in borehole and shaft sealing. Changes in the solubility of dissolved solids and gases would be particularly affected by the temperature increase caused by the storage of nuclear waste in the repository. Plugging of rock fractures or voids by precipitates, dissolution of certain minerals of the host rock, or chemical attack of repository seals could result from changes in hydrochemistry.

2.4.6 Radioactivity Considerations

Radioactivity is the conversion of atoms of one chemical element to those of another resulting from the emission of fundamental particles. These particles are of two types: alpha, which consist of helium nuclei, and beta, which are electrons. Emissions of beta particles have associated with them emissions of gamma rays which are very highly penetrating electromagnetic waves of a nature similar to x-rays but of shorter wave length.

Each radioactive substance or "radionuclide" has a characteristic rate of decay which is constant. Because of the constancy of the decay rate (λ), any isolated initial stock of a particular radionuclide decays exponentially with time. The rate of decay, $N\lambda$ atoms permit time, is called the activity of the source of N atoms. The unit of activity is the Curie (Ci) which is a rate of decay of 3.700×10^{10} disintegrating atoms per second from a source of a single radionuclide. (A Curie is approximately, but not exactly, equal to the activity of 1g of Radium.)

The half-life T of a radionuclide is the time interval in which the number of atoms and hence the activitiy is reduced to one-half its initial value. The half-life is related to the decay constant as follows:

$$T = \frac{\ln 2}{\lambda}$$

where T = the half-life

λ = the decay constant

ln = natural logarithum.

There are two nuclear processes from which energy can be obtained - fission and fusion. At the present level of technology, the latter is not practical. Nuclear fission is the process in which a nuclear target bombarded by neutrons, splits to form two new nuclei of lighter mass and several free neutrons. Only two nuclides, Uranium 235 and Plutonium 239, are, for practical purposes fissionable by neutrons of all energies and, of these, only Uranium 235 occurs in nature - Uranium 233 and Plutonium 237 are produced from Thorium 232 and Uranium 238 respectively by neutron absorption. The fission process occurs in more than 40 ways producing fission fragments with mass numbers ranging from about 72 to 160. These fission fragments themselves are highly radioactive and decay in a succession of step involving formation of other radionuclides.

Spent nuclear fuel has substantial residual uranium and plutonium, so it is reprocessed to recover these materials. The material which is left over from reprocessing is high level waste. The critical radioisotopes contained in high level waste are Strontium 90 and Cesium 137 which have half-lives of 28 and 30 years respectively. Because of such large half-lives, wastes containg these radionuclides will remain active for years. More important from the stand point of geology and hydrology, however, is the fact that Strontium 90 is highly soluble in water. The maximum allowable concentration of Strontium 90 in drinking water is 10 pCi/l.

Migration of radionuclides within geologic media occurs by two means- diffusion and transport. The former occurs with gaseous radionuclides and is a function of the porosity of the material. In the latter case radionuclides dissolve in a fluid and move with the fluid. The fluid of most concern, in the case of wastes stored in a deep repository, is groundwater. In order to ensure that groundwater coming in contact with high level wastes does not interact with public water supplies and contaminate them, the travel time for groundwater in the vicinity of the repository to reach the accessible environment must exceed 1,000 years. This can be accomplished by siting repositories in very low permeability rock and ensuring that this rock is kept isolated from any aquifers.

2.4.7 Thermal Properties

The radioactive nature of the nuclear waste leads to its generating heat. Rock is generally an insulator rather than a conductor, so that heat applied to it is slow to dissipate. This makes the thermal conductivity, coefficient of expansion, and change in properties with temperature very important in the rock mass. These properties are not easy to measure and assess in rocks, and very often field studies are necessary. The bedding and lithologic variations in the rock as well as the discontinuities could tend to make the rock mass thermally anisotropic with profound effects on the behavior of a waste isolation site.

Increasing the temperature of a body causes it to expand. In a continuous rock mass, this expansion is constrained and thermal stresses result. The magnitudes of the thermal stresses are proportional to the coefficient of thermal expansion, the distance from the heat source and the magnitude of the increase in temperature.

2.4.8 Natural Failure

Any thorough geologic study of a potential nuclear waste mined deposit must consider the likely methods by which the repository could fail as a consequence of natural processes as compared to man-made events. The very nature of rock masses assures that we do not know the properties and likely behavior of the rock at every point. The underground openings that constitute the depository along with the required ancillary works could fail by becoming unstable through long term rock deformation and stress readjustment in an unsuspected area of weakness.

In areas of stressed rock, for example areas formerly loaded by glaciation, sudden, violent energy release in the form of earthquakes or other seismic events could lead to failure of a repository by mechanical disruption. Faults are common in rock masses, and only detailed investigations of the rock mass condition and stress state would shed light on the potential for future seismic events.

A change in groundwater storage or flow conditions brought on by faulting or rock deformation as a consequence of the excavation process could lead to a natural failure of the repository by inundating or flooding it. A thorough study of the hydrogeologic regime and any likely changes in it would minimize such a potential.

Many other types of natural failure are possible and detailed geologic assessment of the total environment will help to identify these.

2.4.9 Breach of Repository

Per se, there is little that the geologic study alone could do to prevent or minimize a breach of the repository by man, but anticipation of the possible events can lead to proper site selection and design.

For example, a complete repository may be underlain by a rock unit that is known elsewhere to contain some mineral or substance that at the present is of little or no value, but that - at some distant future time when the knowledge of the repository location and purposes are lost - is of great importance. Examples from the recent past include the relatively sudden interest in the important nuclear materials uranium and lithium and the steel additive molybdenum. Not too many decades ago the minerals bearing these elements were known and deposits of considerable size found, but there was no commercial use for them until the nuclear power and weapons industries developed and steel metallurgy advanced.

The total geologic environment must be well understood so that the repository is sited in some area that is so typical of readily accessible areas that even if a new mineral interest develops it can be exploited more easily elsewhere. Otherwise, drilling, exploratory or other workings could breach the repository.

The geologic environment must be topographically and structurally secure so that it can resist deliberate or accidental nuclear attack. Other man made breaches and the role of the geologic environment on their success must be considered in detail.

2.5 GEOLOGIC APPROACH

With a brief and general background of the geologic and geotechnical considerations for mined disposal and isolation of nuclear waste, the approaches that EI takes on such studies and investigations will be covered in the following sections.

2.5.1 Thorough Understanding of the Geologic Environment

Through its work on many diverse underground and surface rock excavation projects, EI's team of cross-trained geologists and engineers have developed a philosophy of gaining a thorough understanding of the geologic setting. By reviewing all previous work and by detailed examinations in the field and comparison to other better understood sites in similar environments, EI is able to develop an understanding of the source of the rocks and their history down to the present time. In this way, reasonable predictions can be made as to what is where and no surprises are likely.

2.5.2 Field Relationships

Detailed study of the relationship of the rock units in the field and their character and traits allows an anticipation of their form and geometry. Determination of the absolute and relative ages of rocks permits an understanding of which comes where. In many geologic environments, rocks may be found to grade from one rock type to another, both laterally and vertically. This is especially important in analyzing the fracture geometry of rock masses. What may appear to be anomalous and confusing local fracturing often turns out to be a variation of a previously understood tendency if the total environment and rock field relationships are identified.

Such a knowledge of the field relationships can only be developed by thorough mapping and subsurface exploration so that all of the relevant data are collected in the beginning and not overlooked or ignored. By going from the complex and compound to the simple and by conscientiously utilizing in the field the principle of multiple working hypotheses, no important evidences are overlooked.

Investigations in the laboratory and office such as petrographic, mineralogic, and strength studies are also important. In this regard, proper sampling, and knowledge of the sampling technique, is essential.

2.5.3 Determining Structural Domains

In practice, the rock mass--defined as the blocks of intact rock together with the intervening fractures, joints, faults, bedding planes, and other discontinuities--that contains the site, as well as the surrounding and overlying rock, must be examined in a systematic and detailed fashion. Surficial geology maps must be prepared, exploration holes drilled, and core logged for engineering information. The fracturing of the rock mass must be studied to ascertain the three-dimensional distribution of fractures and their characteristics, and faults located and described. The strength and other mechanical properties of the rock material, the fracture surfaces, and the fault filling materials must be tested and reported for later use by designers and planners.

With this basic information, and an uderstanding of the geologic setting, the rock mass can be divided into one or more structural domains which tend to behave similarly in response to engineering activities. One must keep in mind that the determination of the structural domains goes beyond the geologic units present. Several lithlogic units may be lumped together, while a single lithologic unit can be divided into multiple domains.

Proper layout of the exploration program is of critical importance to ensure that a statistically valid representation of the rock mass is obtained. The number, location, size, depth, and orientation of drillholes must be appriopriate in view of directional properties and systematic geologic variation in the rock mass. Techniques for evaluating the statistical significance of site data have advanced greatly in recent years, so that confidence estimates of geologic parameters are now possible.

If the local and regional geologic setting is well enough understood, the study for totally buried sites can by conducted using known geology and the drill core information. Core must be intensively logged and holes surveyed, but the basic characteristics can be deduced.

A necessary part of the inspection is compiling relevent information concerning the regional geology of the project. Preferably, this should be completed beforehand. If the regional geology is understood, many surprises and misinterpretations will be avoided. A feature seen in outcrop is often more acessible and more readily understood than when examined in isolation underground. Complex, geologic environments may have already been described and explained by others. Very old reports should not be overlooked, as they often contain a wealth of detailed description though the interpretations may be in error. In general, the rock types, major faulting, mineralization, immediate areal geology, and ground water regime should be studied as thoroughly as possible before beginning an inspection.

2.5.3.1 Rock Types

Differing rock types respond differently to geologic deformations and rock excavation. The types of rocks expected in the area should be inspected in outcrop and the geologist or engineer doing the inspection must become familiar with their characteristics and descriptions, as well as their variations. In igneous and metamorphic terrains, special emphasis should be placed on a study of pegmatite dikes occurring, as these apparently minor features can cause major construction problems. Likewise, solution features of limestone areas should be well understood.

Present geologic repository concepts consider five rock types as deposition sites - bedded and domed salt, basalt, tuff, and granite. These represent a spectrum of physical mechanical, geological, and engineering characteristics.

2.5.3.2 Major Faulting

The major faults in the area should be mapped and their detailed characteristic features ascertained. Items such surrounding rocks, attitude, and variation over distance and depth are all important.

2.6 DESIGN CONSIDERATIONS

The geologic disposal of nuclear waste in mined excavations has all of the considerations and problems of any other deep underground excavation plus the added problems of heat generation and possibility of breach. Accordingly, the underground excavation needs careful thought during planning and design, which requires much research and analysis.

2.6.1 General Site Location

The physical setting of any considered or proposed site for the long term storage of nuclear waste must be very carefully studied so that the topographic and other impacts or the facility are known. For example, a minimum depth of burial may be desirable, and in a rugged or mountainous terrain, the cover above a given subsurface elevation will vary a great deal.

Any nuclear waste isolation site should be remote for a number of reasons, and the population density and any cultural or archeological significance of a site must be determined. In addition the ecological and meteorological as well as the hydrological setting must be known so that any impact on the planned facility is understood.

2.6.2 Access

Since a waste isolation site is to be remote, access may cause a special problem, and various methods and paths need to be evaluated. The site is presently envisioned as a deep underground facility so, aside from general rail and highway access, access to the underground workings would be by shaft, decline, or adit.

Shaft access has some special considerations such as the nature of the surface where the shaft sinking activities will be carried out. The surficial materials must be able to support the loads imposed by the shaft sinking operations and have the groundwater situation understood. The subsurface conditions would of course have to be explored and the shaft designed accordingly.

A decline may be used if the topography warrants it and must be carefully laid out and the conditions explored. The nature of the surface is not as critical, but a much greater length for the same depth is necessary, unless the land is mountainous.

An adit in mountainous country provides an efficient means of access and is substantially cheaper than a shaft or decline. However, full access by adit means that the repository will be topgraphically elevated with respect to some exposed nearby point, so that the role of gravity in preventing contaminant migration to the surface is minimized or eliminated.

2.6.3 Layout and Plan

Once the overall site seting is known and the method of access investigated a layout of a possible or planned repository can be prepared. The overall requirements would be decided based upon heat generation and closing considerations, and it may be assumed that a basic size and geometry of each underground opening would be known as would minimum room separation distances. After this the overall underground facility could be planned and such items as traffic pattern, muck disposal, ventilation, drainage, and other ancillary services included. This would then provide a basis for design work on excavation, support, and required installation details.

2.6.4 Method of Excavation

Often the method of excavation is left up to the construction contractor to decide, but when it has a significant impact on cost or design performance, the owner will decide.

Drill and blast excavation is most common in harder rocks, especially if the length of drift is 2,500 ft or less. Tunnel boring machines may then be capitalized over longer distances. However, if numerous side branches or cross drifts are required then a TBM has to be almost disassembled each time it starts a new drift. Drill and blast excavation inherently damages the rock being excavated and results in a ragged and often larger excavation than desired.

On the other hand mechanical excavation such as by TBM's, road-headers, cutters, full-facers, and other, leaves the rock mass in much better condition.

In softer rocks, such as the tuff, and salt being contemplated for repository sites, mechanical excavation may be the most desirable alternative, while in the harder rocks, such as granite and basalt, drill and blast may be best. In any event, the method of excavation is important input for later design work.

2.6.5 Rock Stabilization

The factors that will influence ground behavior were summarized in the preceeding section for the purpose of demonstrating that it is inadequate to use only one or a few factors as a basis for design of an underground opening, including the stabilization measures.

The most important step in the design of any stabilization system for a rock excavation is to determine to what extent the inherent strength of the rock mass can be mobilized to make a contribution to the stabilization of the excavation. This basically depends on the deformation rate with respect to time of the rock mass around the excavation and also on the extent to which deformation is allowed to take place.

Some deformation is needed to mobilize the available rock mass strength. However, excessive deformations will reduce or even eliminate the contribution that the rock mass strength can make to a composite stabilization system. Furthermore, excessive deformation will allow more of the rock mass to dilate and loosen, and will, therefore, result in higher 'loads' and problems in terms of stand-up time.

Traditionally, direct rock support, such as steel ribs with blocking and lagging has been designed on the basis of a "rock load" consisting of some height of loose rock which is "supported" by the ribs. This implies that complete failure of the rock has occurred to the height adopted and that stoping and fallout are actively taking place in the rock.

Terzaghi, in his classical work on tunnel supports, gave rules for estimating such ultimate rock loads as a function of ground conditions and the size of the opening. However, he also pointed out that the extent to which the loads develop depends on the time that has elapsed between excavation and installation of the support, the adequacy of blocking, and the development of a "ground arch" in the rock which results from increased deformation of the rock after excavation.

The actual load on the steel sets depends directly on the deformation of both the rock mass and the sets. In other words, the sets will only be stressed if the rock mass deforms after the installation of the sets, and the pressure they exert on the internal surface of the tunnel, that is, their contribution to stabilization, is directly the result of the deformation.

Rock reinforcement is inherently a better method of mobilizing a contribution from the rock mass to the overall stabilization system. It can be used either alone or in combination with other measures depending on the rock conditions.

Rock reinforcement includes tensioned rock bolts either grouted or ungrouted, and untensioned grouted rebars. It can be installed either after excavation behind the face, or before excavation ahead of the face.

At present there [illegible] generally accepted criteria for the numerical analysis [illegible] of reinforced rock structures in blocky and seamy rock. However, a first approximation for rock reinforcement design can be based on comparison with results obtained in similar openings in similar geological environments. This gives a preliminary design that can then be checked by using techniques that have been developed for reinforced concrete beams and slabs, or thick arches and cylinders.

The major difficulty in pursuing such analyses is to identify reasonable elastic constrants and strength values for the reinforced rock system. With the increasing accumulation of case histories correlated to the results of basic research it will be possible to define more clearly the essential elements of a design code for rock structures.

The effectiveness of a rock reinforcement system depends directly on having an adequate pattern installed before substatial deformations take place. In addition to the general improvement in rock mass characteristics, major discontinuities must be held together by rock reinforcement elements of sufficient lengths and spacing to prevent fallouts that could result directly from these particular discontinuities. Such discontinuities require individual analysis and may require additional reinforcement to that used generally for the rock mass.

If test data are available on the load-deformation characteristics of the intrinsic rock and typical discontinuities, then an assessment can be made of the moduli of deformation for the rock mass including discontinuities. In-situ tests bracketing the best and worst rock can aid greatly in making such an assessment. Using these moduli of deformation an analysis can be made of the relative deformations of the reinforced rock arch and the surrounding rock mass. Such an analysis can serve as a guide to the interpretation of the measurements of deformation during construction which are made to monitor behavior and give forewarning of the onset of potentially unstable conditions.

2.6.6 Permanent Support

Once a stable underground excavation has been planned, the permanent support that may be required to assure longterm stability or provide other service conditions such as hydraulic smoothness, insulation, or shielding. Generally such a final lining or support would be achieved by cast inplace concrete. The permanent support and lining would have to be evaluated, analyzed and designed with the function of the facility in mind.

2.6.7 Rock Mass Monitoring

Because of the many uncertainties that exist in the analysis and design of underground openings, the rock mass is generally monitored with instrumentation of some sort to determine its behavior over the life of the facility. Usually, deformations are measured by means of convergence pins or bore hole extensometers. Also, stress may be measured continuously in-situ. In this case the thermal behavior of the rock may require monitoring, but this can be a major enterprise. The information from such rock mass monitoring would be used to adjust the rock stabilization and support during excavation, verify assumptions made during the analysis stage, and provide a warning against any potential instability.

2.7 SHAFT DESIGN

Design of a shaft involves a number of considerations including:

- intended use
- rock mass properties
- expected water inflows
- in-situ stress field
- groundwater chemistry

2.7.1 Intended Use

There are three basic uses to which a mine shaft may be put - production, service, ventilation - and an individual shaft maybe put to more than one use.

In the case of an underground nuclear waste repository, it is envisaged that the following shafts will be used

- ventilation intake
- ventilation exhaust
- service and muck removal
- waste and backfill transfer.

The size of the ventilation shafts will be dependent on the airflows which they are required to handle. The size of the waste transfer shaft would be dependent on the method used to transport the HLW containers and the backfill. The size of the service shaft must be adequate to allow for at least four compartments - cage, two skips and manway. Since mining regulations require two means of escape a small cage will also be required in the intake ventilation shaft.

2.7.2 Rock Mass Properties and Lining Requirements

The shaft lining must be adequate to oppose the expected rock loads. Although a number of different types of lining are used in mining, the best lining for shafts for a repository would be concrete. (This would certainly be true for the ventilation shafts in any case.)

The thickness of the lining is dependent on the predicted rock load which is related to the type and condition of the rock. Where the rock is competent, a nominal thickness of 12 inches is normally employed. When saturated sands, are encountered an impervious sandwich type lining will likely be required - this would be especially true for a repository in salt since no water inflows can be countenanced.

Where sedimentary sequences are encountered, it is common to have more than one type of lining according to the conditions encountered.

2.7.3 Expected Water Inflows

Water inflows not exceeding 15 gpm can be handled in the course of the normal shaft sinking cycle. Where inflows are expected to be greater than this, pre grouting is generally employed. This may be done from surface prior to sinking or from the shaft face when approaching the zone in question. Where expected inflows are very great, freezing may be employed.

2.7.4 In-Situ Stress Field

In some parts of North America, in-situ stress measurements have shown the horizontal stresses to be greater than the vertical ones. This implies that a residual tectonic stress field exists. Furthermore, the horizontal stresses are not the same in all directions. Where the rock mass is competent and not likely to fail even if subjected to increased stress due to thermal loads, this is not problematic. However, if the rock mass is weak, the stress field should be considered in the design of the shaft and lining.

2.7.5 Groundwater Chemistry

Groundwater intersected by the shafts should be analyzed for its chemical content and age. Of special interest is whether the water contains sulfate ions. If so, Sulfate Resistant (Type V) cement should be used rather than Normal Portland (Type II) in grouts or in the concrete shaft lining.

The age of the water is not important for shaft design per se, but young water unexpectedly encountered at depth could indicate the existence of an unsuspected fault zone.

2.8 DESIGN

With background in the mine technology of planning and investigating a nuclear waste repository, and some of the applicable technology, the approach that could be taken by EI will be briefly outlined in the following sections. Basically, a mined repository is still an underground excavation with some very special and important requirements.

2.8.1 Rock Mass Properties

In achieving a stable underground excavation, a thorough understanding of the rock mass properties and the expected behavior of the rock mass during and after excavation can only be gained through detailed field work and laboratory studies and testing that lead to a full characterization of the rock in and near the site.

Analyses in the office using statistical geologic data compilation methods, especially related to the orientation and nature of rock fractures, and including various modeling methods and engineering mechanics methods on both continuous and discontinuous media allow EI to develop a full comprehension of the nature of the prime construction material - rock - and properly assess its anticipated behavior.

In a project involving the long term storage of nuclear waste materials special problems arise in thermal effects and on the long term behavior of rock.

By compiling all of these data on the rock mass, it can be effectively treated as an engineering material and further research and design studies carried out. EI has a wealth of background data in its files on the properties and behavior of rock masses that can be drawn upon to anticipate the behavior of hypothetical or only preliminarily proposed sites.

2.8.2 Analysis and Design

Once the rock mass properties are determined, the actual analysis and design of any planned underground excavation can be carried out. Since an underground excavation is excavated in a step-by-step sequence by known or anticipated methods and equipment, EI analyzes the resulting structure and methods of achieving it at each important stage. For instance, a very large chamber may be relatively stable when viewed as a completed hole, but at some intermediate step, the excavation, owing to its geometry and position, may be in problem areas.

Special attention is given by EI to utilize the most efficient equipment and methods best suited to the job.

In addition to classical engineering mechanics design methods, EI routinely uses computer assisted modeling methods, including Finite Element Methods, to examine more difficult projects.

2.8.3 Constructability

Before deciding on a definite method and plan for achieving an actual underground excavation, the constructability of the proposed items must be considered. This includes examining in detail the intended pursuit of the excavation work, the equipment and materials to be used, the benefits and problems of each, and the effect on any other steps.

EI has found such a constructability assessment to be very valuable and bring to light problem areas in the incomplete structure that require further analysis.

2.8.4 Performance Assessment

In any engineering project the loads and resisting elements interact and excessive deformations or flexibility are deterimental as is the converse of overly conservative support or resistance to applied loads. In this way, the desirable end product and a reasonable and effective method of achieving it are well considered.

Such an approach is especially important in geotechnical and geological projects and in ones involving effects on the rock such as heat and very long design lifetimes. In spite of detailed investigations beforehand, many uncertainties remain. A through review of similar structures and excavations also will reveal problem areas and areas for further research and development.

2.8.5 Natural Failure

The engineered rock excavation needs to be looked at very carefully for the possibility of failure and breach arising from natural processes such as rock deformaion, faulting, groundwater intrusion, and others. If possible, engineered barriers or impediments to such occurrences should be studied and analyzed and their effectiveness determined.

Groundwater intrusions and changes in groundwater flow patterns may be a likely natural source of failure, and rock grouting methods and materials may have to be developed especially for this application.

Seismically resistant structures can be achieved and decoupling or hardening have been attempted in military and some mining applications.

Of course, other sources of natural failure need to be considered as well.

2.8.6 Breach of Repository

At some future time the repository could be breached by human activity such as accidental breach by drilling for known or suspected resources, deliberate recovery of the waste as a resource itself, military destruction, and terrorist purposeful destruction.

Systems could be engineered into the overall repository plan to permanently and clearly mark its location and purpose or to harden it to penetration.

2.9 CURRENT CONCEPTUAL REPOSITORY LAYOUT

As stated previously the rock types currently under consideration for repository sites are basalt, tuff, domed/bedded salt and granite. Of these, salt has received the most attention, since the National Academy of Sciences committee which formulated in 1957, the present U. S. HLW management program recommended its use as a burial site. The suitability of other rock types was also recognized; however, until recently, emphasis was on the use of salt in accordance with the original recommendation.

In any case, the layout concepts are similar for the various host rocks considered, and consist of a room-and-pillar mining layout with the individual rooms grouped into panels. Access to the repositories would be via shafts, with at least four shafts to be constructed at a site- one for men and construction materials; one for waste canisters; one for intake ventilation; and one for exhaust ventilation.

The extraction ratios for the various schemes range from 8 to about 30 percent. The depth of the underground facility ranges from 2,000 ft in the case of both domed and bedded salt to 3,700 ft in the case of basalt. The room cross sections are quite consistent for the various schemes with room heights from 16 to 21 ft and room widths from 14 to 25 ft being considered. These room widths are small compared to those employed in room-and-pillar operations where the lane-and-pillar concept is used; however, the widths are consistent with those which can be driven by a jumbo in a single pass and suggest that single-pass excavation is contemplated.

Development, canister placement, and backfilling are to be carried out in retreat fashion with the rooms most remote from the shafts to be completed first. The extents of the underground facilities are large - overall areas range from 1,500 to 2,500 acres.

2.10 REPOSITORY FACILITIES

The repository layout for the storage of radioactive waste underground can be established by utilizing the principles followed in standard room and pillar mining layouts. The core of the storage layout can be the "rooms" with several rooms constituting a repository "panel." Each of these panels can be established from the submains and can be interconnected through the mains underground haulage system. Specifically, the repository layout will consist of the following:

- access shaft from the surface to the repository. This shaft can be used for hoisting men, material and excavated rock;
- a ventilation shaft to provide the necessary air quantities during the mining operations for the development of the repository;
- hoisting shaft for radioactive waste;
- waste disposal operations ventilation shaft;
- underground development of mains and submains;
- development of rooms to constitute individual panels.

The service and ventilation shafts could ideally be located in the center of the property if topographical conditions are suitable. It may also be advantageous to locate several ventilation shafts or high pressure boreholes around the periphery should the need arise for more ventilation input to the repository.

An important consideration in the repository layout would be to ensure that the mining and waste disposal operations take place simultaneously yet completely separately. The latter needs to be considerated for vital safety reasons. Therefore sequencing development of panels and emplacement of waste should be such as to minimize the number of personnel working in controlled areas and reduce the hazards due to radioactive contamination.

2.10.1 Disposal Rooms

The dimensions of each disposal room should be sufficient to ensure the emplacement of the required number of canisters. The height of the disposal room and the access entry to the submain haulageway should be sufficient to provide clearance for the waste canister transport and emplacement vehicle and for the large hole drilling equipment which will be used to drill the canister emplacement holes. The length and width of each room will be dependent upon the number of canisters to be stored. For a particular room dimension, the number of canisters that can be stored can be easily calculated if the drill hole pattern can be established. The spacing of the drillholes will be dependent upon the minimum thermal loading rate desired. The dimension of each hole will be dependent upon the canister size. An adequate size entry should connect the rear of the disposal room to a ventilation drift. Each room can be connected to the submain haulageway in a herringbone pattern to minimize turning radius, unsupported roof span and to prevent a direct line of sight into the room.

2.10.2 Disposal Panels

As mentioned earlier, each panel will consist of a multitude of disposal rooms grouped along the submain haulageway. It will be necessary to establish a barrier pillar between the first disposal room and the intersection of the main and submain haulageways. A smaller size pillar between each successive room will assure adequate ground control. The storage capacity of each panel can be determined from the number of rooms in each panel. The total number of panels can then be estimated from the total number of canisters to be stored in the whole repository.

2.10.3 Ventilation Considerations

Since mining and waste disposal operations are intended to be done concurrently but separately, the design of separate adequate ventilation systems must take this consideration into account. In fact this is the primary reason why four shafts have been advocated in the layout of the repository. The panel in which mining is in progress could be supplied with fresh intake air through the men, material and rock-hoisting shaft. The return from this panel could be connected to the submain and main returns which in turn could be linked to the main mining operations ventilation shaft to exhaust the return air out of the system. In a similar manner, fresh air to the panel in which radioactive waste disposal is in progress could be provided through the radioactive waste disposal shaft. The return air from this panel could be exhausted from the waste disposal operations ventilation shaft which could be connected to the main and submain returns.

Although the returns from the active mining section and the waste disposal section could be combined and exhausted through a single shaft, this might cause an overload for a single shaft. The actual volumetric requirements will be dependent upon the manpower, equipment and cooling requirements.

Contamination of exhaust air must be considered and filtration systems and backups must be included.

2.10.4 Mining Equipment

The mining equipment necessary for the development of the repository facility can be obtained commercially. The drilling equipment for the large diameter holes requires careful consideration for an efficient operation.

2.10.5 Radioactive Waste Haulage

The handling and transport of hazardous waste underground requires careful selection of an appropriate haulage system. In particular, an efficient and safe system needs to be employed during the loading and unloading cycles. It is anticipated that the use of manned vehicles which will require radiological shielding may prove expensive and heavy and may not be feasible on the routine basis. A remotely operated overhead-crane track system appears feasible and if adequate consideration is given to prevent mishap and spillage it could prove to be the most feasible haulage system, both from an economic and safety viewpoint. The capacity of the haulage system can be estimated from the total round trip haulage cycle time per trip. This includes loading times, travel times (loaded and empty) and unloading times. If the physical characteristics of the haul route is known and the unloading and loading times estimated, the haulage system can be adequately sized for the total number of canisters to be emplaced in the panel.

2.11 WASTE PACKAGE DESIGN

The present waste package system under consideration consists of two types of barriers, engineered and geological. The engineered barriers include the waste canister, fillers, overpack, a sleeve, and a special backfill. The geological barrier consists of one of several rock types.

Waste canister designs now being studied call for a cylindrical-shaped container made up of any one of several materials. These materials include stainless steel, synthetic corundum (Al_2O_3), carbon steel, and copper. In the case of a corundum canister, the walls of the vessel would be 100 mm thick and the canister would have a diameter of 0.3 m. For copper the canister would have a diameter of 77 cm and the walls would be 20 cm thick. The canisters now being considered range from 10 to 16 feet in length.

A thin filler layer of a suitable material, such as clay, sand, or crushed rock would be emplaced around the canister.

Surrounding the filler would be an overpack. Materials under consideration include various metals (i.e. titanium), graphite, carbon materials, glasses, and selected cements.

Next to the overpack another filler would be emplaced.

A hole sleeve to keep the hole open would be placed around the second filler layer. This may be especially important in the case of a salt repository. Materials under study for this component include cast iron caissons, massive shells of cements, or graphite vessels.

A special backfill material (sand, bentonite, crushed rock) would finally be emplaced to partially or wholly fill in the repository storage rooms.

The final barrier between the waste and the biosphere is the rock mass surrounding the emplacement rooms. The rock types are discussed elsewhere and need not be mentioned here.

2.12 THERMAL LOADING RESULTING FROM HLW STORAGE

High level waste is characterized by high levels of penetrating radiation and high generation rates. It contains virtually all the fission products and small amounts of actinides (transuranics) such as Plutonium which are not recovered in reprocessing operations.

Canisters containing 10 year-old HLW will generate a significant amount of heat - magnitudes from 0.25 to 4.3 kW per canister are given in the literature. Because of the complexity of the problem thermal analyses are carried out at several different scales - canister scale, excavation scale, and repository scale.

As regards thermal loading on shafts and bore holes, repository scale analysis is appropriate. However, at that scale, the practical level of detail is low, particularly in the early design stages. It has been shown that one dimensional numerical models are useful for periods up to 500 years.

At room scale, allowable thermal loadings have been proposed for domed and bedded salt, basalt and granite, based on closure rates for salt and pillar safety factor for basalt and granite. These loadings determine the canister spacing for given extraction ratio in the repository.

Using numerical models, these loadings could be used to predict thermal loading in the far field, and hence loads of shafts and boreholes, provided the thermomechanical properties of the rock were known.

The governing equation for one-dimensional heat diffusion is

$$Cp \frac{T}{t} = K \frac{\rho^2 T}{x^2}$$

where

T = temperature

K = thermal conductivity

ρ = density

C = specific heat

This equation can be handled numerically by using a finite difference approximation to the differential equation. It must be pointed out that thermomechanical properties are temperature dependent. Thus such values can vary fairly widely from those assumed. In addition, rocks are heterogeneous entities and vary in mineralogical and chemical composition - another reason for variation in properties.

The temperature at any time after deposition can be evaluated using the closed form thermoelastic solutions for exponentially decaying heat sources.

2.13 STABILITY CONSIDERATIONS

The functional requirement assumed for an isolation room is that access for isolation and retrievability of waste canisters should be available for 50 years. The requirement does not necessarily exclude local failure or fracture of rock around the room. However, any failure resulting from long-term heating must not be violent or other than a local failure. The failed rock mass should be self-supporting, or capable or being supported over the life of the room.

Several important rock mechanics considerations which must be included in any study are:

(a) rock joints and their strength

(b) possible mechanisms and criteria for failure of rock mass, including the phenomenon of thermal spalling

(c) nonlinear behavior of rock mass under prolonged thermo-mechanical loads--modeling of progressive failure of rock around the room.

(d) stabilization pressures for long term stability

(e) parametric analyses--influence of in situ stress, rock mass strength and temperature conditions on room stability.

The failure conditions that can be tolerated include local fracture or all-around fracture of rock to a limited distance beyond the perimeter of an isolation room such that support requirements are minimal.

Two phenomeologically derived failure criteria can be discussed: maximum tensile strain and Mohr Coulomb. These criteria are further related to the possible failure modes (slabbing, thermal spalling and shear) to be discussed later.

The maximum tensile strain criterion has the advantage of explaining, fairly simply, the longitudinal cracking observed in uniaxial compression. The criterion can be extended to two or three dimensional loading but its application to the isolation room stability analysis is limited because of lack of experimental data.

The Mohr-Coulomb criterion, though not the only failure criterion applicable to the brittle fracture of rocks, has the advantage of being simple and having a large experimental data base.

In conventional mining and tunneling operations, regions which usually deserve consideration for support include the roof and the pillar ribs. However, in the case of a radioactive waste repository, support consideration must also be afforded the floor region, in particular, the canister drillholes. The support methodology which could be used in the roof and ribs of the repository isolation room are conventional and are well documented in the literature and quite commonly used in underground as well as surface excavations. Support methodology for the canister drillholes will, however, require some engineering design and possibly some engineering development.

In considering the failed rock regions in the isolation room floors, one should keep in mind that in almost all cases examined, the region of failure is confined to locations above the emplaced canisters. In general, the failure of the floor rock in an underground excavation is of little concern since the rock will still remain in place. When the floor is utilized as a canister storage location, the failed rock can indeed be displaced into the canister drillholes making canister retrievability difficult. However, since the failed rock regions are generally located above the canister, drillhole plugs could be installed at the canister uppermost end to eliminate any displaced rock from entering the canister environment. If the amount of displacement (or closure) exceeded the "tolerance" requirements, sleeves should be installed in the drill holes prior to emplacement of canisters.

The following conclusions can be drawn from various studies.

(1) Failure of jointed rock mass around a ventilated room is restricted to the portions of the room below the springline. The requirements for support in these regions are minimal.

(2) The floor area needs further engineering to ensure retrievability of the waste canisters.

2.14 CREEP

In the case of salt, there is also creep to consider. A great variety of creep functions have been proposed; however, to be adequately representative of actual conditions, the creep strain must be considered as a function of the applied stress, temperature, and time:

$$\zeta^c = f_1(\sigma) f_2(\Theta) f_3(t)$$

where f_1, f_2, f_3 = independent functions

σ = stress

ζ^c = creep strain

Θ = temperature

t = time

It is generally agreed that the most appropriate form for $f_1(\sigma)$ is a power law of the form

$$f_1(\sigma) \propto \sigma^n$$

with $n > 1$. The value of n for rock salt has been found to vary from 2.5 to 7.0 with the most frequent interval being from 2.5 to 3.5

For the temperature function, most investigators have found the Arrhenius equation fits most experimental data well:

$$f_2(\Theta) \propto \exp(-U/R\Theta)$$

where U = apparent activation energy

R = universal gas constant = 8.325/mole-°K

For polycrystalline halite, U has been found to vary from 50 to 130 kJ/mole when temperatures are increased from 29 to 300°C.

The time function is the most difficult to express in a form that would fit all experimental data and enable an extrapolation to be made to very long time intervals. However, a power law

$$f_3(t) \propto t^b$$

with $b \leq 1$ has been found to be reasonable. For rock salt the range for b has been found to be from 0.3 to 0.6.

The importance of creep in rock salt cannot be overemphasized. The use of hot refinery waste to back fill salt mines in Germany has led to accelerated creep which caused numerous gas and water inflows and rockbursts at the time of backfill placement or immediately thereafter. Accelerated creep is not caused by thermal stress but rather by considerably increased plasticities resulting from the elevated temperatures.

2.15 SHAFT HOISTING SYSTEMS.

When acess to underground workings is via one or more shafts, a hoisting system and conveyences are necessary for transport of men, materials and broken rock. Men and materials are transported in a cage (not at the same time, however) and broken rock is hoisted in skips. Hoisting is performed in balance.

There are two basic types of hoist:

- drum hoist on which the hoist rope is stored during the hoisting cycle
- friction (Koepe) hoist where the hoist rope is simply passed over the hoist wheel

With a drum hoist a single rope is used for each conveyance and for balanced hoisting a split single drum or a double drum hoist could be used. In South Africa, multiple drum hoists have been used in very deep shafts, because the required strength safety factor would not be met for a single rope in the size range normally used in hoisting.

The friction, or Koepe, hoist was invented in 1877; however, it was only with the successful introduction of multiple rope friction hoisting in 1947, that it began to gain acceptance outside Europe. Generally, either two hoist ropes or multiples thereof are employed which are connected to the top of one conveyance pass over the hoist wheel and connect to the other conveyance. In addition, either one or two ropes are connected to the bottom of the first conveyance, pass down the shaft, around the timbers, and up the other compartment to connect with the bottom of the other conveyance. The tail ropes are sized to have the same total weight per tail as the hoist ropes.

Hoist ropes sizes vary from 3/8 in. diameter to 2 3/4 in. diameter. The former would be used on small compressed air operated tugger hoists with which the total suspended load does not exceed about 1,300 lb, whereas the latter would be used for large loads hoisted from great depths.

Multi-rope hoisting has several advantages over single rope hoisting including:

- smaller ropes can be used for a given load since the load carried by each rope is less.
- the systems are inherently safer since if one rope breaks, other ropes are still available to carry the load

Mine hoisting systems incorporate a number of safety features including:

- safety dogs to grip the conveyance guides in case of hoist rope breakage
- overspeed devices such as Lilly Controllers
- overwind and underwind protection
- brakes capable of restraining a fully loaded conveyance at any point in the shaft
- emergency braking systems for use in case of power failure

As indicated, shaft conveyances run on guides of which there are 3 common types - ropes, wood and steel. Except in the case of shaft sinking, rope guides are use only for hoisting of broken muck in skips. Steel guides, fabricated either from hollow structural steel or steel having a "top-hat" cross-section are used for the high speed hoisting required in deep shafts - they are preferable to wood guides because they can be manufactured and installed to closer tolerance. With steel guides, however, the normal safety dogs cannot be used, so that steel guides can only be considered where multi-rope hoisting is employed.

Drum hoists are ground mounted at some distance from the shaft determined based on the elevation of the headsheaves and the maximum allowable fleet angle at the hoist. Koepe hoists are either mounted atop the head frame or ground mounted. The height of the headframe is determined by the height required for skip dumping and the distance beyond that required for overwind protection - at the required height crash beams are installed and the shave wheels (or hoist wheels) must be above that.

In a mining situation, the hoisting speed and skip load must be such that the required tonnage is hoisted. Skips are available in capacities up to about 15 tons. With steel skips the weight of the skip is generally about 75% of its payload. By using Aluminum skips, larger payloads can be carried for a given hoist/motor/shaft depth combination than with steel since the skip weight to payload ratio is much less - about 0.4 to 1. Skip compartment sizes are not standardized; however dimensions ranging from 5 ft by 5 ft to 6 ft by 6 ft (inside dividers) are most common. Cycle times from loading pocket to dump are commonly about 90 to 120 sec.

Cage sizes vary widely - from 9 men single deck cages in small exploration shafts to the 250 man double deck cage used at El Teniente in Chile. Depending on shaft and level configurations, cages may have doors at either one or both ends. Doors can be lift type two-panel sliding type, and the collapsible sliding type (as seen in old office elevators). The maximum allowable speed for hoisting men is 2,500 fpm (30 CFR 57.19-61).

2.16 VENTILATION

Ventilation in waste repositories is required not only to provide a safe and healthy work place, but also to help cool the areas of waste storage. Ventilation would be forced by fans and the following discussion summaries the main features.

In discussing the place of ventilation in the overall excavation planning process, it needs to be recognized that ventilation planning is a integral part of the production process and essential to the achievement of maximum productivity. On the one hand, the ventilation facilities available impose certain limitations on the production obtainable. On the other hand, ventilation requirements cannot be defined other than in in relation to a production plan. Therefore ventilation planning must be consistent with utilization intentions.

2.16.1 Long Term Ventilation Planning

Ventilation requirements affect long-term planning, and the conditions it imposes are of fundamental importance in the extensively mechanized underground facilities. The general layout of roadways will be decided, amongst other things, by ventilation considerations. But the sizes of the roads must be adequate for their varying duties as airways at different stages of development. In this connection a choice may have to be made between initial drivage of a larger number of smaller sized airways or a smaller number of large cross-section airways. In addition, the use of auxiliary fans during the last few years of the facility life may also be considered.

With current stringent ventilation and dust standards, any ventilation proposal forwarded should be capable of consistently meeting Federal standards. It is imperative therefore that sufficient quantity of air be coursed through the workings. The assessment of air quantity may be carried out in two parts: first, the removal of dust and noxious and explosive gases which are essential for the well-being of the workers and economics is only a minor consideration; secondly, the air requirements to provide suitable environmental conditions, where economics play a major role. In the latter circumstances not only must the miners working efficiency be considered, but also intangible factors such as public relations with the workers.

2.16.2 Medium-Term Ventilation Planning

When ordering main fans it is necessary to make assumptions as to duty requirements perhaps fifty years ahead. The evaluation of specific details related to ventilation should be made as early as possible and generally not later than the stage of the five-year layout. Naturally, the certainty or otherwise with which items can be forcast depends on the reliability of all data and on socioeconomic factors. Yet, however uncertain these may be, action to develop workings cannot be deferred, and this action involves definite decisions as to routes, cross-sections, etc. Normally the ventilation circulation is calculated on the basis of quantity of air for dilution of contaminants. Heat dissipation will also be important in issues of retrievability. In some cases a deciding feature may be air velocity rather than quantity flowing. Ideally, all ventilation calculations should be firmly founded on pressure quantity surveys of underground workings.

2.16.3 Short-Term Ventilation Planning

The latitude possible and necessary in medium term planning is neither required nor desirable in short-term planning. In general the production objectives are based on the long-term objectives and therefore the ventilation previously planned should be adequate for the short term requirements. Yet specific short-term planning is necessary both to establish various matters of detail and to ensure that all concerned are aware of the nature and timing of actions for which they are responsible. This applies both to development of a new panel and to withdrawal from an old panel. The provision, siting and timing of stoppings and regulators fall into this category of ventilation planning. In addition, measures to increase effectiveness of the present ventilaion system and any requirements for local ventilation need to be taken care of.

2.17 DESIGN OF VENTILATION SYSTEMS

A underground ventilation system may be divided into three basic parts:

- Primary distribution system consisting of main intakes, returns and fan or fans
- Face ventilation that consists of the air circuit from the loading point to the face
- Control devices that maintain the airflow through the desired paths or channels.

2.17.1 Primary Distribution System

MSHA mining regulations require certain minimum worker exposure levels to radon daughters that are measured by air sampling and workers' hours in various environments are accordingly limited.

Under Federal Law, a minimum velocity of 60 fpm in working places is required and respirable dust levels (minus 10 microns) cannot exceed 2 mg/cu.m. average per shift as measured by a standard instrument. Methane accumulations are not allowed to exceed 1% in the working area. The minimum volume of air at the last open crosscut has been increased to 9,000 cfm, with 3,000 cfm required at the face. These more stringent face requirements are coupled with regulations which make distribution more difficult. Belt conveyors cannot be placed in main airways and the maximum velocity of air on trolley entries is limited to 250 fpm.

Splitting the air is necessary for safety as well as minimal power cost. Placing each working section on a separate split insures that each crew will have a fresh air supply, uncontaminated by dust and gas accumulated on a previously ventilated section.

The design of main ventilation systems consists of selecting fans, locating portals, selecting the proper number of entries for the mains, submains and panels and locating and sizing the required shafts. It should be kept in mind that, in operating mines, it is common to lose 50 to 70% of the air between the fan(s) and last open crosscuts on the working section where the major job of diluting and carrying away gases and dust is conducted.

EI's background in ventilation system design is both comprehensive and up-to-date. Present practices in mining and tunneling create an adequate technological base for the assessment of ventilation systems in a mined waste repository.

2.17.2 Fans and Entries

The main fan is often required by law to be placed on the surface in a fireproof housing, offset at least 15 feet from the line of any potential mine explosive force. Main fans can be of the blowing or exhausting type and the advantages and drawbacks for each have been exhaustively dealt with in several publications. The blowing mode is generally utilized for special shallow, mountain top applications.

The number of intake and return airways are determined by the total quantity of air needed to maintain air velocities below certain prescribed limits. Usually, main intakes and returns are designed for maximum air velocities of between 600 and 800 fpm. while in shafts a velocity of 2,000 to 2,500 fpm is acceptable. While power costs are the primary factor limiting air velocities, high velocities on intake airways do produce dust contamination. This number may be influenced by ground control and safety considerations.

2.17.3 Face Ventilation

The principal ventilating methods used to control dust and gas in mining systems can be classified as conventional or secondary ventilating systems.

In conventional face ventilation, brattice or ducting is used to direct fresh air toward the face (blowing system) or exhaust air away from the face (exhausting system). It is apparent that although the blowing system is good for gas control, it adversely affects dust control as dust laden air passes over the equipment operators.

When carefully used, ventilation can be effective against gases or dust. However, proper use of brattice or ducting to achieve good ventilation is burdenson and difficult to maintain near the face and has reduced productivity. A well erected minimal leakage exhaust brattice system may provide better performance than an equal capacity of the exhaust tube type. But maintainance and keeping the brattice close to the face is difficult and hence the drawback of exhaust brattice systems.

In general, for exhausting systems, the intake should be as close as possible to the face of an effective application. Dust and gas reduction is believed to be much more effective by moving the brattice closer to the face than by increasing the amount of face ventilation. When sections are still out of compliance it may necessitate some form of secondary exhaust system.

2.17.4 Ventilation Control Devices

Control devices used to course the air through the facility are stoppings, overcasts and regulators. Stoppings are walls constructed to separate intake and return airways. Overcasts permit the crossing of intake and return air. A secondary use of overcasts is to balance pressures in separate parallel return entries. Regulators are used to control and redistribute the airflow through the facility. They usually consist of a frame with a sliding door and are arranged so that each split is controlled by one regulator.

2.17.5 Ventilation Surveys

If ventilation is to be continuously maintained, monitoring is necessary, requiring ventilation surveys.

In order to plan improvements and evaluate effectiveness in ventilation systems according to engineering practice rather than by trial- and-error methods, complete information must be available on the quantities flowing in various parts of the system and on the rates at which pressures produced by fans and natural drafts are used up on the major airways. Quantities and pressure differences together determine where the horsepower applied to the system is used and where changes can be made economically.

All repository systems should have provisions for ventilation surveys or monitoring.

2.18 COOLING OF FACILITY AIR

The thermal environment in hot mines or heat-generating facilities has a major influence on productivity, safety, and equipment. It is recognized that wet-bulb temperatures below 84°F are generally satisfactory, in that acclimatized workers will be reasonably alert mentally and able to work under hot conditions at almost peak productivity and in complete safety from a physiological point of view.

Improvement of ventilation with respect to thermal effects can be achieved either by increasing the air velocity, thus the air quantity, or by decreasing the temperature of a combination of both.

The proposed waste disposal systems generate considerable heat which must be dissipated by either heating the surrounding rock or by using ventilation air.

Also, it is well known that the virgin rock temperature increases with depth. The temperature at a given working face will depend on the temperature and velocity of the incoming air and on the amount of heat transferred to the air by rock. Both wet and dry bulb temperatures of the intake air will themselves increase due to autocompression oas air descends a shaft. Since it is desirable, as stated previously, that the wet-bulb temperature of the incoming air not exceed about 84°F, a critical depth will be reached beyond which, heat must be removed. This depth will vary from one mine to another. As stated before, air arriving at the shaft station on this level will be at the critical temperature and additional heat will be picked up before the air reaches the working face.

To reduce the wet-bulb temperature of tha air, some means of refrigeration is required. Several methods of cooling can be used: vapor-compression refrigeration systems, water to air heat exchangers (cooling coils) and direct spray chambers.

2.18.1 Vapor-Compression Refrigeration System

A suitable refrigerant substance circulates continuously through vapor-compression machines. It enters the evaporator as a liquid and is vaporized, the heat required for this coming from the air which is being cooled. The resultant vapor then enters the compressor where it is compressed to a higher pressure and then discharged to the condenser. In the condenser, the refrigerant vapor is cooled and condensed to a liquid, the latent heat which is released in the process of condensation being transferred to the circulating condenser water. The liquid refrigerant leaves the condenser and passes through an expansion valve before once again entering the evaporator.

2.18.2 Cooling Towers

If the water heated by the refrigerant in the condenser is to be recirculated through the condenser, it must be cooled. This can be accomplished in a forced-draft, counter flow cooling tower in which the hot water rejects heat to the exhaust air which is being upcast out of the facility.

Air velocities in underground cooling towers vary between 8 and 25 fps. Increasing the air velocity increases the retention time of the water droplets. However if the air velocity exceeds 25 fps the carry-over of the water droplets is large.

Towers are usually designed to cool the condenser water by 12° to 16°F. The water flow rate in the tower therefore depends on the amount of heat to be transferred. The actual water-air ratio, L/G, in existing towers varies from 0.5 to 2.5.

The design of cooling towers is complcated because of the number of factors which must be considered. The actual characteristics of a tower can only be fully determined by testing.

2.18.3 Cooling Coils

Cooling coils are used to transfer heat from air to the chilled water. Performance of cooling coils can be analyzed in a manner similar to that employed for a vapor compression refrigeration system. However, heat transfer at cooling coils is more complex since heat is transferred both by convection and condensation. A satisfactory approximation for mining purposes is to consider the difference between the wet-bulb temperature of the air and the water temperature as the driving force for the heat transfer. Total heat transfer is the product of the heat transfer coefficient, the area of heat transfer, and the log mean temperature difference.

2.18.4 Spray Chambers

Chilled water could be used directly to cool downcast intake air in a spray chamber. This method employs the same principle as the cooling towers mentioned previously except here water is cooling the air.

This method has the disadvantages that it requires a fair amount of space and that the cooled air can pick up heat before reaching the working faces especially if the spray chamber is remote from the faces.

2.18.5 Elements of Typical Heat Exchangers

The evaporator in a vapor-compression refrigeration system usually consists of tubes in the path of the moving air. It can be operated at presures from 0 to 500 psi and the overall heat transfer coefficient, U, is usually found in the range of 2 to 10 Btu/hr^{o}F per square ft of heating surface.

The condenser in a vapor-compression refrigeration system can be either a shell-and-tube type or double tube exhanger and has an operating pressure range of 0 to 500 psi. The heat transfer coefficient, U, is usually between 80 and 250 Btu/hr-^{o}F per square ft of heating surface.

Air coolers can be either shell-and-tube type or tubes in the path of the moving air. Both types have an operating pressure range of between 0 and 100 psia and a "U" value between 2 and 10 Btu/hr-^{o}F per square ft of heating surface.

2.19 POWER DISTRIBUTION

Primary power distribution for underground mines is generally supplied by a substation located at the surface, which transforms public utility supplied voltages of 69 kV to 115 kV to 4.16 kV to 13.8 kV for use in the mine. Transmission of the pruchased power to the face is accomplished through this surface substation, several intermediate substations or distribution boxes, and cables to underground equipment. power is taken underground by one or more mine power feeders supplied from breakers at the primary substation. Feeder cables are thus high voltage cables and are of special construction. It is fed down a steel cased borehole to a portable underground switchgear in the mine. There may be several of these with branch circuits to feed power to all sections of the mine.

2.19.1 Underground Switchgear

There are one or more switch gears underground connected to the surface substation depending on the size and extent of the mine. In a mine sectionalized by switchgear, the main function of this equipment is to protect the other sections of the mine from short-circuit interruption. It is often a skid-mounted metal encased box of flame-proof construction. It is possible to lock out power during maintenance to prevent accidents due to inadvertent energizing. The incoming and outgoing cables are connected to the switchgear through cable couplers to facilitate movement of the switchgear mechanism without removing the cables. Most couplers are of multipole type with contacts of staggered length to insure that the ground circuit is completed first, the phase circuits completed second and the pilot circuit completed last. The reverse procedure is followed during disconnecting. The purpose is to ensure that the power conductors are not energized when contact is being made or broken. This feature minimizes the chance of electrical ignition through arcing and protects personnel from electrical burns.

2.19.2 Underground Mine Transformer Stations

The incoming substation voltage is transformed here to the utilization voltage between 480 and 1,000 volts. From here, the cables for different mining equipment are taken. This can also be a skid mounted unit of permissible construcion. The essential parts consist of an incoming line, primary voltage compartment, a dry-type air cooled transformer, and a low voltage panel board of air circuit breakers. Dry type transformers are used instead of the oil-filled type or other liquid filled type to reduce the fire or explosion hazard potential.

2.19.3 Capacitor Pack

The fluctuating nature of mine loads at the face result in adverse power factors necessitating the use of capacitor packs. They can be skid mounted and connected to the transformer stations or built into the latter. They correct for power factor outby of the transformer station, before the power is transmitted to the equipment.

2.19.4 Distribution Centers

Power from the transformer stations is fed either directly to the machine trailing cables or to distribution circuit centers located away from the transformer stations. Using this equipment should be limited except where absolutely necessary because of voltage regulation problems. These machines are skid mounted and are of explosion-proof construction. Instantaneous tripping circuitry is provided here as these are the last circuit breakers in the distribution system.

2.19.5 Grounding Circuits

Since electrically powered equipment pose a potential shock hazard, each piece of equipment is grounded through special conductors with its cable. Most mines practice frame grounding of electrically powered equipment and grounding of electrical equipment enclosures. In most cases a continuous metallic grounding circuit is carried throughout the electrical power system from substation ground beds to secondary transformer groundbeds and finally to the end equipment powered by the system.

2.19.6 Batteries and Battery Charging Stations

Much of the modern equipment uses batteries as the electrical power source instead of a trailing cable or a trolley wire to do away with the nuisance tripping of a.c. circuit breakers. Batteries and the associated underground charging stations are hazardous in the sense that batteries emit explosive hydrogen gas during charging, are capable of delivering a shock, and are a potential fire hazard. Batteries used are usually of the lead-acid type.

Batteries are charged at underground charging stations. These consist of a transformer-rectifier combination and receive their power from the main a.c. distribution system in the mine. Most accidents occuring at the battery charging stations are due to improper grounding of the charger frame. It should be properly insulated. The secondary windings of the transformer and all d.c. components should be isolated from the system ground. The power rectifiers should have over temperature relays. Proper ventilation should be provided to dilute the hydrogen gas liberated during charging. The equipment must also be protected from short circuiting and arcing to prevent ignition of the flammable gases.

2.20 ELECTRICAL EQUIPMENT AND MACHINES

Several different types of electrical equipment and production machines are supplied power from the main distribution circuit and all these equipment and machines have to be evaluated in terms of permissibility and safety.

2.20.1 Trailing Cables

A majority of underground mining machines receive their power through trailing cables. They typically carry power up to 1,000 v but are rated for 2,000 v. These cables should be of adequate length (usually up to 500 ft) and current carrying capacity. The cable must have an outer sheath of rubber or equivalent material that is highly resistant to abrasion, moisture, and flame. The cables must be properly insulated to prevent short circuiting and arcing.

A wire bushing is used to the place where the cable is connected to the machine to prevent abrasion of the cable and the clearances when going into the machine should be small enough to maintain the flame proofing of the machine. Also, strain relief clamps must be used in the connections to prevent the cable being pulled out of the machine.

Cables are generally very rugged and can withstand a great deal of abuse. However, an extremely local stress such as crushing, pinching, or abrading can result in immediate or eventual need for splice repair, because a broken cable can be a source of shorting or arcing, thus causing a fire or explosion hazard, and also electrocution of personnel.

A permanent trailing cable splice must be mechanically strong, flexible, well insulated, and sealed against moisture. The conductors must be joined together with suitable connectors. It must be flame resistant to prevent catching fire due to a malfunction in the splice. Any splice which is hot, smoking, sparking, or damaged must be repaired immediately.

2.20.2 Trolley Wires and Nips

A typical d.c. power distribution circuit consists of a feeder and trolley wire with a ground rail for return. Trolley wires are operated at a potential of 300 v d.c. or [illegible]0 v d.c. with respect to the grounded return through the rail. Because the conductors are exposed, the system is vulnerable to faults caused, for example, by accidental contact of the trolley wire with a ground path. The current flowing in these unwanted paths may be much less than normal load currents, but can be capable of starting a fire due to arcing.

In addition to the fire hazard, all trolley wire installations are guarded to reduce the hazards of electrocution.

Nips are used to supply power to auxilary electrical equipment from the trolley wire. Trolley nips are also a potential hazard due to arcing problems. They should be provided with proper grounding and return clamps.

2.20.3 Electric Motors

Electric motors, whether a.c. or d.c., are integral parts of all electrical equipment and are the main prime movers. Integral horsepower, polyphase indruction motors are the most common type of motors used, of which the squirrel-cage type is the most popular. Usually operating voltages of these motors are of the order of 550 v, though the trend is towards higher voltages.

The motors must be enclosed in flame-proof enclosures to prevent ignition of methane from sparks inside the motor. Protective devices used in conjunction with motors are fuses, circuit breakers and overload delays.

Starters must always be used with a.c. motors in order to avoid the high current requirements of ordinary starting which causes voltage regulation problems and possibly a hazard.

2.20.4 Mining Machines

Most of the electrically powered machines used underground are operated by an electric motor, either a.c. or d.c., supplied from a trailing cable, battery, or trolley wire. Most of these electrical systems have been approved by the Mine Safety and Health Administration.

These include hydraulic drill jumbos, tunnel and raise boring machines, mining machines, such as continuous miners, underground hydraulic support systems, load-haul-dump units, slushers, shuttle cars, belt conveyors, rail haulage, pumps, and auxiliary fans. Each of these types of machinery has particular safeguards related to insulation and fire prevention.

2.20.5 Electric Blasting

All blasting cables or wires leading from the source of power for electric blasting to the working face must be installed on insulators or wooden plugs. They should not come in contact with metallic objects like pipes, rails, electric power wires, fans, drill steel, and so on. Blasting switches, boxes and reels should not be closer than 20 ft from any electrically operated machine.

The wires of the firing cables should be shorted at the blasting switch while the leads from the blasting caps are being connected to the firing cable. These wires should be disconnected from the blasting swith only during shortfiring.

A separate blasting generator or other power source should be supplied for each working where electric caps are used. Parallel blasting lines feeding different areas must be separate as far as practical.

2.20.6 Ancillary Electrical Systems

Ancillary electrical systems include communication equipment such as telephone and lighting.

2.20.6.1 Communication Systems

Adequate and reliable communication systems are an essential part of mine safety and production. Federal law requires telephones to be installed at each underground landing and connected to the surface and in each working section more than 100 feet away from the mine portal.

The telephone system is powered by either a 12 v or a 24 v system. A voltage of 24 v is considered to be a safe under gassy and dusty operating conditions.

The cables used depend on the number of telephones installed, the total length of the cable run, the configuration of the branch lines and available battery voltage. Cables should be properly insulated and installed in track entries and should be hung on the remote side from the trolley wires so as to prevent short circuiting. It should not run close to the power conductors as far as possible. Lightning protection must be provided for telephone circuits going underground. Cable connections must be properly insulated using electrical tape. Fuses are provided in the circuits to provide added protection against overcurrent.

Grounding for the telephone circuitry must be provided and such cables must at least be of the same cross-sectional area as the conductor cable.

2.20.6.2 Lighting Circuits

There are two kinds of lighting possible, namely, machine mounted and stationary.

Machine mounted lights derive their power from the machine itself. Care must be taken to see that the lights are in proper condition. Headlights should not have their glass covering broken exposing bare wires.

Stationary lighting fixtures can be energized by both a.c. or d.c. power. In case of d.c. power the voltage must not exceed 300 v. In case of a.c. power the conductors should not be energized at voltages greater than 70 v to ground and must operate at at least 50 Hz. Lighting fixtures operating at 100 v or more must derive their power from a transformer having a neutral tap grounded to earth through a proper resistor. The grounding circuit must pass through all equipment energized by the circuit.

Machine mounted lighting fixtures must be electrically grounded to the machine by a separate grounding conductor.

Cables conducting power to stationary lighting fixtures from both a.c. or d.c. power sources, other than intrisically safe devices should be considered as trailing cables and protected against short circuits and overloads.

2.21 SAFETY

2.21.1 Materials Handling

The following basic criteria may be applied to such machinery considering the nuclear waste environment:

- Protective systems for operator basic to design
- All thermal and shielding requirements will be based on 3-year old spent fuel or high level waste
- Exposure level is not to exceed 500mR/yr
- Spent fuel emplaced in separate rooms from high level waste.

Retrieval of HLW, if required, poses some difficult problems for equipment design. Feasibility of equipment design for retrieval must be assessed in terms of several basic groups of conditions, depending on whether the repository has or has not been sealed. Thus, potential retrieval situations that may require evaluation include recovery of waste in the floor of tunnels still open for access, or recovery after the tunnels are closed and sealed, or ultimately, recovery after the entire disposal site is sealed to the surface. With this in mind, we view the functions and criteria that the design would have to meet as including:

1. Detection of a failure of the disposal criteria.
2. Location of a failed system component (cannister, over-packing, etc.).
3. Movement of the retrieval equipment to the exact

location of the waste. This may or may not involve excavation.

4. Quantitative incorporation of radioactive materials into the retrieval system.

5. Removal of the retrieval waste to the recovery center.

6. Processing and storage of the recovered wastes and any materials contaminated during the recovery process.

Detection, location and subsequent movement of recovery equipment to the failed system component is greately facilitated to the failed system component is greatly facilitated by the access provided by the open tunnels. Temperature and radiation monitors can provide the necessary information for radiologic isolation of the recovery operation.

2.21.2 Human Factors Engineering

Human factors engineering applied to nuclear waste repositories is a blend of mine and radioactive environments. Both have two points in common, cramped quarters and difficult access, and hazardous materials. The technology for transportation, handling, and isolation in these environments is well-developed. The critical items are access and failsafe sytems. For example, components most likely to wear out or fail, such as pumps or drills, must be readily accessible, and furthermore, when a man must be present during repair or maintenance, enough safeguards must be built in so that his actions themselves do not lead to hazard. If a hydraulic pump fails on a drill jumbo used during retrieving, the task of replacing the pump must not lead to uncontrolled drill thrust or movement if another subsystem is inadvertently started. When evaluating or designing such equipment the system requirements must be known, and the range of human control and information processing desired, so that following equipment design, a trial or shakedown period indicates how it is operated, and then this operating experience is related back into design.

2.21.3 Safety Analyses

Safety analyses involve studying the working environment, equipment, and job actions to reduce the frequency or severity of accidents.

Two most used measurements of safety are "frequency rate" and "severity rate."

Frequency rate has been defined as the product of the number of disabling injuries times one million divided by the number of man-hours worked during the period (NSC, 1972). Disabling injuries are defined as:

1. Death.
2. Permanent total disability. Any injury which prevents the employee from engaging in gainful employment, or which results in the loss of or the complete loss of use of any of the following in one accident:

    a. Both eyes,
    b. One eye and one hand, or arm, or leg, or foot,
    c. Any two of the following not on the same limb: hand, arm, foot, or leg.

3. Permanent partial disability. Any injury which results in the complete loss or loss of use of any member of the body, or any permanent impairment of functions of the body or part of it, regardless of any pre-existing disability of the injured member or impaired body function.
4. Temproary total disability. Any injury which, in the opinion of an authorized physician, renders the injured person unable to perform a regularly established job that is open and available to him, during the entire time interval corresponding to the hours of his regular shift on any one or more days (including Sundays, days off, or plan shutdown) after the date of the injury, (NSC, 1972).

Thus the frequency rate measures only the occurrence of accidents and not their severity.

Severity rate has been defined as the product of the number of days charged as lost times one million divided by the number of man-hours worked during the period. For serious accidents, standard averages are used for days charged as lost, and are given in Table 2.1, since an individual's actual time lost may vary widely.

By using frequency rates and severity rates, varying industrial operations can be compared solely on a safety basis.

When analyzing particular accidents, they can be broken down into their five basic elements (NSC, 1972):

1. The agency or source of the accident.
2. The type of accident or the manner in which the person was injured.
3. The unsafe condition of the tool, material, or machine.
4. The unsafe act or unsafe practice of the person.
5. The personal factor or reason for the person's unsafe action or practice.

Detailed studies have shown (NSC, 1972) that most accidents are attributable to a combination of these elements, and not to a single one.

Furthermore, items no. 3 and no. 4, the unsafe condition and unsafe act, may themselves be subdivided further. For unsafe condition, the following categories have been developed (Simonds and Grimaldi, 1963):

1. Inadequate mechanical guarding.
2. Defective condition of equipment.
3. Unsafe design or construction.
4. Hazardous process, operation, or arrangement.
5. Inadequate or incorrect illumination.
6. Inadequate of incorrect ventilation.
7. Unsafe dress or apparel.

For unsafe act, the following categories have been developed (Simonds and Grimaldi, 1963):

1. Working unsafely.
2. Performing operations for which supervirsory permission has not been granted.
3. Removing safety devices or altering their operation so that they are ineffective.
4. Operation at unsafe speeds.
5. Use of unsafe or improper equipment.
6. Using equipment unsafely.
7. Horseplay, teasing, abusing, etc.
8. Failure to use safe attire or personal devices.

Table 2.1

AMERICAN STANDARD SCALE OF TIME CHARGES FOR DEATH OR PERMANENT PARTIAL DISABILITY

Nature of Injury	Time Charge, Days
Death	6,000
Permanent Total Disability	6,000
Loss of Member or Function:	
Arm, at or above elbow	4,500
Arm, below elbow	3,600
Hand	3,000
Thumb	600
Any 1 finger	300
2 fingers on same hand	750
3 fingers on same hand	1,200
4 fingers on same hand	1,800
Thumb and 1 finger on same hand	1,200
Thumb and 2 fingers on same hand	1,500
Thumb and 3 fingers on same hand	2,000
Thumb and 4 fingers on same hand	2,400
Leg, at or above knee	4,500
Leg, below knee	3,000
Foot, at ankle	2,400
Great toe	300
2 great toes	600
1 eye, loss of sight	1,800
Both eyes, loss of sight	6,000
1 earm loss of hearing	600
Both ears, loss of hearing	3,000

from Peurifoy (1970, Table 23.1).

When further investigating accidents in detail, the type of accident can be divided into several classes (Simonds and Grimaldi, 1963) given below:

1. Caught in or between.
2. Struck by.
3. Struck against.
4. Fall of person (same level).
5. Fall of person (different level).
6. Abraded, punctured, scratched.
7. Overexertion.
8. Contact (electric current).
9. Contact (temperature extremes).
10. Contact (radiation sources, toxic and noxious substances).

With this background information on the causative factors of accidents, a safety analysis can then be made of a new industrial situation such as HLW repositories. The job or situation is broken down into its component parts by a person knowledgeable in the job and observing the job, and each of these component parts is in turn analyzed for potentially hazardous acts or conditions using a listing such as those given above. Accident causing steps or components can then be discerned and the likely nature of resulting accidents described.

Corrective actions in machinery design, working environment, job procedures, training, and other items can then be formulated and incorporated, and then further analyzed for adequacy and resulting complications.

2.21.4 Fires

During a previous study conducted by EI staff it was found that during 1968 to 1972, for underground metal and nonmetal mines, 4 fires killed 115 workers (including 91 in the Sunshine disaster in 1972). Two of the four fires started in mine shafts. The location of the other two fries was not know. The cause of these fires could not be determined positively during investigations since the evidence was lost, either due to fire or subsequent flooding or other unknown reasons. Identified possible causes of fires in shafts were:

- welding operations
- overheating of wooden guides
- throwing of a cigarette butt on cross-timbers
- electrical fires.

The possible causes of other fires were cited as:

- welding equipment
- spontaneous combustion of timber
- carelessness on the part of workmen

Analysis of tha gross injury data indicate that about 6.2 fatal and 86.4 nonfatal injuries occurred each year due to fires and explosions during 1961 to 1970. The corresponding figures for 1966 to 1970 are 8.0 and 100.0. This category included burns from controlled fires. Although the causes and sources of these accidents could not be identified from the gross injury data, possible sources include:

- diesel fuel storage and fueling stations
- battery charging stations
- store rooms where combustible materials such as grease, or timber were stored
- electrical fires
- welding operations

these studies have indicated that the following items can significantly improve the underground fire problem:

- Ventilation of work areas susceptible to fire (storage areas, battery charging stations, maintenance shops for diesel locomotives) should be studied and improved. Controlling their air current during a fire can play an important role in dealing with it.

- Methods to prevent fire and smoke spread into shafts and other excape routes are extremely useful areas of research.

- Refuge areas should be provided in parts of the mine where fire in escape routes would prevent withdrawal of workmen to safety.

- Automatic fire doors should be developed and required at suitable points in the mine ventilation circuit.

- Federal metal and nonmetal health and safety standards under Section 57.4 require measures for the prevention of mine fires. If these are enforced, most mine fires could be prevented. During visits to the mines, several violations of these regulations were observed. For example, smoking in timbered stopes which could lead to a major fire, was observed. Workers should be permitted to smoke only in designated areas (e.g. lunchrooms or other suitably constructed rest areas).

- Generally heavy accumulations of combustibles were observed near the shaft and landing levels. These areas were sometimes used as storage areas for timber, electrical cables, hoses, grease drums, et cetera. Mandatory Standard 57.4-534 prohibits this. Only suitable cut-outs should be used for storage.
- At the present, there is no requirement for the regularly scheduled inspection of fire control equipment. This should be mandatory.
- MSHA should restrict the use of lumber for lining, cage guides, or other support purposes in mine shafts. Only fire-retarded timber should be permitted underground.
- Worked-out areas should be sealed off to prevent the flow of air.
- Automatic or remote controlled fire fighting equipment should be installed in areas (for example fuel storage areas, battery charging stations, stationary equipment, and storerooms) where fires may spread before they are detected. The results of research projects involving control of mine fires in underground coal mines should be evaluated for application to noncoal mines.

2.21.5 Overall Safety Considerations

Assessing the adequacy of stored nuclear waste from the waste package, materials handling, and safety aspects is primarily a task of postulating accidents and failures and describing the likely events and consequences. Since a great many different details of waste packaging are being proposed, and materials handling follows the same basic steps, at this stage a look at the materials handling problems illustrates the nature of this aspect of the overall system. The Tables on the next several pages are taken from a DOE report on Radwaste technology, and summarize the safety problem.

TABLE 2.2 Postulated Minor Accidents - Once Through fuel Cycle Repositories

Accident No. and Description	Sequence of Events	Safety System	Release
1 – LLW drum rupture due to handling error.	TRU LLW not produced in this fuel cycle.		
2 – Minor canister failure. Estimated frequency ~1/yr	1. Rough handling during transportation and unloading or presence of canister defect results in the formation of a pin hole leak in canister containing a failed fuel rod. 2. Leak detected in receiving facility. 3. Canister overpacked and placed in storage.	1. Canisters inspected prior to shipment. 2. Canisters pressurized with helium for leak detection. 3. Overpacking facilities available	One failed pin in a PWR fuel assembly releases gaseous activity from the canister. The following activity is released over a 2 day period. ^{85}Kr - 3 Ci ^{14}C - 4×10^{-5} Ci ^{129}I - 5×10^{-6} Ci ^{3}H - 5×10^{-3} Ci Others - negligible
3 – Receipt of externally contaminated canister.	1. Canister received with smearable contamination above specification limits. 2. Contamination detected. 3. Canister decontaminated and placed in storage.	1. Canisters inspected prior to shipment. 2. Canister inspected on receipt. 3. Decontamination facilities available.	None
4 – Dropped shipping cask.	1. Equipment failure or operator error drops shipping cask into transfer gallery. 2. Cask inspected. Expected to be undamaged. 3. Impact absorber removed and replaced.	1. Impact absorber minimizes cask damage.	None

TABLE 2.2 (Cont'd) Postulated Moderate Accidents - Once Through Fuel Cycle Repositories

Accident No. and Description	Sequence of Events	Safety System	Release
5 – Waste Container drop during handling.	1. Equipment failure or operator error results drop sufficient to fail waste container. 2. Particulate release to cell filters. 3. Container contents repackaged. 4. Area decontaminated.	1. Drop height minimized by facility design. 2. Cell HEPA filters reduce release to atmosphere. 3. Repackaging and decontamination facilities available.	The maximum drop height for any waste form is 20 m. This is much less than a drop down the mine shaft. Therefore it is expected that releases from this accident would be much less than Accident 6.
6 – Waste package dropped down mine shaft. Estimated frequency 1×10^{-5} per year.	1. Canistered waste shaft hoist fails. 2. Hoist cage containing 4 canisters drops to mine level. 3. Canister is breached on impact. 4. Canister contents repackaged using specially designed remotely operated equipment. 5. Area decontaminated.	1. Failsafe wedge type braking system on hoist cage. 2. Mine exhaust filter system reduces atmospheric releases. 3. Repackaging and decontamination equipment available.	Four PWR assemblies (2 MTHM) are dropped releasing the following activities over a one hour period. ^{3}H - 6 Ci ^{14}C - 4×10^{-2} Ci ^{85}Kr - 4×10^{3} Ci ^{129}I - 6×10^{-3} Ci Other FPs - 1% of Table 3.3.8 per MTHM. Actinides - 1% of Table 3.3.10 per MTHM. Activation Products
7 – Tornado strikes mined salt storage area. Estimated frequency 8×10^{-5} km^{2}-yr.	1. Tornado strikes mined salt storage area. 2. Salt dispersed to atmosphere.	1. Site selection criteria limit maximum credible tornado. 2. Salt is covered as it accumulates.	Tornado strikes when pile contains maximum amount of salt. Pile is 1 km wide at bottom, 310 m wide at top, 30 m tall and 940 m long. 3.6×10^{7} MT is total salt stored in pile. Only 7×10^{4} m^{2} is uncovered and available for dispersion. 2.2×10^{4} MT (1%) is removed by tornado.
8 – LLW drum rupture due to mechanical damage and fire.	TRU LLW not produced in this fuel cycle.		
9 – LLW drum rupture due to internal explosion.	TRU LLW not produced in this fuel cycle.		

TABLE 2.2 (Cont'd) – Postulated Non-Design Basis Accidents – Once-Through Fuel Cycle Repositories

Accident No. and Description	Sequence of Events	Safety System	Release
10 – Nuclear warfare.	1. 50-megaton nuclear weapon bursts on surface above repository. 2. Crater formed to 340 m, with fracture zone to 500 m.	1. Repository depth of 540 m - Salt 590 m - Granite 420 m - Shale 560 m - Basalt	Although the fracture zone reaches the repository in shale, releases are expected to be less than those from Accident 11 (repository breach by meteorite).
11 – Repository breach by meteorite. Expected frequency $\sim 2 \times 10^{-13}$ per year.	1. Meteor with sufficient mass and velocity to form 2 km dia crater impacts repository area after closure. 2. Crater extends to waste horizon, dispersing waste to atmosphere. 3. Crater partially refilled with rubble covering repository.	1. Repository depth of 600 m.	One percent (1%) of the inventory is released on impact with one half going to local fallout and one half going to stratopheric dispersion.
12 – Repository breach by drilling No expected frequency can be assigned to this occurrence.	1. Societal changes lead to loss of repository records and location markers. 2. Drilling occurs.	1. Repository depth 2. Repository location monuments and records. 3. Site criteria--no desirable resources.	Drilling may occur anywhere in repository. Probability of contacting a cotaminated zone and/or canister (within 30 cms radius of canister), 0.005. One-fourth of a canister is brought to the surface in the drilling mud. The activity is uniformly distributed over 1.2 acres in the top 2 inches of soil.
13 – Repository breach by solution mining (salt only).	1. Societal changes lead to loss of records and location markers. 2. Exploratory drilling (see Accident 7.12) leads to the discovery of salt. 3. Salt is mined using solution extraction techniques. 4. Contamination is discovered after 1 year and mining is discontinued.	1. Monuments mark repository location. 2. Repository depth of 540 m. 3. Site criteria exclude areas with desirable resources. 4. Other plentiful and accessible salt deposits are available.	As salt is dissolved and carried away, water comes into contact with exposed spent fuel. At a leach rate of 1×10^{-5} g/cm^2 day 7 MTHM are leached into the brine during the first year of solution mining.
14 – Volcanism	1. Volcanic activity at repository carries wastes to surface.	1. Site criteria--no history or potential for volcanic activity.	Release equal to or less than Accident 15.

TABLE 2.2 (Cont'd)

Accident No. and Description	Sequence of Events	Safety System	Release
15 – Faulting and groundwater transport. Estimated frequency 2 x 10-13 per year.	1. Fault intersects repository 2. Access is created between high-pressure aquifer, waste and surface. 3. Aquifer carries wastes to surface.	1. Site criteria--low seismic risk zone. 2. Site criteria--minimal groundwater. 3. Repository depth 4. Low leachable waste forms.	Estimated frequency of a fault intersecting the repository is 4 x 10^{-11}/yr. Assumed frequency that high pressure aquifer exists with canister and surface access is 0.005. The overall expected frequency is 2 x 10^{-13}/yr. A 12 m wide line fault is assumed to intersect the repository in an orientation to maximize waste contact. The following spent fuel MTHM are available for leaching. PWR BWR Salt 220 120 Granite 450 420 Shale 240 150 Basalt 530 280
16 – Erosion	1. Repository overburden subject to high erosion.	1. Site criteria--low erosion rates. 2. Repository depth.	Release equal to or less than Accident 11.
17 – Criticality	1. Fault or groundwater action brings two spent fuel canisters together.	1. Site criteria--low seismic risk zone 2. Site criteria--minimal groundwater. 3. Repository depth.	None

2.22 SEALING REQUIREMENTS AND CONCEPTS

10 CFR Part 60 requires that shafts and boreholes be sealed, "as soon as possible after they have served their operational purpose."

The seals must inhibit transport of radionuclides to the same degree as the undisturbed units of rock through which they pass. In the case of soluble rocks, for example salt and limestone, the seals must also prevent ground water circulation that would result in dissolution. The seals must be able to accomodate potential variations in temperature, stress level and moisture.

The seal zone has three components

- the seal itself
- the interface between the seal and surrounding rock formation
- a zone of distrubed (fractured) rock immediately surrounding the sealed opening

Each of these component zones is a potential pathway for migration of groundwater and radionuclides.

Because of the long time periods ove which the seals are required to be effective and because of he uncertainties and lack of guarantees concerning such long term materials behavior, the engineered system must contain multiple barriers. For this reason, the multiple material/geometry concept was introduced in work for the Office of Nuclear Waste Isolation (Battelle Memorial Institute).

Current conceptual design work is focussed on the Los Medanos Repository site where the host rock is bedded salt. Conceptual designs for other rock types will follow and are scheduled for completion by mid-1985 (Ellison et al., 1981).

2.22.1 Concept for Los Medanos Shaft Seals

The Los Medanos site was selected for development of the first conceptual design because it had been explored in the greatest detail.

The geology at the site consists of:

- surface to 900 ft - overburden, sandstones and mudstones including three aquifers

- 900 ft to repository depth - salt containing thin anhydrite layers and very thin clay seams.

The existence of the aquifers is of prime importance, especially the one which is near the top of the salt. Expected quantities of flow are low; however no water can be allowed to contact the salt since this will result in solutioning. With reference to sealing this means that all potential water sources must be isolated from the seal zone and especially from the salt.

It is planned that the shaft will have steel liners through the overlying materials and into the top of the salt. Thereafter, the shafts will be unlined (this is possible in salt since the shafts could be drilled.)

One very advantageous aspect of the shaft seal design is that it can be constructed in logical sequences.

2.22.2 Borehole Seals

Seals for boreholes at the Los Medanos site would be similar to those for the shafts. A problem, however arises with regard to placement of the bore- hole seals. Furthermore testing of post construction seal integrity would be much more difficult than in a shaft as well.

In current practice, two types of seals are generally used - mechanical seals and slurry seals. Mechanical seals are devices which can be lowered down a borehole and expanded under pressure against the borehole wall. The effectiveness of this type of seal is dependent on continued application of pressure to the seal and hence this type of seal is suitable for use as a temporary measure, for example while a grout seal is hardening.

Slurry seals are placed either by pumping or pouring. The technology exists to place seals over distinct portions of a borehole so that the multiple seal concept is feasible from the standpoint of seal placement. (Placing of "zonal" seals is, in fact, standard procedure in oil well plugging. Between zonal seals, boreholes are normally filled with drilling mud.)

For abandoned holes which have been located, existing seals should be evaluated. It is probably wise to assume that old holes have not been sealed properly and to reopen them, clean them and reseal them according to sealing concept previously mentioned (Koplick et al., 1979)

The information required for all holes to be sealed includes:

- location

- variation in drilled diameter
- true dip and direction with depth
- location of steel casing left in the hole

Additional information concerning drilling techniques and drilling history should be collected if possible.

Holes drilled upward from the repository can be sealed by installing a plug and valve at the collar and then pumping seal slurry into the holes under pressure. Similarly, holes which penetrate the repository zone can be sealed from the bottom, when intersected during repository development.

2.22.3 Grouting

Shafts in weak materials such as salt can be drilled. However, in stronger rocks like granite and basalt the upper limit for diameters of drilled holes is about 10 ft and holes longer than 1500 ft are very uncommon. Thus in these materials it will be necessary to use conventional drill-and-blast shaft sinking.

Although Section 60.132 of 10 CFR Part 60 requires that excavation methods be such that damage to and fracture of rock be minimized, even with controlled blasting there will be some fracturing of surrounding rock which results from blasts. Since this fractured zone could provide a preferential path for groundwater migration in spite of any seals, grouting will be required.

A number of materials can be used as grouts including cement, clays, bentonite, bitumen, and chemicals such as sodium silicate and acrylamide (AM-9). Most rock grouting is done using cement grouts because of their high strength and low cost and the relatively large size of rock discontinuities. The Corps of Engineers indicated that for successful injection the ratio of crack width to grout particle size should be at least 3.

Grouting specifications commonly call for a maximum grout pressure of 1 psi per foot of overburden depth. The allowable injection pressure depends on the strength of the rock, the in-situ stresses, the pore pressure existing prior to injection and on structural discontinuties (joints, to bedding, etc).

During shaft sinking, sinking will be interrupted and grouting of the walls and face carried out any time water inflows exceed 15 gpm. When aquifers are known to exist, they will generally be pregrouted, if possible from the shaft face as they are neared or from surface prior to commencement of sinking. However, in the case of repository shaft design, 100 percent of the shaft walls must ultimately be grouted and the most practical means of doing so would be to incorporate wall grouting into the sinking cycle. This will result in slower than normal sinking progress; however, this would be more effective and easier to perform than grouting through a concrete shaft lining immediately prior to seal placement. Radial ring grouting would probably be most affective with holes drilled beyond the disturbed zone and stage grouted using packers from the hole bottom toward the shaft wall.

Any deficiencies in the grouting will need to be remedied prior to seal placement. Monitoring over the active life of the shafts (likely several decades) will provide some information of the long term durability of the grouting.

In order to assess the durability of grouts in the very long term, comparison could be made with the natural cement in cemented sedimentary rocks and cemented volcanic ashes (Gyenge, 1980).

2.22.4 Shaft Sealing Methods

In general, the methods used to seal shafts are similar to those used to seal boreholes. The difference is that in a shaft, seals can be installed and inspected manually. Usually, a shaft will require a liner, typically of concrete, and the rock behind it will be grouted. An exception is the case of drilled shafts in salt which may not require a liner. Shaft sealing methods for use in nuclear waste repositories are being investigated by ONWI.

As in the case of boreholes, aquifers penetrated by the shaft will require individual treatment. Impermeable bulkheads, above and below the aquifer are constructed to cut off upward or downward water movement.

Also similar to borehole seals, shafts can be sealed using a single or multi-material seal.

2.22.5 Sealing Materials

Portland cement is the most commonly used sealing material. Many cements have been developed for use under the temperature, pressure, and chemical conditions encountered in oil wells. These will not be further described. In addition, the following specialty cements are also available (Daemen, et al. 1979)

- Pozzolanic Cements
- Pozzolan-Lime Cements
- Resin or Plastic Cements
- Gypsum Cements
- Diesel Oil Cements

- Expanding Cements
- Calcium Aluminate Cements
- Latex Cement
- Permafrost Cement

Cement additives are also available to accelerate or retard its setting time, reduce or increase its weight, improve its flow characteristics, and increase its penetration into pervious zones.

There is a wide variety of chemical grouts available. These can be classified as either aqueous solutions, non-aqueous solutions and emulsions.

Chemical grouts that are aqueous solutions may be:

- mineral gels
- organic gels
- polyacrylamides
- phenoplasts
- aminoplasts
- combinations of the above

Non-aqueous chemical grouts may be:

- synthetic resins

- vulcanizable oils

- heat sensitive compounds including bitumen

Bituminous, epoxy and polyester resins, polyvinyl, and latex emulsions are also used as chemical grouts. (Daemen et al., 1979)

Materials which were tested at Pennsylvania State University as hydrothermally transported sealants are cement, quartz, calcite, and clay. Sulfur is also being investigated, but permeability problems are expected.

Of the natural earth materials which could be compacted in boreholes, shale cuttings from the formation to be sealed or from surface sources, and montmorillonite are mentioned as possible choices. Mixtures such as sand and clay are also being considered.

2.23 RETRIEVABILITY

Emplacement of wastes in a geologic repository is intended to be permanent. Nonetheless, provisions must be made to retrieve the waste since one or more of the following situations could occur:

- canisters may be defective
- a portion of the repository may be found unsuitable
- the entire repository may be found unsuitable
- alternative waste management technology may have been developed
- governmental or societal policy changes

Regulation 10 CFR Part 60 requires retrievability for up to 50 years following placement or decomissioning, so that these provisions must be carefully considered.

Presently planned geologic repositories allow for the waste to be "readily retrievable" by using steel sleeves and concrete plugs for canister holes and not backfilling rooms that essentially have the same effect is expended in emplacing as in retrieving. However, after the repository is proven, in say 5 years, the sleeves are eliminated and rooms are backfilled, requiring more effort to remove canisters, so that they are "recoverable." Recovering canisters at this stage could be difficult, since heat will be generated and not dissipated, backfill could consollidate, and canisters could be stuck or cemented into their holes.

In order to maintain full ready retrievability for 50 years, the rooms would have to remain accessible and stable. This requires continuous ventilation, extra support effort, continuous inspection or monitoring, and continuous maintenance or re-installation of all support equipment.

Each aspect of the various planned repositories has to be fully evaluated for its retrievability functions.

Many underground openings and mines have been in continuous service for 50 years or more, but none with the thermal loading requirements of nuclear waste repositories. The phenomena of long-term thermal loading has been extensively studied by various modeling techniques and by full-scale field tests on-going at the Basalt Waste Isolation Project, where preliminary indications are that little or no effect has been observed on the rock mass behavior or stability.

Salt storage, however, is subject to rock creep, especially at elevated temperature. These are old salt mines, especially in Poland, that have been open for hundreds of years, but, again, not at elevated temperatures. Room closure or creep in dome salt is accompanied by a steady rain of detached salt crystals so that a layer gradually accumulates on the floor. The proposed Project Manager, Mr. Kendorski, was employed as a surveyor in an underground dome salt mine, and observed this phenomenon first-hand.

2.24 BOREHOLES

Due to the sealing requirements detailed consideration needs to be given to boreholes that intersect or lie in the repository vicinity.

There are two types of boreholes to consider:

- old abandoned boreholes drilled prior to repository site investigation ·
- recent boreholes drilled in connection with repository site investigation.

2.24.1 Abandoned Boreholes

Old abandoned boreholes pose a greater problem since they may have been put down over a period of years and since records may be scanty or nonexistent. In at least one instance, aerial photographs have successfully located old holes at a gas storage site.

By considering the type of drilling that had been previously been carried out in an area - for example water, gas/oil, or mineral exploration, one might be able to estimate the number, type, and distribution of abandoned holes that have gone undetected.

In any case it is essential that maximum effort be expended to locate all abandoned bore holes using all the means available.

2.24.2 Recent Boreholes

Boreholes may be drilled at the repository site to collect information on the geologic, geotechnical and hydrolic aspects of the host rock to verify site design assumptions. The number, location, and depth of these holes will be site specific; however, some minimum number of holes will be required.

The depth of individual boreholes may range from shallow, for holes used to investigate overburden thickness and near surface rock, to intermediate, for holes drilled to about the depth of the repository, to deep, for holes drilled to intersect basement rocks below the repository.

During repository development, it is likely that relatively short holes could be drilled from the repository itself to provide more detailed local geological and hydrological data. These holes could be drilled at a variety of azimuths and dips but are unlikely to exceed 300m in depth.

Holes which penetrate from surface to the repository horizon and beyond should be located in pillars to provide an additional barrier against leakage should the borehole seal fail. This requires that the repository design and layout be known at the exploration stage.

The number of holes drilled should be minimized but sufficient to provide design data with a satisfactory amount of confidence. The holes should be sealed as soon as they are abandoned in order to ensure that sealing serves its purpose.

There are a number of available drilling methods but the most likely are rotary and diamond. Diamond drilling can be used for holes up to 1,000m long and is restricted to diameters not exceeding 7.75 in. Rotary drilling can be used to much greater depths and with diameters up to 17 in. and occasionally greater.

With diamond drilling, cores are obtained from the holes which when logged provide a record of the rock quality, lithology, joint locations and dip. Drill cores can also be used to obtain rock properties in laboratory tests.

With rotary drilling lithology can be inferred from the drill cuttings; however for detailed information well logs of various types are required.

2.25 SEISMIC EFFECTS

An earthquake, blast, or rockburst induced strain wave can have affect on an underground structure. In general, seismic waves from earthquakes are much lower in frequency than those from blasting, but the magnitude and areal extent of earthquakes is greater. The rock mass contracts and dilates in response to the passing wave which may disrupt any contained structure, such as a sealed repository.

Vibrational ground motions may affect a tunnel or shaft structure in several ways:

- Longitudinal Distortion
- Circumferential Distortion
- Loosening of Structural Elements;

also, fault displacements may shear or deform a structure if the structure actually crosses the fault.

In unlined underground structures, which may occur while under construction, the seismic waves essentially result in compression and expansion of the rock mass, which may loosen individual blocks or areas of rock, leading either to nuisance deformation or failure. In steel or cement lined shafts or tunnels, the tunnel support is closely coupled to the rock, so it does not behave under seismic loadings as a free standing structure such as a surface structure. Therefore, the deformation experienced by the rock mass is felt by the underground structure, and no further vibrations are induced into the structure.

If the wave propagation direction is parallel to the tunnel or shaft line, the structure is shaken from side to side and compressed and released axially, which may lead to support distress such as circumferential cracking.

If the wave propagation direction is perpendicular to the line the profile is compressed and structured, which may also lead to support distress, such as radial cracking.

However, field observations and theoretical studies have both shown that lined shafts or tunnels coupled to the rock are much more stable than equivalent surface structures since they cannot develop separate vibrational phenomena.

Non-recoverable dilation of the rock mass or induced shear displacements may physically disrupt grout or other seals.

2.26 REFERENCES

Bathe, K. J., Wilson, E. L., and Peterson, F. E., 1974, SAP IV, A Structural Analysis Program for Static and Dynamic Response of Linear Systems, Report EERC 73-11, College of Engineering, University of California, Berkeley, June 1973, revised April 1974.

Battelle Memorial Institute, 1979, Status of Borehole Plugging and Shaft Sealing for Geologic Isolation of Radioactive Waste. Office of Nuclear Waste Isolation Report ONWI-15. Battelle Mem. Inst., Columbus. 296 p.

Bradshaw, R. L. and McClain, W. C., editors, 1971, Project Salt Vault: A Demonstration of the Disposal of High Activity Solidified Waste in Underground Salt Mines, Oak Ridge National Laboratory, ORNL-4555.

Chan, T., Littlestone, N., and Wan, O., 1980, Thermo-mechanical Modeling and Data Analysis for Heating Experiments at Stripa, Sweden, Proc. 21st U. S. Symposium on Rock Mechanics, Rolla, MO. P. 16-25.

Cook, N. G. W. and Witherspoon, P. A., 1978, In-situ Heating Experiments in Hard Rock: Their Objective and Design. Proc. Seminar on InSitu Heating Experiments in Geological Formations, Organization for Economic Cooperation and Development, Ludvika, Sweden, LBL-7073.

Daemen, J. J. K., South, D. L., Jeffrey, R. G., and Klejbuk, L. K. 1979 Rock Mass Sealing, Annual Report Oct. 1, 1978 through Sept. 30, 1979. Contract No. NRC-04-271. Prepared for the U. S. Nuclear Regulatory Commission, Safer Division, Office of Nuclear Regulatory Research 291 p.

Davis, S. N. and DeWiest, J. M., 1966. Hydrogeology. John Wiley and Sons, Inc. N. Y. 463 p.

Ellison, R. D., Stephenson, D. E., and Shukla, D. K., 1981. "Sealing of Shafts, Tunnels, and Boreholes for Waste Repositories." Proceedings, 1981 AIME Rapid Excavation and Tunneling Conf. R. Bullock and H. Jacoby ed. Amer. Inst. of Mining, Metallurgical, and Petroleum Engineers, Inc. N. Y. pp. 1251 - 1268.

Fairchild, P. D. and Jenks, G. H., 1978, Avery Island Dome Salt In Situ Tests, Union Carbide Corporation, Nuclear Division, Office of Waste Isolation, Y/OWI/TM-25.

Gregory, E. C., and Kim, K., 1981, Preliminary Test Results from the Full-Scale Heater Tests at the Near-Surface Test Facility, Proc. 22nd U. S. Symposium on Rock Mechanics, M. I. T., p. 137-142.

Jenks, G. H., 1977, Maximum Acceptable Temperatures of Wastes and Containers During Retrievable Geologic Storage, Y/OWI/TM-42, Office of Waste Isolation, Union Carbide Corp., Oak Ridge, TN.

Keller, G. V., 1960, Physical Properties of Tuffs of the Oak Spring Formation, Nevada. U. S. G. S. Prof. Paper 400-B. pp. 396-400.

Koplick, C. M., Pentz, D. L., and Talbot, R., 1979, Borehole and Shaft Sealing vol. 1, Information Base for Waste Repository Design, NUREG/CR-0495-, TR-1210-1. Prepared for Division of Waste Management, Office of Nuclear Material Safety and Safeguards, U. S. Nuclear Regulatory Commission. The Analytic Sciences Corporation, Reading, MA 127 p.

Krynine, D. P., and Judd, W. R., 1957, Principals of Engineering Geology and Geotechnics. McGraw-Hill, New York, NY, 730 p.

Lee, C. F., and Klym, 1977, Stability of Heated Caverns in a High Horizontal Stress Field, Rockstore 77, Stockholm, Sweden, p. 219-226.

Lundstrom, L. and Stille, H., 1978, Large scale permeability test of the granite in the Stripa mine and thermal conductivity test, Lawrence Berkeley Laboratory, LBL 7052, SAC-02, 33 p.

National Safety Council, 1974, Accident Prevention Manual for Industrial Operations, 7th ed., Chicago, NSC, 1523 p.

Peurifoy, R. L., 1970, Construction Planning, Equipment, and Methods, 2nd ed., McGraw-Hill Book Co., New York, 696 p.

Runchal, A., and Maini, T., 1980, The Impact of a High Level Nuclear Waste Repository on the Regional Ground Water Flow, Int. J. Rock Mech. Min. Sci. and Geomech. Abstr., V17, p. 253-264.

Russell, J. E., 1977, Areal Thermal Loading Recommendations for Nuclear Wastes Repository in Salt, Y/OWI/TM-37, Office of Waste Isolation, Union Carbide Corp., Oak Ridge, TN.

SAI, 1976, The Selection and Evaluation of Thermal Criteria for a Geologic Waste Isolation Facility in Salt, Y/OWI/SUB-76/07220. Office of Waste Isolation, Union Carbide Corporation, Oak Ridge, TN.

Simonds, R. H., and Grimaldi, J. V., 1963, Safety Management, rev. ed., Richard D. Irwin, Inc., Homewood, IL, 597 p.

Tsui, K., and Lee, C. F., 1980, Thermomechanical Stability of Heated Rock Caverns. Proc., 21 st U. S. Symposium on Rock Mechanics, Rolla, MO, p. 183-191.

U. S. Department of Energy, Nevada Operations Office, 1978, Safety Assessment Document for the Spent Fuel Handling and Packaging Program Demonstration at the Nevada Test Site.

Wahi, K. K., Trent, B. C., Maxwell, D. E., Pyke, R. M., Young, C. and Ross-Brown, D. M., 1980, Numerical simulations of earthquake effects on tunnels for generic nuclear waste repositories, Science Applications Inc., SAI-FR-126, Vols. I and II.

Witherspoon, P. A., Cook, N. G. W., and Gale, J. E., 1980, Geologic Storage of Radioactive Waste - Results from Field Investigations at Stripa, Sweden. Proc. of Waste Management '80, Univ. of Arizona, Tucson, AZ.

Witherspoon, P. A., Degerman, O., 1978, Swedish-American Cooperative Program on Radioactive Waste Storage in Mined Caverns - Program Summary. LBL-7949, SAC-01, Lawrence Berkeley Laboratory, Berkeley, CA 94720, May.

3.0 PROGRAM PLAN

Engineers International, Inc. (EI) manages each project it undertakes in accordance with a formal program plan which presents:

- the objectives of the project
- task descriptions
- requirements for reviews, reports, and presentations
- dependence of activities by means of networks, as necessary, schedules and milestones
- personnel allocation for each task by category
- material requirements
- travel schedules
- subcontract responsibilities
- schedule of deliverable items, with due dates
- budget

The proposed plan for this program is presented here for review by the NRC. The schedule is given in the next section, and the budget is deleted from this volume and submitted in a separate volume - in accordance with the instructions of the RFP.

EI has taken the basic requirements for this contract directly from the Statement of Work, included in the RFP. The work to be done is outlined under Section 3.3, entitled Technical Plan, which clearly identifies the individual tasks and establishes their comprehension by EI. This also facilitates communications between the Program Manager, the project staff, consultants, and the NRC Project Officer. The basic tasks outlined in the RFP have been retained in order to facilitate reference, should that be desired.

3.1 OBJECTIVE

Nuclear waste exists now and is being generated steadily. Ultimately it must be disposed of in some fashion so that it does not pose a hazard to present or future generations. The apparently best systems developed to date are repositories in geologic media. Geologic repositories involve placing the packaged waste in mined rooms underground, and utlimately sealing the repository. The Nuclear Regulatory Commission (NRC) is charged with licensing high level nuclear waste repositories in order to safeguard the public, while the Department of Energy (DOE) is charged with designing, constructing, and operating repositories to efficiently and safely store the waste. The NRC role is detailed in the recently promulgated 10 CFR 60 which spells out certain requirements to be met for repository licensing. The underground engineering, mining, and geologic tasks required are newly evolving technologies and the civil, mechanical, and electrical applications are for an unusual and unique technology, so that in order to thoroughly review and evaluate repository designs for conformance with 10 CFR 60 requirements, especially safety, the NRC requires technical assistance. An organization to assist the NRC must have qualifications and experience in all of the relevant disciplines, and also be unbiased and objective, not reviewing their own or related work, thus avoiding actual or potential conflicts.

3.2 PROJECT RESPONSIBILITY

Engineers International, Inc. (EI) will perform all of the work in the project, which includes detailed reviews of designs and other assistance to the NRC. EI will be responsible for providing all personnel and materials required for this project, except for the NRC furnished material detailed in the Statement of Work.

3.3 TECHNICAL PLAN

3.4 SUPPORT ACTIVITIES

3.4.1 Meeting Participation

In order to coordinate the work of assisting the NRC in reviews of aspects of geologic nuclear waste repositories, EI will participate in such meetings with personnel deemed appropriate by the EI Project Manager and the NRC Project Officer, and generally would include the Project Manager, Project Engineer, Mining Engineer, and Rock Mechanics Consultant.

Within 15 days of each meeting a written report will be submitted to the NRC that will serve as a record of the meeting, and will include the meeting purpose, participants, costs, important or significant findings, EI's conclusions and recommendations, and other items as appropriate.

3.4.2 Workshops

At the request of the NRC, EI personnel will participate in 5-day workshops dealing with review aspects of geologic nuclear waste repositories. It is estimated that the EI Project Manager, Project Engineer, Mining Engineer, and Rock Mechanics Consultant will participare.

Topics and materials to be related or presented would be as requested by the NRC. All EI project personnel have considerable experience in organizing and participating in such workshops.

A written report on the workshop activities will be submitted within 15 days of the close of the workshop.

3.4.3 Site Visits

As appropriate for carrying out each review, EI staff will visit each site and gain first-hand knowledge of physical conditions and status. It is planned that such visits would take place in the early stages of the review process, but not until the particular Task Order Items are understood and underway, so that any additional required information can be obtained.

Staff participation would be the Project Manager, Project Engineer, and staff from other disciplines as appropriate.

3.5 TASK 2 ACTIVITIES

3.5.1 Meeting Participation

This task effort consists of assisting the NRC in various meetings concerned with design review aspects of geologic nuclear waste repositories. EI participation on such meetings will be personnel deemed appropriate by the EI Project Manager and the NRC Project Officer, and would generally include the Project Manager, Project Engineer, and specialists in required disciplines.

Within 15 days of each meeting a written report will be submitted to the NRC that will serve as a record of the meeting, and will include the meeting purpose, participants, costs, important or significant findings, EI's conclusions and recommendations, and other items appropriate.

3.5.2 Workshops

At the request of the NRC, EI personnel will participate in 5-day workshops dealing with design aspects of geologic nuclear waste repositories. It is estimated that the EI Project Manager, Project Engineer, and specialists in various disciplines would participate.

Topics and materials to be related or presented would be as requested by the NRC. All EI project personnel have considerable experience in organizing and participating in such workshops.

A written report on the workshop activities will be submitted within 15 days of the close of the workshop.

3.5.3 Report Reviews

As requested by the NRC, certain reports or portions of reports will be reviewed and the results reported to the NRC. EI will comply with all requested review items and submit a comprehensive and complete report within the NRC review request schedule.

EI has carried out considerable work on mine and tunnel design for industry, so has specific experience in responding quickly and accurately to review requests, and no difficulties are foreseen.

3.5.4 Site Visits

As appropriate, EI staff will visit sites as requested and gain first-hand knowledge of physical conditions and status, and hold discussions with knowledgeable individuals so that any additional information can be obtained.

Staff participating would be the Project Manager, Project Engineer, and staff from other disciplines as appropriate.

3.6 QUALITY ASSURANCE

Throughout the work, EI will maintain a quality assurance program so that the work and the resulting assessments are efficient and accurate. All design assumptions will be identified and justified, all design methods and concepts will be verified as being in accordance with accepted practices and standards, all materials will be verified as being adequate, safe, and of the desired quality.

Computations and calculations, wherever required, will be checked for proper method, arithmetic, and carefully documented and explained.

EI has experience in planning and executing Quality Assurance Programs through their work on civil design projects that require review by independent agencies such as the Federal Highway Administration and the Federal Energy Regulatory Commission.

The Quality Assurance Engineer will report directly to the Project Manager, thus having direct and clear communication to the responsible individual.

Any standards desired by NRC will be utilized, and a QA Manual for the project will be developed and submitted, if desired.

3.6.1 Commitment and Organization

It is the purpose of the EI Quality Assurance Program to insure that the standards embodied in appropriate and applicable regulations and guidelines are met in the performance of testing and research programs conducted under the Quality Assurance Manual.

The chart on the next page indicates the organization established within Engineers International, Inc. to conduct programs requiring Quality Assurance procedures.

3.6.2 Responsibilities

3.6.2.1 Project Manager

The Project Manager is the responsible individual to whom the Quality Assurance Engineer and the Project Engineer report.

3.6.2.2 Quality Assurance Engineer

The Quality Assurance Engineer (QAE) is responsible for insuring that all work conducted under the Quality Assurance Program is in compliance with the manual. The QAE will establish and maintain Quality Assurance files in the EI building and will forward a copy of same to the client. The Quality Assurance staff will not be assigned from the group conducting the project. The responsibilities of the QAE include:

1. Audits at least annually or twice during the course of the project to insure that procedures being used are in compliance with the manual. In the event that procedures not in accordance with the manual are being used, the QAE will issue a memorandum to the PE (copy to PM) stopping work until the work is rectified, re-audited, and permission to resume work has been issued.

2. Maintain files in which are stored:

   a.) check lists from all audits.

   b.) stop work order, including:

      - the reason for stoppage
      - corrective action ordered
      - audits check list showing re-audit and permission from the QAE and if necessary the client to resume work

   c.) biographies showing experience and skills of all EI personnel assigned to the work.

   d.) control documents regarding the Quality Assurance Manual.

   e.) a copy of all data and test results conducted under this Quality Assurance Program. This material will be stored for a period of one year. If requested by the client, the experimental data will be retained for a longer specified time at a maintenance fee to be set by the QAE, or forwarded to the client at his option.

3. Under item 2(d) above, the QAE will maintain the Quality Assurance Manual, all revisions that are made, and distribution of all copies. At the close of each project, copies of the Quality Assurance Manual distributed under that project will be inactivated by written notice, and their holders will not receive subsequent revisions.

3.6.2.3 Project Engineer

The Project Engineer (PE) is responsible for the activities of the engineers and technicians on the project team and for the technical conduct of tests performed under the Quality Assurance Program. The PE will maintain in the EI building a duplicate copy of computations and experimental data, and other material pertinent to the Quality Assurance Program and work being conducted thereunder.

3.6.3 Document Control

The policy and each procedure of the manual will be prepared by a competent individual, reviewed for adequacy by an equally competent individual and approved by a responsible individual.

Revisions to the manual will be processed in the same manner.

The manual will be maintained and controlled by the QAE who shall:

a.) maintain a log of manual distribution, and

b.) will employ a transmittal and receipt form for the initial distribution and subsequent revisions.

Each page of the manual will display the latest date and revision number. A history of all revisions will be maintained in the Quality Assurance files by the QAE. Single page revisions will not be allowed.

All records will be identified by the project name supplied by the client.

3.6.4 Trained Personnel

Trained personnel will be used for all work and testing, and experience and education histories will be filed in Quality Assurance files. Records will be maintained of all additional training, including the use of the Quality Assurance Manual.

3.6.5 Handling, Storing, Identification, and Control of Test Specimens

Handling, storing, identification, and control of all test specimens will be conducted in accordance with established Quality Assurance Manual procedures. Measures will be taken to prevent damage, deterioration or mismarking of test specimens. If required, special protective environments will be used.

3.6.6 Calibration of Instruments

All instruments on which data critical to tests are being performed, shall be calibrated at least annually using standards traceable to the National Bureau of Standards. Instruments so calibrated will be numbered, and duplicate calibration records and a log will be maintained by the PE and the QAE. Instruments will not be required to be calibrated to a greater degree than is required by the test procedure.

3.6.7 Auditing

The QAE shall conduct audits of the program when at least half the project effort has been conducted. Audits shall be performed in accordance with checklists. documented and suitably signed off. The audit report shall be distributed to the Project Manager, responsible Project Engineer, and files. The QAE will include in the audit report a statement regarding the effectiveness of the Quality Assurance Program.

3.6.8 Reporting

Work conducted under this Quality Assurance Program will be reported in a format specified by the client. A typical letter report will include a letter of transmittal, a table summarizing test results, and copies of the data. The report will be approved by the Project Manager.

3.7 PROJECT REVIEWS AND PRESENTATIONS

The RFP stipulates that there shall be numerous reviews of the project. The first will be a kick-off meeting, at the NRC Washington offices. The presentation will be made by the Project Manager, who will be accompanied by the Project Engineer and other appropriate personnel. The presentation will be accompanied by slide or other visual aids as are deemed appropriate by EI or the Project Officer. A proposed agenda will be submitted to the NRC fifteen (15) days prior to the scheduled meeting. Any questions or comments that arise on the work completed to date, will be answered by the EI team.

All other Task Order Items meetings and reviews will be held with prior schedule and content approval by the NRC.

3.8 PERSONNEL REQUIREMENTS

Based on the tasks described above, and the time limitations stipulated in the RPF, the requirements for personnel are presented in matrix for each task and labor category in Table 3.1.

3.9 EQUIPMENT AND MATERIALS

No special equipment and materials are required for this project, aside from the documents to be supplied by NRC.

3.10 TRAVEL

Based upon the stipulations in the RFP Statement of Work, the following travel has been planned:

- Kick-off meeting in Washington, DC, one day, 4 persons
- Technical meetins in Washington, DC, one day, three per Task Order, 25 Task Orders, 3 persons, plus 4th person in one-third of meetings.
- Review Meetings in Washington, DC, one day, one per Task Order, 3 persons, plus 4th person in one-third of meetings.
- Workshops in Washington, DC, 5 days, one per Task Order, 25 Task Orders, 3 persons, plus 4th person in one-third of workshops.
- Site Visits in field, 3,000 miles from EI office, 5 days, one per Task Order, 25 Task Orders, 3 persons, plus 4th person on one-third of visits.

3.11 SUBCONTRACTS

EI will conduct this project with no Subcontractors, except for the Project Consultant.

3.12 REPORTS AND DELIVERY REQUIREMENTS

3.12.1 Program Plan and Schedule

A detailed program plan and schedule, including milestone charts, and labor allocation by category and by tasks, is presented in this proposal for review by NRC. This may be altered if so desired and the approved plan will then be submitted at the time of contract negotiations, prior to contract award. This will be submitted in the number of copies desired by NRC.

After award an even more detailed Program Plan will be submitted, if so desired by the Project Officer. This will divide the entire project into phases and tasks. The personnel working on each task will be identified, as will the work they will perform and the product that will result therefrom. The initiation and completion of each task will be shown by milestones. The travel to be undertaken, along with the staff involved, will be indicated. The plan will present the work by labor category and give cumulatives for tasks as well as the entire project. Any other graphics, progress charts of interest, will be included. Labor, material, subcontract, and total costs will be given for each task. It is recognized by EI that any changes in the proposed plan must be approved by the Project Officer.

3.12.2 Monthly Progress Reports

Monthly reports will be submitted as required by the RFP. These will be in the form of a narrative and will include as a minimum:

- the technical results of the research and documentation accomplished during the report period

- any problems that arose during the course of the work and their current status as well as steps taken to alleviate the problems

- a forecast of the work anticipated to be performed during the next work period

- anticipated problems during the future, as far as can be predicted, and how these are expected to be attacked

- a comparison of the work schedule proposed in the original plan with the current status of the work. If the work is behind schedule the reasons for the same will be provided, as will the actions to be taken to rectify the situation

- a graph depicting the projects versus actual expenditures
- any change of key personnel anticipated in the future
- report on any trips undertaken in connection with the project and work accomplished
- any inventions or patent applications resulting from the work during the preceding report period

Any other information that is considered to be of interest to the Project Office or NRC will be included.

The number of copies and due dates will conform to the contract requirements and are presented under the section on "Deliverable Items."

Each month, Engineers International, Inc. will prepare a financial statement depicting the current situation. It will be in tabular form, and will provide the expenditures of the past work period in sufficient detail to be consistent with the categories in the cost proposal. The cumulative costs to that date will also be given, and a graph of expenditures versus time prepared. This will be superimposed on the plot depicting planned costs. Any gross deviations from the anticipated expenditures will be explained.

3.9.3 Deliverable Items

All delivery requirements mentioned in the RFP and included in the contract will be met. These are expected to be:

Deliverables	Quantity	Due Date
Monthly Progress Report	5	Within 20 days after the end of the reporting period.
Oral Reviews	1	At contract initiation and as requested.
Technical Meetings	100	As requested.
Workshops	25+	As requested.
Site Visits	25+	As requested.
Draft Report	10	Within 3 months after the issuance of each Task Order.
Final Report	10+ reproducible master	15 days after the receipt of NRC comments.
Meeting, Workshop, and Site Visit Reports	5	15 days after item.

4.0 PROJECT SCHEDULE

Based on the time limitations mentioned in the RFP and the tasks discussed in the Technical Plan (Section 3.3) a schedule and milestone chart has been prepared which is shown on the following page. The schedule depicts the duration of each task and the time required for the preparation and submission of reports. An attempt has been made to initiate each task as early as possible and to conduct tasks concurrently whenever practical, so as to ensure timely completion.

Reports to the Nuclear Regulatory Commission and project reviews are also indicated.

EI anticipates no problems in fully complying with the RFP requirements outlined in the RFP. All time stipulations in the RFP will be met.

ENGINEERS INTERNATIONAL, INC.

PROGRAM SCHEDULE

EI PROPOSAL P-313

MONTHS

TASK	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1. REPOSITORY DESIGN REVIEWS																								
2. SITE VISITS, WORKSHOPS AND REPORT REVIEWS																								

5.0 ORGANIZATION

5.1 ENGINEERS INTERNATIONAL, INC.

Engineers International Inc. (EI), was established in 1975 as a consulting engineering firm, serving the minerals, construction, energy, and environmental industries. To date, it has been engaged in exploration, feasibility, design, planning, and research.

Engineers International personnel have varied experience in industry, consulting, research, and teaching. Most of the professional staff have advanced degrees and registration in various states. In addition to its own competent staff, EI has agreements with a number of nationally and internationally known advisors and consultants who participate in projects as their services are required. Thus, EI can bring to bear an enormous reservoir of expertise to any given project.

Engineers International, Inc. is a project-oriented company and assigns its best talent in a given specialty to each project requiring such competence. Each project is managed by a senior person with qualifications appropriate to the project under consideration. This Project Manager then assigns the component project tasks to the staff members best equipped to perform the work. Thus, the benefits of the best available knowledge are obtained for the project. The overall responsibility for the projects rests with the Principal of the Company.

As a matter of policy, Engineers International maintains a strong commitment to research, in addition to performing design and construction projects. This helps EI staff to remain abreast of the latest technology, while still retaining a pragmatic approach to its projects.

The firm offers extensive expertise and experience in the fields of mining systems, tunnel design, ground control, blasting, subsidence, slope stability, ventilation, dust control, mine reclamation, drilling mechanics, foundation engineering, high-pressure water-jet technology, and mineral exploration.

The corporate offices and major laboratory facilities of Engineers International, Inc. are located in Downers Grove, Illinois, about 25 miles due west of downtown Chicago.

PARTIAL LIST OF CLIENTS

Private Organizations

- A and H Engineering Corporation, Downers Grove, IL
- Alite Enterprises, Downers Grove, IL
- Burns and McDonnell, St. Louis, MO
- Denison Mines Ltd., Ontario
- ENSCO, Inc., Springfield, VA
- Exxon Production Research Co., Houston, TX
- Goodman Equipment Corporation, Chicago, IL
- Granite Construction Co., Skokie, IL
- Harza Engineering Company, Chicago, IL
- IIT Research Institute, Chicago, IL
- Illinois Drilling & Testing Co., Inc., Addison, IL
- Keifer Engineering, Inc., Chicago, IL
- Ketron, Inc., Wayne, PA
- Leeco, Inc., London, KY
- Molycorp, Inc., Questa, NM
- Paschen Contractors, Inc., Chicago, IL
- Cecil V. Peake, Inc., Bethlehem, PA
- Piacenta, Cifelli and Sims, Chicago Heights, IL
- PSM International Corporation, Chicago, IL
- Rockwell International, Inc., Hanford Operations
- Rooftree, Inc., Rockton, IL
- Soil Drilling, Inc., St. Charles, IL
- Southern Company Services, Inc., Birmingham, AL
- Stearns-Roger, Inc., Denver, CO
- Technical Advisory Service for Attorneys, Ft. Washington, PA

Public Agencies

- Argonne National Laboratory, Argonne, IL
- Bureau of Land Management, Portland, OR
- Chicago Board of Education, Bureau of Architecture, Chicago, IL
- Colorado School of Mines, Golden, CO
- Denver Research Center, U. S. Bureau of Mines, Denver, CO
- Metropolitan Sanitary District of Greater Chicago, Chicago, IL
- National Park Service, Denver Service Center, Denver, CO
- National Science Foundation, Washington, DC
- Pittsburgh Research Center, U. S. Bureau of Mines, Pittsburgh, PA
- Pittsburgh Mining Technology Center, U. S. Department of Energy, Bruceton, PA
- Spokane Research Center, U. S. Bureau of Mines, Spokane, WA
- Twin Cities Research Center, U. S. Bureau of Mines, Minneapolis, MN

5.5 MANAGEMENT SYSTEM

5.6 KEY PERSON INVOLVEMENT

At the present time it is planned that the following proposed key persons will be committed to this project.

Francis S. Kendorski
Leif G. Eriksson
Michael F. Dunn
Robert A. Cummings
Douglas F. Hambley
Mark S. Ma
M. Ashraf Mahtab
Madan M. Singh

5.7 EXPERIENCE

In addition to the considerable "hands-on" experience of the staff listed above, EI has also been involved in investigations, evaluations, design, review, and design for other projects.

EI is presently designing twin-bore highway tunnels in highly fractured rock in Colorado utilizing diamond drill coring, rock mass classification, and detailed laboratory testing, and for a large diameter tunnel and shaft in 17 different sedimentary rock units for a pumped storage hydroelectric project in Georgia. Also, EI has just completed similar investigations for a single entry-longwall coal project in Alabama, and conveyor belt tunnel in granite rock in New Mexico.

EI has also carried out extensive mining systems and equipment evaluations for numerous project, as well as ventilation investigations.

EI staff have pertinent high level nuclear waste repository experience as well as extensive underground construction design and analysis experience, so that EI has a very strong capability for this project.

The following project summaries briefly describe the nature of EI's work.

- Investigation and Design of the Tunnel and Shaft for Rocky Mountain Pumped Storage Project, Rome, GA

Client: Southern Company Services, Inc.
Birmingham, AL
EI Project No: 1055

In a major undertaking, EI is designing the 35 ft finished diameter tunnel and connecting shaft for the 675 megawatt Rocky Mountain Pumped Storage Project being built by Georgia Power Company near Rome, Georgia. The tunnel is to be over 2,000 ft long with a 90 ft radius vertical curve to a shaft over 700 ft deep. Where the tunnel enters the powerhouse, it branches twice to feed the turbines. The site is in a syncline so the underground works transect a total of 17 different geologic units. EI geologists are logging core and mapping rock mass fracture characteristics as well as summarizing a wealth of previously collected data. In situ determinations of the rock mass modulus are being done since the tunnel and shaft will contain water pressure. Working with the overall planners and civil engineering designers, EI tunnel engineers are producing designs for rock excavation, stabilization, and support for all underground works.

- Rock Core Analysis

Client: Rockwell Hanford Operations
Hydrology Group
Richland, WA
Contract No: K-276617
EI Project No: 1070

Testing will be conducted in the EI laboratory on diamond-drilled, NX rock cores obtained from the Basalt Waste Isolation Project Site, Richland, WA. The tests to be performed include:

- geologic characterization of the cores
- heated confined triaxial compression tests at 50°C ambient temperature and 1,300 psi confining pressure to determine ultimate compressive strength at failure, static Young's modulus and Poisson's ratio
- ultrasonic velocity determinations to determine the veolocities of P-wave and S-wave, and dynamic Young's modulus
- laboratory permeability tests to determine the intrinsic permeabilities of rock cores
- physical measurements of effective porosity, bulk specific gravity, and porosity.

The rock cores from the site are basalts. All the above test results will be used to complement the extensive work, conducted by the Hydrology Group, to characterize the groundwater flow systems within the Columbia River Basalts underlying the Hanford Site, Washington.

- Investigation and Design of Beavertail Highway Tunnels, Colorado

Client: Stearns-Roger Engineering Corporation and
Colorado Division of Highways, Denver, CO
EI Project No: 1046

In association with Stearns-Roger Engineering Corporation, EI is investigating the subsurface conditions and formulating tunnel support and lining requirements, as well as excavation methods for twin 40-ft diameter highway tunnels each approximately 650-ft long. The tunnels will carry Interstate Route 70 through a rock bluff cut by the Colorado River. The work involves extensive diamond drill coring, geotechnical mapping, laboratory testing of rock and discontinuity properties, inspection of a nearby railroad tunnel nearly 100 years old, and assessing the rock mass response to tunneling. Several multiple tunnel schemes will be examined including various tunnel geometries and support methods, and studies of the desirability of mechanical excavation versus drilling and blasting. The tunnels are situated immediately above the Colorado River about 30 miles east of Grand Junction, CO, in thinly bedded horizontal sedimentary rocks. In the latter phase of the project, complete construction documents will be prepared, along with a construction estimate.

- Engineering and Testing Services for the Design of the Riverside Slide Snowshed

Client: Stearns-Roger Engineering Corp. and
Colorado Division of Highways,
Denver, CO
Contract No: Subcontract 7000 C24849
EI Project No: 1064

Of the numerous avalanche zones in the Colorado Rocky Mountains, the notorious Riverside slides along US 550 near Ouray are unpredictable and not amenable to most methods of avalanche control. There have been a number of fatalities resulting from unexpected violent releases in past years. The Colorado Division of Highways is funding studies to investigate the feasibilities of various construction alternatives that would isolate this highway from the avalanche paths.

Avalanche velocities commonly exceed 100 mph, and may generate enormous destructive forces. Accordingly, Engineers International, Inc., has estimated the bearing capacity of the rock mass for likely modes of loading due to such avalanche impacts. The site is in faulted, altered, and mineralized pyroclastic and flow rocks of the San Juan caldera system, at an elevation of over 9500 ft.

For this project, EI performed a full laboratory testing program, extensive field mapping, geophysical testing, aerial imagery interpretation, slope stability studies, and determined static and dynamic rock mass properties. A key to project success was the recognition, mapping, and projection of the various types of rock alteration present, since alteration was found to strongly influence rock mass strength.

- Mine Support Requirements Based on Rock Quality Indices

Client: U. S. Bureau of Mines
Spokane, WA
Contract No: J0100103
EI Project No: 1058

Engineers International, Inc. investigated the suitability of existing rock classification systems for predicting ground support requirements for production drifts in block caving mines. Although these classifications have experienced increased popularity in tunneling applications, complications such as dynamic stresses, multiple openings, multiple levels, and variable spans, have precluded their application to mining. Design of drift support in block caving mines has thus remained largely a trial-and-error process.

EI geologists and engineers visited block caving mines in the western United States and collected highly detailed information on rock conditions, compared existing support with that predicted by the classifications, and developed modifications and adjustments to make the classification systems more responsive to the mining situation. This required an integrated and specific knowledge of the fracture patterns and conditions, structural geology, alteration, rock strengths, support design and effectiveness, development and mining procedure, and rock mass behavior at each mine visited.

The usefulness of the improved classification system in vein mining was also determined. The results of the study are available for use by mine operators and planners in determining long-range drift support requirements without an extensive geomechanical investigation.

- Cost-Effectiveness of Increasing Airflow at Any Location in Underground Coal Mines

Client: Pittsburgh Research Center
U. S. Bureau of Mines
Pittsburgh, PA
Contract No: J0100066
EI Project No: 1054

This project was directed at determining the cost-effectiveness of increasing airflow at any location in underground coal mines. In order to achieve this, detailed ventilation surveys were conducted at 3 mines. One was an old, extensive mine in Illinois with both longwall and room-and-pillar operations, the second was a mine with a relatively high seam in Utah, and the third was a gassy mine in Appalachia.

Based on the data collected and the mine projections for future development, a computer simulation was conducted for each. Factors considered during the simulation included:

- increasing the output of the main fan system
- adding a new ventilation shaft
- reducing the resistance to airflow, considering both modification of the old workings and redesigning of new developing sections
- reducing leakage by coating or recoating stoppings, with cognizance of stopping life expectancy
- novel approaches to increasing airflow.

The results of the investigation were reported, and comprehensive guidelines prepared to predict the cost-effectiveness of increasing airflow.

- Profiling of Tunnel-Shaft Intersections

Client: Granite Construction Company
Skokie, IL
EI Project No: 1053

Before pouring concrete linings in 25 intersections of conventionally excavated drop shafts and TBM driven tunnels, the contractor requested that EI produce a photographic record of the actual excavated geometry. The technique employed by EI engineers utilized a flash between vertical flat plates to produce a narrow band of light around the tunnel, which, when photographed and examined on a grid, allows rapid and accurate measurement of actual tunnel dimensions. This information allowed the contractor to optimize his concrete forming and pouring operations.

- Open Pit Ore Pass Design Manual

Client: Spokane Research Center
U. S. Bureau of Mines
Spokane, WA
Contract No: J0205041
EI Project No: 1052

The objective of this contract is to develop a manual for design, construction, and maintenance of vertical and inclined ore pass systems for use in underground haulage from open pit mines. Still in the initial phases of this contract, EI has reviewed the literature pertaining to flow of bulk solids in ore passes and to ore pass systems in use (or formerly in use) at open pit and underground mines. Several mines throughout the United States and Canada have been visited and detailed data on their ore pass systems have been collected. In the next phase, design criteria for the ore passes will be developed based on the theory of the flow of bulk solids, location requirements, and the size and length parameters dictated by the quantity and type of material to be handled. The completed manual will enable mine staff at open pit mines to design ore pass systems and evaluate the feasibility of such systems at their mines.

- Reverse Performance Characteristics of Main Mine Fans

Client: U. S. Bureau of Mines
Pittsburgh, PA
Contract No: J0308044
EI Project No: 1050

Main mine fans are occasionally reversed in emergency situations or to reduce ice build-up in the shaft, but their performance while operating in reverse has never been fully evaluated.

The objectives of this project are to test vane axial type main mine fans in both laboratory and field conditions and compare their performance for moving air in forward and reverse directions. From these data, guidelines for estimating fan performance in the reverse mode will be developed. Still in the initial phases of this project, EI has reviewed literature and other productive sources which are applicable. Fans of 8 feet in diameter are being built and will soon be tested in the laboratory under AMCA specifications. The next phase will be to test fans at eight operating mines and compare these data to laboratory measurements. The work will help mine ventilation engineers and regulatory agencies access ventilation efficiencies.

- Design of Rock Reinforcement and Excavation Methods for TBM Tunnels

Client: Paschen Contractors, Inc.
Chicago, IL
EI Project No: 1049

EI was requested by the contractor on a project driving 32 ft 4 in diameter tunnels by TBM, that are a part of the Chicago TARP system, to investigate the geologic conditions in areas of the tunnel where a faulted zone was indicated and where a branch tunnel is to be driven. EI geologists mapped the rock mass conditions and collected samples of jointed rock for shear testing. Based upon these investigations, EI engineers were able to design rock reinforcement systems that could replace the originally estimated steel arches, allowing the contractor more flexibility in his operations. For the branch tunnel turnout from the main tunnel, EI engineers designed an excavation sequence and rock reinforcement plan that would allow efficient excavation of this difficult geometry of intersecting TBM tunnels.

- Geotechnical Investigations for Longwall Coal Mine Design, Wayne Mine, WV

Client: Cecil V. Peake, Inc.
Bethlehem, PA
EI Project No: 1048

For a planned underground coal mine near East Lynn, WV, operated by Monterey Coal Company, a subsidiary of Exxon, EI engineers and geologists extracted core samples from previously drilled diamond drill holes and re-logged the core for geotechnical data. Also, core was tested for physical properties and joint shear properties which included overlying shales and sandstones, underlying clays and shales, and the coal itself. In the mine, EI field personnel carried out floor bearing capacity tests in various areas of the mine. This information, when combined with the geologic mapping, allowed mine planners to select proper longwall mining equipment and optimize the longwall face layout, location, and operations plan.

- Blasting and Erosion Study,
  Bryce Canyon National Park, Utah

Client: Rocky Mountain Regional Office
National Park Service
Denver, CO
EI Project No: 1047

This project was conducted in response to environmental concerns about the stability of the spectacular erosional features (pinnacles and arches) of Bryce Canyon National Park, due to expected blasts from a proposed coal mine, about 4 miles away. The short duration of the entire project, under 4 months, necessitated immediate mobilization of EI crew and equipment. The remote location of and difficult access to the site obliged the staff to work out of a tent camp, and the fragility of the environment required obtaining permits from the Bureau of Land Management, the Forest Service, and the National Park Service. The program entailed drilling blastholes, and detonating nearly 7 tons of explosives in these holes and on the surface. Pinnacle response was observed by means of suitably located seismographs, including one on top which was 97-ft high. The effects of airblasts, windstorms, and pulling the pinnacle peak by means of a rope, were also noted.

Owing to the rugged nature of the canyon, a suitable test site was located by means of an aerial survey, and a helicopter was used to place the seismograph on the target pinnacle. The pinnacle was also vibrated by means of a mechanical vibration generator transported to the area on a snow cat, and positioned by lowering it 400 ft over a 40° scree slope. The device was capable of producing frequencies of 1 to 10 Hz and 500 lbf when bolted to the pinnacle. This was operated for nearly 100,000 cycles, simulating the anticipated blast vibrations that would be experienced over the life of the mine. Mechanical strain gages were used to monitor crack movements during this shaking test.

The detailed geology of the area was mapped, physical properties of rock cores obtained, and stability analyses performed for the Bryce Canyon features, for both single events and long term vibration exposure. Recommendations for the blasting practices that could be adopted by the mine were formulated.

- Design Guidelines for Improved Water Spray Systems

Client:	Pittsburgh Research Center U. S. Bureau of Mines Pittsburgh, PA
Contract No:	J0308017
EI Project No:	1043

The objective of this study is to prepare design guidelines for spray nozzle installation for various mining applications in both coal and noncoal mines. Typical applications for coal mines include longwall plow, longwall shearer, ripper miner, borer miner, auger miner, and transfer points, and those for noncoal operations are roadheaders/cutting machines, drilling and blasting, slushing/mucking, dumping/transfer points, crushing, cooling, and roadway wetting.

Ten mines were visited to ascertain current practices. Also, domestic and foreign literature was searched to determine what technology is available, and several knowledgeable persons were contacted to obtain information on current designs. A detailed analysis of all this information was conducted to identify applications where improvements in spray technology were most needed. Consideration was given to airborne capture efficiency, wetting of dust on surfaces of broken material, effects of air entrainment, and effect of additives to the water.

Design guidelines were prepared for various mining applications, and new guidelines formulated. These were presented in the form of a manual for use by industry. Recommendations for future research were also presented.

- Collection of Data on Small-Scale Drilling Machines Used in Underground Noncoal Mines

Client: Twin Cities Research Center
U. S. Bureau of Mines
Minneapolis, MN
P. O. No: P3300486
EI Project No: 1042

This project involved collecting data on small-scale percussive drilling machines. The data included both commercial and experimental machines manufactured and/or used in the United States, Sweden, Finland, England, France, Germany, and Japan. Data were collected on hydraulic drills and legs, air-leg drills, and monorail mounted drills. Information obtained was on cost, construction drawings, special features, and field experience. Drilling rates, ease of use, accuracy of hole placement, capital and operating costs, maximum hole diameter and hole length, and productivity were considered. Comments were also included on maintenance, operator acceptance, and other items considered pertinent. A report was prepared which presented all these data.

- Long-Term Load Measuring Instrumentation of Slurry Wall Tiebacks

Client: Board of Education
Chicago, IL
EI Project No: 1041

For the expansion of the Westinghouse Vocational High School within the City of Chicago, which involved a deep basement constructed using slurry wall techniques with high-strength ground anchor tiebacks at the wall base, EI designed and installed several load measuring devices that had to continue to measure accurately loads in excess of 100 tons over 25 years. The installed system consisted of sensitive, rugged electronic load cells with center holes and redundant internal electronics, together with mechanical strain measurement of changes in tieback bar length. The installation of these sensors required standoff collars with access holes, bearing plates, bar extensions, and other items, all expected to continuously perform at high percentages of their yield stress.

- Improved Techniques for Boulder Blasting at the Crusher

Client: Twin Cities Research Center
U. S. Bureau of Mines
Minneapolis, MN
Contract No: J0100007
EI Project No: 1039

The objective of this project is to examine procedures used for blasting of boulders in crushers and grizzlies, study case history examples, present improved technology that can be applied to this area, and make recommendations for safer blasting practice. Still in the initial phase of this project, EI has reviewed all up-to-date state and federal regulations that pertain to boulder blasting and crushers. A critical evaluation is underway as well as a collection of accident data from surface and underground mines in the United States that relate to boulder blasting and crushers. A hazard analysis of each task needed to perform a particular boulder breaking technique will help measure the relative danger of different boulder breaking methods. In the next phase, field trips to mines with various boulder breaking methods will provide considerable input to this study. The economic factors will also be studied in regard to any affects on the small operator.

- Investigation of Problems and Benefits of Underground Multiple Seam Coal Mining

Client:	Pittsburgh Mining Operations U. S. Department of Energy, Bruceton, PA
Contract No:	DE-RP01-79ET14242
EI Project No:	1038

In this project, EI will assess the economic benefits of multiple seam mining as compared to single seam mining under United States conditions. This will involve an assessment of the existing technology in Europe or elsewhere and whether it could be applied under United States conditions. Special emphasis is also being placed on identification of constraints that may have been put on multiple seam mining by state or federal mining regulations and institutional practices. Technologic areas requiring research and development to make multiple seam mining cost effective under United States conditions will be identified, and an estimation will be made of the benefit/cost ratio of developing and transferring such technology to the industry.

For this project, EI geologists will estimate in detail the domestic reserves of coal that could involve multiple seam mining, and EI engineers will visit 40 operating coal mines throughout the country to collect data on the technologic and economic aspects of underground multiple seal coal mining.

- Laboratory Experiments to Determine the Roof Behavior of Auger Mining with Aerostatic Support

Client: Twin Cities Research Center
U. S. Bureau of Mines, Minneapolis, MN
Contract No: J0295060
EI Project No: 1035

A new method of ground support invented by the Bureau of Mines (Patent No. 4,072,015) entitled, "Borehole Aerostatic Ground Support System", will be investigated by EI in the laboratory. The concept involves placing pressurized rubber bladders in the holes resulting from auger mining and bleed the air out in a controlled fashion thus control subsidence. Some preliminary experimental work has been carried out previously by the Bureau of Mines and it is the objective of this program to design and construct a 1/20th scale model of the system in the laboratory and to determine the parameters influencing roof behavior and subsidence control. Numerous models will be constructed, the simulated coal seam extracted by augering, aerostatic supports emplaced, and the deformations will be continuously monitored through several methods. A relationship between the aerostatic support pressure, overburden pressure, hole size and spacing, and coal and rock physical properties is sought to be determined.

- Design of Conveyor Decline and Underground Production Openings, Questa Mine, NM

Client: Molycorp, Inc.
Questa, NM
EI Project No: 1030

This project consisted of the design of the configuration and support requirements for the conveyor decline and underground production openings for the new gravity-feed, block caving, underground molybdenum mine being developed by Molycorp, Inc., a Union Oil subsidiary, at Questa, NM. The work involved logging core and reviewing geologic data, completing an extensive rock materials testing program to determine the characteristics of both the rock material and the rock fracture surfaces to define the rock mass properties of the initially encountered granitic rock, inspecting the 19 ft diameter conveyor decline (ultimately to be more than 6000 ft long at a 17% downgrade) as it is driven, and then designing rock reinforcement and shotcrete stabilization systems using both dry-mix conventional and wet-mix fiber-reinforced shotcrete. Structural steel supports were also designed for expected heavier ground in deeper portions of the tunnel. Investigations were also carried out on the long-term performance of mechanical versus grouted rock reinforcement.

- Consultation on Design of Underground Service Openings, Questa Mine, NM

Client: Stearns-Roger, Inc.
Denver, CO
EI Project No: 1024

For the new gravity-feed, block caving, underground molybdenum mine being developed by Molycorp, Inc., a Union Oil subsidiary, at Questa, NM, EI was retained by the overall designer, Stearns-Roger, Inc., to review geologic conditions and recommend design and support requirements for the service and ventilation shafts and shaft stations, an underground ore loading and storage complex, and a complex decline. This work involved site visits, core logging, and meeting with planners and structural designers to provide for practical long-term utility of the service openings.

- Criteria for Determining When a Body of Surface Water Constitutes a Hazard to Mining

Client: Denver Research Center
Contract No: J0285011
EI Project No: 1021

In past Bureau of Mines and contract work, guidelines have been developed for mining under near-surface bodies of water. However, the guidelines as promulgated in USBM IC 8741, assume that a hazard exists. In this project, EI is determining what relevant factors must enter into such a hazard assumption. Items being considered include reasonable rates of inflow of water into mines, identification of possible water pathways, studying the hydraulic phenomena associated with water flowing through a mine, and investigating the ability of mines to pump and store water. Further work will include the requirements for decision making by regulatory agencies and the preparation of a manual or guidebook for hazard determination.

- Inspection and Rehabilitation Recommendations, Gallery No. 3 Area, Zion - Mt. Carmel Tunnel

Client: Denver Service Center
National Park Service, Denver, CO
P. O. No: PX20008D167
EI Project No: 1019

In September 1978, EI inspected the Zion - Mt. Carmel Tunnel in Zion National Park, Utah. The tunnel was constructed in 1927 as a two-lane highway tunnel 1.1 miles in length. The tunnel was built just inside the face of an 800 ft high vertical cliff of Navajo Sandstone with windows, or galleries, looking out of the tunnel in several places. At one of the galleries the concrete and gunite lining had cracked and steel reinforcement stressmeters indicated steadily increasing load. EI inspected the tunnel condition in this area, examined all construction and repair records, and the instrumentation data. In a comprehensive report to the NPS, the probable causes for the distress were examined, the severity of the cracking discussed, and several alternative repair schemes were outlined. The NPS accepted these recommendations and is initiating a program of detailed tunnel inspection and repair to improve tunnel conditions.

- Evaluation of Air Conditioning Chambers for Prevention of Moisture Induced Disintegration of Shale Roof

Client: Pittsburgh Mining & Safety Research Center
U. S. Bureau of Mines, Pittsburgh, PA
Contract No: J0188028
EI Project No: 1018

The objective of this program was to evaluate and document the effectiveness and feasibility of using air conditioning chambers to reduce and stabilize the humidity level in mine air to control shale roof deterioration and failure. In order to accomplish this, EI compiled an extensive bibliography of reports and papers related to shale deterioration on exposure to the atmosphere. All major coal mine operations using air conditioning chambers were visited and a comprehensive reference on humidity control methods prepared. A mine was selected for investigation in which the effects on the shale roof of humidity, air flow, temperature, and barometric pressure were monitored for conditioned and unconditioned air. The mine roof was systematically examined, mapped, and photographed over a period of about 16 months. The results were analyzed and reported. The cost effectiveness of air conditioning was determined.

Further, EI developed a simple field test that could be performed on roof rock drill cores to ascertain the tendency for the exposed roof to disintegrate with time, estimate the extent of such damage that might occur, and suggest appropriate remedial action. This procedure was verified against actual field conditions.

- Safety and Cost Benefits from Improved Highwall Blasting Practice

Client: Twin Cities Research Center
U. S. Bureau of Mines
Minneapolis, MN
Contract No: H0282011
EI Project No: 1017

The objective of this project was to develop and evaluate a blasting system, using current technology, for overbreak control in contour strip mining that will result in an undamaged stable highwall and properly fragmented overburden. During the course of this project EI reviewed literature and other productive sources for blasting techniques which are applicable with present mining equipment. A number of mines were visited throughout Appalachia and their rock slope stability problems and blasting practices analyzed, from which a mine was selected for blast design testing and analysis. Geologic conditions were closely examined with regard to joint orientation and spacing. Better borehole blasting agent distribution, optimization of burden, spacing, and delay periods allowing minimal backbreak were prime considerations. EI engineers and geologists spent many months in the field working with the mine operator and planning and supervising blasts. A test series of eight blasts with the highwall were monitored by repetitive photography. Measurements of block falls indicated that successful results were achieved. A study of drilling/blasting economics, and equipment performance, led to an economic model of blast parameters and the indentification of blast design cost benefits.

6.0 PERSONNEL

Engineers International, Inc. have adequate professional staff to undertake this program. Immediate assignments can be made during the time frame of this project. No new hiring is anticipated at this time.

The key individuals indicated in the Project Team are definitely committed to this program. The assignment of junior staff, however, must be regarded as tentative. The reasons for this circumstance are:

- EI, as a matter of policy, does not maintain surplus personnel from which to staff new projects as they are awarded.
- Our operating practice, which has been very successfully applied in the past, is to assign the best qualified person on our staff according to program requirements and individual capability. If a replacement is required because of project demands, the person employed would have training and skills comparable to those of the person originally scheduled.

Due to the nature and timing of projects and to the timing requirements of personnel on specific programs, it is our policy to often assign a single individual to more than one project at a time. Additions or deletions to a program personnel complement are made progressively according to the needs of the specific program. Our past experience has demonstrated that only on occasion does this practice interfere with or delay projects while, on the other hand, it does contribute significantly to the minimization of project costs and maximizes the involvement of the best suited individuals.

The assignment of all personnel can be more specifically discussed with the sponsor and confirmed prior to contract award, if so desired.

6.1 RESUMES OF EI STAFF

FRANCIS S. KENDORSKI
Engineering Manager,
Mining & Tunneling

EXPERIENCE

Mr. Kendorski has gained much valuable experience as an engineer in site investigation, design, and construction on projects in tunneling, mining, dams, and rock excavations throughout the United States and in Papua New Guinea, in environments ranging from hardrock to cavernous limestone to rock salt to soil.

1977-Present: Engineers International, Inc., Downers Grove, IL.
Engineering Manager, Mining & Tunneling: Manages projects in applied rock engineering, with particular reference to ground control, rock reinforcement, rock excavation, blasting, and underground design. Project Manager for the investigation and design of twin 40 ft diameter highway tunnels at Beavertail Mountain, Colorado, and the 41 ft diameter tunnel and shaft for Rocky Mountain Pumped Storage Project, Georgia. Managed the field investigation and design requirements for a dynamically loaded avalanche protection structure in Colorado. Also Project Manager on a study of the effect of blasting vibrations on the erosional rock features at Bryce Canyon National Park, Utah, which involved helicopter supported test blasting and vibration and fatigue measurements.

Projects Manager for research, development, and demonstration projects for innovative roof bolts, production blasting to improve slope stability, safer secondary blasting, ore pass design, block caving drift support design, main and auxiliary mine fan performance mining beneath surface waters, and others. Consultant to the National Park Service on Rehabilitation of the Highway tunnel in Zion National Park, Utah, and on the design of underground service openings for the new underground block caving mine at Questa, New Mexico. Consultant to tunneling contractors on excavation and support methods for both drill and blast and TBM tunnels.

1973-1977: Leeds, Hill and Jewett, Inc., San Francisco, CA.
Senior Staff Engineer: Project Engineer for the design and construction consultation for the 45 ft diameter Second Bore of the Eisenhower Memorial (Straight Creek) Tunnel in Colorado. Also Project Engineer on cavability and ore fragmentation of the Questa Molybdenum Deposit in New Mexico. Project Engineer on the investigation, inspection, or repair of several tunnels, dam sites, and underground powerhouse for projects in the western USA and Papua New Guinea.

1971-1973: Climax Molybdenum Company, Climax, CO.
Geological Engineer: Engaged in the design and monitoring of rock slopes and underground support systems, and studying the effectiveness of shotcrete.

1970-1971: U. S. Bureau of Mines, Tucson, AZ, and Denver, CO.
Mining Engieer: Researched rock mass properties and rock fracture mapping techniques at the San Manuel Copper Mine in Arizona.

FRANCIS S. KENDORSKI (cont.)

1969-1971: University of Arizona, Tucson, AZ.
Graduate Research Assistant: Duties included rock strength testing and research into tunnel engineering prediction techniques.

Summer 1969: Belle Isle Salt Mine, Cargill, Inc., Franklin, LA.
Assistant Mine Engineer: Helped in various underground engineering functions and organized a complete volume survey of the mine.

Summer 1967: Friedensville Zinc Mine, New Jersey Zinc Co.,
Center Valley, PA.
Underground Miner: Gained firsthand experience in all phases of excavation and support of an active underground operation.

EDUCATION

MS (Geological Engineering) - University of Arizona, Tucson, 1971.

BS (Mining Engineering) - South Dakota School of Mines and Technology, Rapid City, SD, 1969.

Short Courses in Underground Mine Safety, 1971, 1972; Blasting and Explosives Safety, 1975; Reinforced Concrete Design, 1976; Coal Mining Productivity, 1979; Probabilistic Methods in Rock Engineering, 1981. Certification for Mine Safety Training by MSHA for Surface and Underground, Coal, Metal, and Nonmetal Mining, 1980.

REGISTRATION

Professional Civil Engineer, California, No. C-27994, 1977.
Professional Engineer, Illinois, No. 62-36080, 1977.
Professional Engineer, Colorado, No. 16531, 1979.
Professional Engineer, Georgia, No. 12616, 1981.

PROFESSIONAL SOCIETIES AND TECHNICAL COMMITTEES

Society of Mining Engineers of AIME.
Society of Explosives Engineers.
Colorado Mining Association.
Geological Society of America.
Association of Engineering Geologists.
International Society for Rock Mechanics
American Concrete Institute
U. S. National Committee for Rock Mechanics
Geomechanics Unit Committee, SME/AIME, Chairman.
AIME Rock Mechanics Award Committee.
Underground Construction Research Council, Task Committee on Blasting, 1977-1978.

PUBLICATIONS

Authored 29 technical papers on underground mine and tunnel design, rock properties, and blasting.

FRANCIS S. KENDORSKI
PUBLICATIONS

1. Influence of Jointing on Engineering Properties of San Manuel Mine Rock, Unpub. MS Thesis, University of Arizona, 1971, 126 p.

2. "Tunnel Advance Rate Prediction Based on Geologic and Engineering Observations," with W. D. Gentry and J. F. Abel, Jr., International Journal of Rock Mechanics and Mining Sciences, 1971, v 8, p 451-475.

3. "Analysis of the Geometry of Fractures in San Manuel Copper Mine, Arizona," with M. A. Mahtab and D. D. Bolstad, US BuMines, Report of Investigations 7715, 1973, 24 p.

4. "Outline of Fracture Geology of the Climax Area," presented at the Ninth Annual Intermountain Minerals Conference, Vail, Colorado, August 1973, Intermountain Section, AIME.

5. "Effect of Blasting on Shotcrete Drift Linings," with C. V. Jude and W. M. Duncan, Mining Engineering, 1973, v 25, n 12, p 38-41.

6. "Applied Rock Mechanics at Climax," in Applications of Rock Mechanics, Proceedings of the Fifteenth Symposium on Rock Mechanics, New York, 1975, p 639-647.

7. "Performance of Shotcrete Linings at the Climax Mine," with R. K. Towner, in Proceedings of the Second North American Rapid Excavation and Tunneling Conference, San Francisco, New York, AIME, 1974, p 1013-1026.

8. "Some Design and Construction Considerations for Large Permanent Underground Openings at Shallow Depths," with T. L. Brekke and T. A. Lang, in Proceedings of the Third Congress of the International Society for Rock Mechanics, Washington, National Academy of Sciences, 1974, v IB, p 1507-1517.

9. "Fracture Patterns and Anisotrophy of San Manuel Quartz Monzonite," with M. A. Mahtab, Bulletin of the Association of Engineering Geologists, 1976, v 13, n 1, p 23-52.

10. "Caving Operations Drift Support Design," in Design Methods in Rock Mechanics, Proceedings of the Sixteenth Symposium on Rock Mechanics, New York, ASCE, 1977, p 277-286. Being Reprinted by SME/AIME for Underground Mining Handbook, in press.

11. "Engineering Inspection and Appraisal of Rock Tunnels," with J. A. Bischoff, in Proceedings of the 1976 North American Rapid Excavation and Tunneling Conference, Las Vegas, New York, AIME, 1976, p 81-99.

12. "Effect of Rapid Water Pressure Fluctuations on Unlined Water Tunnel Stability," with T. A. Lang and K. S. Chawla, in Proceedings of the 1976 North American Rapid Excavation and Tunneling Conference, Las Vegas, New York, AIME, 1976, p 417-429.

13. "The Cavability of Ore Deposits," Mining Engineering, June, 1978, v 30, n 6, p 628-631. Being Reprinted by SME/AIME for Underground Mining Handbook, in press.

14. "Development and Testing of Self-Drilling Roof Bolts," with M. M. Singh and R. P. Curtin, in Proceedings of the 1979 North American Rapid Excavation and Tunneling Conference, Atlanta, New York, AIME, p 635-655. (Synopsis in Tunnels and Tunnelling, v 11, n 8, Oct. 1979, p 39.)

15. "Development and Testing of Self-Drilling Roof Bolts," with S. D. Singh and M. M. Singh, US BuMines Report on Contract No. H0272022, (EI Rept 1014) August 1979, 225 p.

16. "Criteria for Determining When a Body of Surface Water Constitutes a Hazard to Mining," with I. Khosla and M. M. Singh, US BuMines Report on Contract No. J0285011, (EI Rept 1021) August 1979.

17. "Field and Laboratory Assessment of Rock Mass Strength for Tunnel Design with Allowance for Dilation," in Proceedings of the Thirteenth Canadian Rock Mechanics Symposium, CIM Special Volume 22, Montreal, P 162-167.

18. "Geomechanical Assessment of a TBM Excavated Tunnel in Carbonate Rock," with D. R. Bassarab and B. L. McCormick, presented at 23rd Annual Meeting Association of Engineer-Geologists, Dallas, TX, October 1980.

19. "Blasting Procedures for Improved Highwall Safety and Cost," with M. F. Dunn, presented at Seventh Kentucky Blasting Conference, Lexington, KY, December 1980.

20. "Safety and Cost Benefits from Improved Highwall Blasting Practice." with M. F. Dunn, presented at 110th AIME Annual Meeting, Chicago, IL, February 1981.

21. "Safety and Cost Benefits from Improved Highwall Blasting Practice," with M. F. Dunn, US BuMines Report on Contract No. H0282011, (EI Rept 1017) February 1981, 167p.

22. "Response of Rock Pinnacles to Blasting Vibrations," with C. D. Dowding, submitted for publication to International Journal of Rock Mechanics and Mining Sciences.

23. "Inspection of an Old Concrete Lined Tunnel for a New Tunnel Design," with D. F. Hambley, in preparation.

24. "Crusher Safety," with M. F. Dunn and L. R. Fletcher, in preparation.

25. "Blasting Practices for Improved Coal Strip Mine Highwall Safety and Cost," with M. F. Dunn, *Third International Conference on Stability in Surface Mining*, Vancouver, B. C., Canada, 1981.

26. "Field Study of the Blasting Vibration Stability of Large Natural Rock Pinnacles," with R. A. Cummings and C. H. Dowding, submitted to *1982 Conference on Explosives and Blasting Techniques*, Society of Explosives Engineers.

27. "Strata Disturbance Prediction for Mining Beneath Surface Water and Waste Impoundments," with M. M. Singh, *presented at the Conference on Ground Control in Mining*, Morgantown, WV, July 1981.

28. "Case Histories of Tunnel Distress and Failure from Non-Application of Soil and Rock Mechanics Principles," in preparation.

29. "A Comparison of Different Finite Element Methods in a Practical Coal Mine Rock Mechanics Problem," with S. Bhattacharya, *17th Annual International Symposium on Computer Applications in the Mineral Industry*, April 1982.

LEIF G. ERIKSSON
Staff Consultant

EXPERIENCE

Mr. Eriksson has extensive experience in the analysis and design of underground facilities, especially those for nuclear waste repositories and oil storage in North America, Europe, Asia, and Africa.

1981-Present: Engineers International, Inc., Downers Grove, IL.
Assistant Project Manager: Provides technical assistance and consulting on projects in underground construction, geological investigations, and research.

1978-1981: AB Engineering Geology, Stockholm, Sweden.
Managing Director: Special assignment to Lawrence Berkeley Laboratory (LBL) Earth Sciences Division. Technical assistance to LBL preparing two reports for the Nuclear Regulatory Commission on "Geologic Site Characterization for Nuclear Waste Disposal in Basalt," and "Reconnaissance Inspections and Assessments of Underground Openings for In Situ Test Facilities in Crystalline Rock." Special assignment to Rockwell Hanford Operations as Resident Consultant at the Near Surface Test Facility at the Hanford Reservation on construction procedures, test programs, facility safety and maintenance, test layouts and investigation techniques. The facility was constructed for test purposes to qualify basalt as a candidate geological media for storage of High Level Radioactive Waste. Special assignment to Dames & Moore as Senior Engineer Underground Space and Storage. Principal Investigator of Rock Salt Mines, Geotechnical Site Evaluation Studies for Underground Radioactive Waste Test Facilities, Battelle Memorial Institute/Office of Nuclear Waste Isolation. Moderator Group V Hard Rock Formations: Thermal analyses and Rock Mechanics, NWTS In-Situ Test Needs Workshop, Battelle Memorial Institute/Office of Nuclear Waste Isolation. Project Manager and Principal Investigator of Sudden Outbursts Phenomena in the Weeks Island Salt Mine, Phase I, Morton Salt Company. Reviewer of Proposed Solution for Permanent Sealing of a High Level Radioactive Waste Repository in Sweden, Swedish Ministry of Industry.

1965-1978: HAGCONSULT AB, Stockholm, Sweden.
Project Manager, Underground Energy Storages, and Office Manager, United Kingdom Branch Office: Preparation of hydrogeological models and studies for energy and radioactive waste storage including pumped compressed air and liquid hydrocarbon storage projects for the Swedish State Power Board. Project Manager-Principal Investigator of Basalt formations, Geotechnical and Hydrological Site Evaluation Studies for Underground Oil Storage Facility, Landsverks Frudingorin, Farao Island, Denmark. Principal Investigator of geological and hydrological conditions at 4 different areas for underground storage of irrigation water in Libya, Skanska/Libyan Agriculture Department. Impartial engineering geological evaluations in construction disputes for storage facilities in Finland (Granite), and France (Chalk), for a nuclear power plant foundation and an oil storage excavation, respectively, ABV and Skanska. Project Manager Off-Shore investigations for foundation of V.L.C.C. jetties, Zetland County Council, U.K. Project Manager Engineering Geological Site Investigations for 1.5 million m^3 underground hydrocarbon storage in poor granite rock (mainly granodiorite). Responsible for investigation

LEIF G. ERIKSSON (cont.)

systems; reports and recommendations for the preliminary layout and civil engineering construction and excavation works, B.P./Sullom Voe Association, U.K. Supervisor Geophysical Investigations for 3.8 million m^3 underground hydrocarbon storage in sandstone, SENTAB/Cromarty Petroleum Ltd., Scotland. Project Manager Engineering Geological Site Investigations for 0.5 million m^3 underground hydrocarbon storage calcareous schist. Reconnaissance investigations at 3 other locations in Italy in diabase, dolomite, calcareous sandstone and micaceous shales. Responsible for engineering geological; hydrogeological reports, and civil engineering construction and excavation recommendations, SENTAB/SNAM, Italy. Site Manager Geotechnical and Hydrogeological Investigations for construction of pile walls and foundations of warehouse PRIOR II. Consultant for the foundation and supervisor for anchoring of pile walls, reinforcement of adjacent buildings and hydrogeological observations and evaluations during excavation, ABV/Strohexport, Czechoslovakia. Supervisor Geological and Hydrogeological investigations for 1.0 million m^3 underground hydrocarbon storage in volcanic rocks (i.e., ignimbrite and granitic rock types) in Hong Kong, SENTAB/ Shell den Hague. Site Manager Geological and Hydrogeological Investigation for 0.3 million m^3 underground hydrocarbon storage in Mica schist, SENTAB/B.P., Scotland. Site Manager at investigations and civil engineering for construction works for foundations in soil, rock and underground installations. Developing different inspection, maintenance and repair techniques for underground installations, Off-shore drilling techniques, equipment and systems. Research and development of the In-Situ anchorage system, investigation equipment and shotcrete and grouting techniques. Site Manager Geotechnical Investigation for the new Parliament Building, Stockholm, Byggledare AB. Site Manager for investigation and construction of 600 In-Situ anchors for the underground transport system in Solna and 800 In-Situ anchors for the foundation of Tegelbacken, Vägbolaget.

1973-1974: The Stockholm University, Stockholm, Sweden.
Lectures in methods, equipment and systems for different investigations in soil and rock for students of geology.

1963-1965: The Essinge Bridges Consortium, Stockholm, Sweden.
Foreman on construction of free suspending bridges and connecting viaducts.

1960-1963: Stockholm City Municipal Services Department,
Stockholm, Sweden.
Surveyor and Assistant Supervisor on road construction, sewage systems, excavation works and reinforced concrete works.

EDUCATION

M.A. & Sc. (Geology) - The Stockholm University, Stockholm, Sweden, 1975.

BS (Civil Engineering) - Technical High School in Sweden, Stockholm, Sweden, 1960.

LEIF G. ERIKSSON (cont.)

Short Courses in Hydrology, The Upsala Univ., Upsala, Sweden, 1969. Advanced Concrete Technology, Swedish Cement and Concrete Research Institute at the Royal Institute of Technology in Stockholm, Sweden, 1970. Soil Mechanics for Postgraduates, Royal Institute of Technology in Stockholm, Sweden, 1973.

PROFESSIONAL SOCIETIES AND TECHNICAL COMMITTEES

Society of Mining Engineers of AIME.
ASCE/AIME Underground Technology Research Council, Committee on Deep Underground Space.
Swedish Society of Civil Engineers.
Geological Society of Sweden.
Swedish Society of Engineering Geology.
International Society for Rock Mechanics.
International Association of Engineering Geology.
American Underground-Space Association.

MICHAEL F. DUNN
Senior Mining Engineer

EXPERIENCE

1978-Present: Engineers International, Inc., Downers Grove, IL.
Senior Mining Engineer: As a mining engineer with considerable industrial experience in both underground and surface mining, Mr. Dunn is actively involved in several blasting projects which include the demonstration of improved blasting techniques in contour strip mining of coal, and improved techniques for boulder blasting in crushers. Both projects required visits to mines in Appalachia and elsewhere in order to make detailed studies of mining and blasting practices including cost/benefit studies of alternative blasting techniques. The work requires considerable direct contact and coordination with the mining operators. Mr. Dunn is also investigating problems and benefits of underground multiple seam coal mining in the United States, which requires mine design and economic evaluaion. With a strong industrial background, Mr. Dunn is carrying out projects dealing with the performance of both main fans and auxiliary fans in metal and nonmetal mining. These two projects require extensive field investigations of fan characteristics and ventilation methods at operating mines throughout the country. For EI tunnel design projects, he has worked out detailed excavation and rock reinforcement plans for use by contractors.

1975-1978: Warner Company, Bellefont, PA.
Mine Engineer: All work involved with a sublevel open stoping method in underground limestone mining. Designed structural work necessary to the mine operation including a shaft collar extension, settling pond bulkheads, and fan installations. Participated in planning for the changeover to a gassy mine classification. Performed general engineering duties associated with mine operations such as ventilation checks, mine surveying, and map revisions. Obtained supervisory experience as a licensed mine foreman in charge of stope development crews.

1974-1975: Morrison-Knudsen Company, Inc., Boise, ID.
Mining Engineer: Area leader involved with the Kemmerer Coal Project, Kemmerer, Wyoming. This included dragline studies involving production capabilities, boom and bucket sizing, pit planning, volumetrics, and project reporting. This offered exposure to Northwestern open pit and strip coal mining techniques and problems.

1973-1974: Standard Industries, Inc., Tulsa, OK.
Plant Engineer: Responsible for safety program and administration, dust control, and general engineering work associated with limestone quarry operation.

Summer 1971: Old Ben Coal Company, Benton, IL.
Industrial Engineer's Aid: Carried out time studies of equipment operations of other necessary functions in an underground coal mine which utilized continuous mining in a room and pillar method.

MICHAEL F. DUNN (continued)

EDUCATION

BS (Mining Engineering) University of Missouri, Rolla, MO, 1972.

REGISTRATION

Engineer-In-Training, Missouri (No. 18410-E), 1972.
Authorized Mine Foreman (Mines other than coal), Pennsylvania, No. DMS-MF-003) 1976.
Certification for Mine Safety Training by MSHA for Surface and Underground, Coal, Metal and Nonmetal Mining (1980).

PROFESSIONAL SOCIETIES

Society of Mining Engineers of AIME.

MICHAEL F. DUNN
PUBLICATIONS

"Blasting Practices for Improved Coal Strip Mine Highwall Safety and Costs" (with F. S. Kendorski), 3rd International Conference on Stability in Surface Mining, Vancouver, British Columbia, Canada, June 1981.

"Safety and Cost Benefits from Improved Highwall Blasting Practice" (with F. S. Kendorski), US BuMines Rept. (under Contract No. H0282011), Feb. 1981, 169 pp.

"Boulder Handling and Blasting for Greater Safety and Efficiency in Crushers" (with F. S. Kendorski), US BuMines Rept. (in preparation under Contract No. J0100007).

"Investigation of Problems and Benefits of Underground Multiple Seam Coal Mining" (with M. M. Singh), Dept. of Energy Rept. (in preparation under Contract No. DE-AC01-79ET14242).

MADAN M. SINGH
President

EXPERIENCE

Dr. Singh has 25 years of experience in mining, tunneling, and applied rock mechanics and has been involved in projects encompassing mining methods, rock reinforcement, subsidence, safety, mine ventilation, reclamation, equipment development, evaluation of new technology, drilling mechanics, and geotechnical engineering. He has contributed to the coal, metal, nonmetal, and tunneling industries. He has authored over 70 technical publications, has lectured extensively in the USA and abroad, and is active in professional activities. He was elected to the U. S. National Committee on Rock Mechanics (1977-80) and has served on the U. S. National Committee on Tunneling Technology (1974-76). In 1958 he won the Graduate Paper Contest of SME-AIME, and in 1978 he was presented the Distinguished Alumnus Award by the Indian School of Mines and Applied Geology. He has chaired 4 national conferences and has visited mining operations in UK, West Germany, France, Belgium, Holland, and India. He is listed in Who's Who in the Midwest, American Men and Women of Science, and several other biographical compendia.

1975-Present: Engineers International, Inc., Downers Grove, IL.
Responsible for all activities of the corporation, including the firm's consulting, design, and research assignments. Personally managed several industrial and government contracts. Consulted on longwall mine design; subsurface exploration; shaft-tunnel intersection and chamber design; sewer tunnel and building foundation investigations; monorail bridge conveyor; geothermal/geopressure energy. Projects included economics of new tunneling methods; multiple seam mining; single-entry longwall; aerostatic supports for auger mining; roof bolt tension indicators; inclined bolts; self-drilling roof bolts; haulage patents; control of shale deterioration; water sprays for dust control; cost-effectiveness of changes in mine ventilation.

1974-1975: Foundation Sciences, Inc., Lombard, IL.
Vice President: Provided design support for 40 miles of tunnels and 120 shafts in the Metropolitan Chicago area. Investigated inclined roof bolt installation in coal mines.

1966-1974: IIT Research Institute, Chicago, IL
Manager, Soil and Rock Mechanics (1968-1974): Consulted on new salt mine development. Managed contracts for Bureau of Mines, Dept. of Transportation, Dept. of Defense, and National Science Foundation. Contributed toward transfer of NASA technology to mine problems. Projects included safety in metal and nonmetal mines; feasibility of pneumatic stowing; water jet mining and tunneling; shotcrete design; determination of in-situ stresses in soils; hypervelocity pellet impact; dynamic response of soil/concrete interfaces to high pressures; stresses in tunnel liners; utilization of water sludge.

Madan M. Singh (continued)

Senior Research Engineer (1966-1968): Investigated novel methods of roof bolting, lunar drill bit and conveying mechanism, photoelastic transducers for solution mining. Taught PERT/CPM to construction personnel.

1963-1966: Pennsylvania State Univ., University Park, PA.
Director, Rock Mechanics Laboratory and Assistant Professor of Mining Engineering: Evaluated coal deposits in the Kaiparowits Plateau. Studied mine subsidence; microseismic activity; an- elastic phenomena in rock; drilling; gas storage reservoir design.

1961-1963: Gulf Research and Development Co., Harmarville, PA.
Research Engineer: Rock mechanics and drilling research, including water jet assisted drillbit design.

EDUCATION

PhD (Mining Engineering) - Pennsylvania State University, University Park, PA, 1961

MS (Mining Engineering) - Univ. of Illinois, Urbana, IL, 1957

AISM (Mining Engineering) - Indian School of Mines and Applied Geology, Dhanbad, India, 1956
Advanced Drilling Engineering Course - Texas A&M University, College Station, TX, 1961
Shallow Foundation Design, Including Structural Design of Footings - University of Missouri at Rolla, Rolla, MO, 1977
In-Situ Energy Recovery Technology - University of New Mexico, Albuquerque, NM, 1978
Current Developments in Rock Engineering - Massachusetts Institute of Technology, Cambridge, MA, 1978

REGISTRATION

Professional Engineer, Pennsylvania, No. PE 011733E, 1966;
Illinois, No. 62-27134, 1967.

PROFESSIONAL SOCIETIES

Society of Mining Engineers of AIME.
American Society of Civil Engineers.
International Society of Rock Mechanics.
American Underground Association.
American Arbitration Association.
British Tunnelling Society.
Society of Petroleum Engineers of AIME.
American Society for Testing and Materials.
Pittsburgh Coal Mining Institute of America.
Illinois Mining Institute.
American Association for the Advancement of Science.
Society of Sigma Xi.

MADAN M. SINGH
PUBLICATIONS

1. "The International Classification of Coal," MS Thesis, U of Illinois, Urbana, IL, Oct 1957, 128 p.

2. "Slim Holes, Large Holes, Air Drilling and Drilling In Unconsolidated Materials," Proc Ninth Ann Drill Symp, Penn State U, Min Ind Expt Stn Bull 72, 1960, p 123-124.

3. "Mechanism of Rock Failure Under Impact of Chisel-Shaped Bit," PhD Thesis, Penn State U, University Park, Jan 1961, 149 p.

4. "Hypothesis for the Mechanism of Rock Failure under Impact," (with H.L. Hartman), Proc Fourth Symp On Rock Mech, Penn State U, Min Ind Expt Stn Bull 72, 1961, p 221-228.

5. "Progress in Coal Testing," (with R. G. Wuerker and N. Chakraverty), U of Illinois, Eng Expt Stn Tech Rept n 1, 1962, 43 p.

6. "Interpretation of Transient Strain Pulses Recorded in Rock Under Impact of a Chisel-Shaped Bit," (With H.L. Hartmen), Trans AIME, v 225, 1962, p 283-289. Also Soc Petr Engrs Jour (AIME), v 2, n 3, Sep 1962, p 283-289.

7. "Rock Mechanics: Its Scope and Potential," Mineral Industries, Penn State U., v 33, n 5, Feb 1964, p 1, 3-8, n 6. Mar. 1964, p 7-8; n 7, Apr 1964, p 8.

8. "Mechanism of Drilling Wells with Air as the Drilling Fluid," (with R. J. Goodwin), Proc Second Conf on Drill and Rock Mech, U of Texas, Austin, TX; Soc. Petr. Engrs. (AIME), Pre-print SPE 1052, Jan 1965, 31 p.

9. "Stress Distribution at the Bottom of a Borehole by a Numerical Method," (with Y.J. Wang and H. L. Hartman), Proc Seventh Symp on Rock Mech, Penn State U, v 1, Jun 1965, p 89-118.

10. "Photoelastic Devices for Mining," (with J. M. Mutmansky), Eng and Mng Jour, v 166, n 12, Dec 1965, p 87-94.

11. "Stress Distribution at the Bottom of a Borehole by a Numerical Method," (with Y. J. Wang and H. L. Hartman), Trans AIME, v 235, Tech Note, Mar 1966, p 31-34.

12. "Excavating with Nuclear Explosives," (with T. J. O'Neil, Mng and Min Eng, v 2, n 2, Feb 1966, p 26-70; n 3, Mar 1966, p 97-104.

13. "An Investigation of Microseismic Activity in Rocks under Tension," (with J. W. Brown), Trans AIME, v 235, 1966, p 255-265.

MADAN M. SINGH
PUBLICATIONS (cont.)

14. "Optimization of Gas Storage Pressures in Reservoirs," Proc Amer Gas Assoc Transmission Conf, Dallas, TX, May 9-10, 1966, 17 p.

15. "A Numerical Method for the Determination of Stresses Around Underground Openings," (with Y. J. Wang), Proc First Intl Cong Rock Mech, Lisbon, Portugal, Sep 25-30, 1966, v 2, p 363-373.

16. "Mechanical Stress Problems in Underground Gas Storage," Proc Fifth Ann Conf Ontario Petr Inst, Chatham, Ontario, Canada, No. 1-4, 1966, Tech Sess 4, Paper 14, 16 p.

17. "Rock Mechanics: An Emerging Science," Frontier, IIT Research Institute, Chicago, IL, v 28, n 1, Spring 1967, p 14-19.

18. "Lateral Extensometer for Brittle Materials," (with Y.S. Kim), Rev of Sci Instr, Amer Inst Phys, v 38, n 6, Jun 1967, p 769-771.

19. "What to Consider in Selecting Rock Bits," Eng and Mng Jour, v 168, n 6, Jun 1967, p 165-172.

20. "Design of Roof Bolt Installations in Stratified Deposits," (with Y. P. Chugh), Soc Mng Engrs (AIME) Preprint 67F24, Ann Mtg, Los Angeles, CA, Feb 19-23, 1967, 28 p.

21. "A Statistical Study of Relationships Between Rock Properties," (with J. M. Mutmansky), Proc Ninth Symp Rock Mech, Golden, CO, Apr 17-19, 1967, p 161-177.

22. "Static and Dynamic Failure of Rock Under Chisel Loads," (with A.M. Johnson), Soc Mng Engrs (AIME), Preprint SPE 1047, p 49-58. Also Trans AIME, v 238, 1967, p 366-373.

23. "Design of Roof Bolt Installations," (with Y.P. Chugh), Mng and Min Eng, v 4, n 3, Mar 1968, p 98-104.

24. "Brittle Failure of Rock," Proc Materials Conf, Amer Inst Chem Engrs, Philadelphia, PA, Mar 31 - Apr 4, 1968, Preprint 6A, 41 p.

25. "Fluid Impact Using Light Gas Gun Techniques," Proc Fluids Eng Conf, Amer Soc Mech Engrs, Philadelphia, PA, May 6-9, 1968, 10 p.

26. "Rock Breakage by Light Gas Gun Projectiles," (With V. G. Gregson, Jr.) Office of High Speed Ground Transportation, Dept of Trans Rept (on Contract DOT 3-0171), Jan 22, 1969, 120 p, PB 184 191.

MADAN M. SINGH
PUBLICATIONS (cont)

27. "Novel Methods of Rock Breakage," Proc Second Symp Rapid Excavation, Sacramento State College, Sacramento, CA, Oct 16-17, 1969, p 4-1 to 4-27.

28. "Rock Breakage by Pellet Impact," Office of High Speed Ground Transportation, Dept of Trans Rept FRA-RT-70-29 (on Contract DOT 3-0171), Dec 24, 1969, 48 p., PB 190 965.

29. "Rock Fracture by High Speed Water Jet," (with P. J. Huck), Office of High Speed Ground Transportation, Dept. of Trans. Rept. FRA-RT-71-58 (on Contract FR-9-0031), Dec., 1969, 85 p.

30. "Experimental Investigation of Small Scale Lined and Unlined Cylindrical Cavities in Rock," (with I.M. Daniel and R. E. Rowlands), Air Force Weapons Lab. Rept AFWL-TR-70-55, Mar 1970, 339 p.

31. "Rock Breakage by High-Speed Impact," Proc Second Intl Cong Rock Mech, Belgrade, Yugoslavia, Sep 21-26, 1970.

32. "Rock Breakage By High Velocity Water Jets," (with P. J. Huck) Soc Mng Engrs (AIME), Fall Mtg, St. Louis, MO, Oct 21-23, 1970, 14 p.

33. "Correlation of Rock Properties to Damage Effected by Water Jet," (with P. J. Huck), Proc Twelfth Symp Rock Mech, U of Missouri at Rolla, Rolla, MO, Nov 16-18, 1970, p 681-695.

34. "Effect of Specimen Size on Rock Properties," (with P. J. Huck), Soc Petr Engrs. (AIME), Preprint SPE 3528, 46th Ann. Fall Mtg, New Orleans, LA, Oct 3-6, 1971, 12 p.

35. "Feasibility of Pneumatic Stowing for Ground Control in Coal Mines," (with W. J. Courtney), U. S. Bur Mines Rept. on Contract HO210057, (IITRI Rept D6068), Jan 1972, 128 p.

36. "Rock Breakage by High Pressure Water Jets," (with L. A. Finlayson and P. J. Huck), Proc First Intl Symp Jet Cutting Tech, Coventry, England, Apr 5-7, 1972, p B8-113 to B8-124.

37. "Owner-Engineer-Contractor Relations in Tunneling," (with H. Sutcliffe and G. B. Wallace), Proc Rapid Excavation and Tunneling Conf, AIME, New York, NY, Chpt 43, p 797-800.

38. "Large Scale Triaxial Tests on Rock," (with P. J. Huck), Proc Fourteenth Symp on Rock Mech, (New Horizons in Rock Mechanics), New York, NY, ASCE, 1972, p 35-60.

39. "The Energy Crisis - Fact or Fiction?" Proc Nat'l Symp on the Future Status of Earth Resources, Chicago, IL, Mar 23-25, 1973, 24 p.

MADAN M. SINGH
PUBLICATIONS (cont)

40. "Use of Special Cements in Shotcrete," (with S. A. Bortz), Use of Shotcrete for Underground Structural Support, Proc Eng Fdn Conf, Jul 16-20, 197, Amer Concrete Inst Publication Sp-45, 1974, p 200-231.

41. "Coal Mining Using High Pressure Water Jets," (with T. J. Labus and L. A. Finalyson), US BuMines Rept Contract H0111789, (IITRI Rept. D6062), Oct 1973, 81 p.

42. "Soil Mechanics, Applications of," Encyclopedia Britannica, U. of Chicago Press, Chicago, IL, 15 ed, 1974, p 1011-1014.

43. "IITRI Hydraulic Jet Coal Miner," Coal Mng and Processing, v 11, n 1, Jan 1974, p 66.

44. "Pneumatic Stowing in Coal Mines," (with W. J. Courtney), Coal Mng and Processing, v 11, n 2, Feb 1974.

45. "Design of a Hydraulic Jet Coal Miner," (with T. J. Labus), Rept on Contract H0133119, (IITRI Report D6088), Feb 1974, 104 p, PB 243 733/AS.

46. Feasibility of Pneumatic Stowing in United States Coal Mines," (with W. J. Courtney), AIME, v 258, 1975, p 232-239, (Preprint Soc Mng Engr 74-AR-38, Feb 1974, 32 p).

47. "Statistics on Accidents in the Noncoal Mining Industry in the United States," (with Y. P. Chugh and J. Church), Soc Mng Engrs (AIME), Ann Mtg, Dallas, TX, Feb 23-28, 1974, 36 p.

48. "Dynamic Repsonse of Soil/Concrete Interfaces at High Pressure," (with P. J. Huck, T. Liber, R. L. Chiapetta, and TR-73-264, Kirtland AFB, NM, (on Contract F29601-73-C-0020), (IITRI Rept D6076) Apr 1974, 290 p.

49. "Field Testing of Water Jets for Coal Breakage," (with T. J. Labus and L. A. Finalyson), Proc Second Intl Symp on Jet Cutting Technology, Cambridge, England, Apr 2-4, 1974, 25 p.

50. "A Study of Accidents in Metal and Nonmetal Mines," (with Y. P. Chugh, D. W. Kos and G. R. Schottler), Lake Superior Mines Safety Council Ann Conf, Duluth, MN, May 9-10, 1974, 24 p.

51. "Measurement of In-Situ Stress in Soils," (with P. J. Huck) Subsurface Excavation and Heavy Construction, Proc Eng Fdn Conf, Henniker, NH, Aug 11-16, 1974, p 269-294.

52. "What's Ahead in Subsurface Exploration," Subsurface Exploration for Underground Excavation and Heavy Construction, Proc Eng Fdn Conf, Henniker, NH, Aug 11-16, 1974, p 387-393.

MADAN M. SINGH
PUBLICATIONS (cont)

53. "Determination of the In-Situ State of Stress in Soil Masses," (with P. J. Huck, H. J. Pincus and Y. P. Chugh), US Dept of Transportation Rept FHWA-RD-74-68 (on Contract DOT-FR-11-802), Sep 1974, 316 p.

54. "Metallic and Nonmetallic Mining in the United States," with Y. P. Chugh, J. Church and D. W. Kos) US Bu Mines Rept on Contract H0220012, (IITRI Rept D 6071) Sep 1974, 378 p, PB 250 595.

55. "High Pressure Hydraulic Jetting, An Emerging Technology," (with T. J. Labus), Proc 30th Natl Conf on Fluid Power, Philadelphia, PA, Nov 12-14, 1974, 9 p.

56. "Water Jet Tests to Establish A Specific Energy Curve for Rocks," (with T. J. Labus), US Dept of Transportation Rept FRA-ORD-D 74-53 (on PO 40201), (IITRI Rept D 6091), Aug 1975, 29 p.

57. "Mine Waste Embankments Need the Same Attention as Earthfill Dams," Coal Age, v 81, n 5, May 1976, p 112-116.

58. "Experience With Subsidence Due to Mining," Evaluation and Prediction of Subsidence, Proc Eng Fdn Conf, Pensacola, FL, ASCE, Jan 20-28, 1978, p 92-112.

59. "Effectiveness of Inclined Roof Bolts in Coal Mines" US BuMines Rept on Contract J0275031, (EI Rept 1013), Jul 1978, 96 p.

60. "Evaluation of Roof Bolt Tension Indicators," US BuMines Rept on Contract H0166096, (EI Rept 1006), Nov 1978, 227 p.

61. "Technical Assessment of Patents Related to Underground Coal Mines Haulage," (with J. S. Jaspal, R. LoPresti, R. T. Hair and G. A. Yates), US Dept of Energy Rept FE/9040-1 (on Contract ET-76-C-01-9040), (EI Rept 1005), Nov 1978, 4 vols, v 1, 97 p; v 2, 544 p; v 3, 575 p; v 4, 68 p.

62. "Development and Testing of Self-Drilling Roof Bolts," (with F. S. Kendorski and S. D. Singh), US BuMines Rept on Contract H0272022, (EI Rept 1014), Aug 1979, 225 p.

63. "Development and Testing of Self-Drilling Roof Bolts," (with F. S. Kendorski and R. P. Curtin), Proc 1979 North American Rapid Excavation and Tunneling Conf AIME, New York, NY, v 1, Chpt 37, p 635-655. (Synopsis in Tunnels and Tunnelling, v 11, n 8, Oct 1979, p 39).

64. "Criteria for Determining When a Body of Surface Water Constitutes a Hazard to Mining," (with F. S. Kendorski and I. Khosla), US BuMines Rept on Contract J0285011, (EI Rept 1021), Aug 1979, 366 p.

MADAN M. SINGH
PUBLICATIONS (cont.)

65. "Use of Inclined Roof Bolts in Coal Mines," (with W. J. Karwoski), Proc First Conf on Ground Control Problems in the Illinois Coal Basin, Carbondale, IL, Aug 22-25, 1979, p 103-117.

66. "Strength of Rock," Physical Properties of Rocks and Minerals (ed. Y. S. Touloukian, W. R. Judd and R. F. Roy), McGraw-Hill/CINDAS Data Series on Material Properties, v II-2, McGraw-Hill Book Co., New York, NY, 1981, Chpt 5, p 83-121.

67. "Rock Behavior in the Geopressure Environment," Geotechnical and Environmental Aspects of Geopressure Energy, Proc Eng Fdn Conf, Sea Island, GA, Jan 13-18, 1981; ASCE, New York, NY (in press).

68. "Tunnel Ventilation," Mine Ventilation and Air Conditioning, (ed. H. L. Hartman and J. M. Mutmansky), John Wiley and Sons, Inc., New York, NY, 1981, Chpt 16 (in press).

69. "Strata Disturbance Prediction for Mining Beneath Surface Water and Waste Impoundments," (with F. S. Kendorski), presented at the Conference on Ground Control in Mining, Morgantown, WV, July 1981.

MARK S. MA
Geotechnical Engineer

EXPERIENCE

1979-Present: Engineers International, Inc., Downers Grove, IL.
Mining Engineer: Participates in several on-going projects such as a physical model study of underground mining and field examinations of coal mine roof deterioration as influenced by humidity. Mr. Ma also carries out laboratory and field studies of soil and rock properties in support of other EI projects, including extensive coal mine rock mechanics investigations.

1977-1979: University of Wisconsin-Madison, Madison, WI.
Research Assistant to the Dept. of Metallurgical & Mineral Engineering: Carried out research work on comparative studies on in-situ stress measurement systems such as the USBM Borehole Deformation Gage, CSIR "Doorstopper", and hydrofracturing. He also carried out subsurface investigations to assess the suitability of bedrock formations for housing the underground facilities for the superconducting magnet energy storage scheme. In addition, Mr. Ma participated in hydrofracturing stress measurement projects for energy storage sites in Wisconsin, a nuclear power site in Toronto, Canada, and a quarry in Ohio.

1976-1977: University of Windsor, Windsor, Ontario, Canada.
Teaching Assistant in Engineering Geology: Participated in studies of aggregate-concrete reactivity.

1974-1976: General Telephone and Electronics, Taiwan.
Logistics Supervisor.

1972-1974: Army of the Republic of China (Taiwan).
Commissioned Officer: Commanding Officer of infantry troop unit on Taiwan and Matsu Islands.

EDUCATION

MS (Mining Engineering - University of Wisconsin-Madison,
Madison, WI, 1979.

BS (Earth Science) - National Cheng Kuang University,
Taiwan, 1972.

Graduate Studies (Engineering Geology) - University of Windsor,
Windsor, Ontario, Canada, 1976-1977.

CERTIFICATION

Certification for Mine Safety Training by MSHA for Surface and Underground, Coal, Metal, and Nonmetal Mining, 1980.

MARK S. MA (continued)

PROFESSIONAL SOCIETIES

Society of Mining Engineers of AIME
International Society for Rock Mechanics

PUBLICATIONS

Author of two technical publications on subsurface investigation for underground energy storage schemes.

TIMOTHY W. ZEIGLER
Engineering Manager,
Geotechnical & Coal

EXPERIENCE

Mr. Zeigler has a diversified background in coal mining technolgy, including research and demonstration programs for new mining methods and situations. He also has considerable experience in soil and rock mechanics for a wide variety of construction projects.

1981-Present: Engineers International, Inc., Downers Grove, IL. Engineering Manager, Geotechnical & Coal : Mr. Zeigler manages EI's projects dealing with soil and rock mechanics applications in a very wide variety of construction and research projects, including tunnels, foundations, slopes, mine design, and environmentally oriented projects. He also manages projects in coal mining methods, ventilation, and equipment that involve considerable industry contact and coordination.

1977-1981: Department of Energy, Carbondale Mining Technology Center, Carbondale, IL.
Manager, Underground Hydrocarbons Mining Division: Responsible for the development and execution of multi-million dollar research programs leading to the demonstration of new or improved mining technology or systems used in the recovery of coal, oil shale, tar sands, and heavy oils. Major research programs in the following fields were conducted: seam access equipment and techniques (coal), subsidence (coal), acid mine drainage (coal), waste disposal (coal), methane drainage (coal), oil shale mining, tar sands mining, and heavy oil mining.

Subprogram Coordinator: Responsible for the management of the Seam Access research program to develop and improve seam access equipment to achieve a minimum 300 percent increase in the rate of shaft and slope development. This program addresses the two main areas of excavation systems and equipment, and lining systems and equipment. Assisted in the development and implementation of oil shale mining research.

As a member of the Systems and Equipment Group and Subprogram Coordinator "Automated Continuous Roof Support," worked with a great deal of independence in planning and executing multi-million dollar research in development of advance techniques for coal mine roof support for increasing productivity and safety. Projects were conducted in four major areas: continuous miner bolter systems, longer-than-seam-height drills, automated bolter modules, and high-speed drills.

TIMOTHY W. ZEIGLER (cont.)

1969-1977: U. S. Army Engineer Waterways Experiment Station,
Vicksburg, MS.

Research Civil Engineer: Responsible for developing, conducting, and assisting in difficult and complex civil engineering research problems. Major projects included the study of basic rock properties such as kinetic shear strength and permeability, design and construction of compacted shale embankments, a dredged material research program, and field investigation for a marsh development site. As Civil Engineer, participated in projects dealing with in-situ tests for the determination of rock mass shear strength, confined disposal of dredged material, and finite element seepage analysis of a hurricane barrier.

EDUCATION

MS (Civil Engineering) - University of Illinois, Urbana, 1969.
BS (Civil Engineering) - University of Illinois, Urbana, 1968.

Corps of Engineers Advanced Training Program - University of Minnesota, 1973.
Geological Engineering - University of California, 1970.
Explosive Excavation Design - Trinidad, CO, 1971.
Time Share - Fortran - Vicksburg, MS, 1970.
Advanced Technical Writing - Vicksburg, MS, 1971.
Instructional Methods - Vicksburg, MS, 1972.
Management Seminar in Value Engineering - Vicksburg, MS, 1975.
Fundamentals of Reliability Engineering - Oklahoma State University, 1978.
Elements of Underground Coal Mining - Pennsylvania State University, 1978.
Microprocessor Workshop - West Virginia University, 1978.
Introduction to Supervision - St. Louis, MO, 1978.
Project Planning and Management - Carbondale, IL, 1980.
Developing Performance Standards - St. Louis, MO, 1981.
Shale Oil Production, Properties, Utilization - Denver, CO, 1981.

REGISTRATION

Professional Engineer, Illinois, No. 62-036652.

PROFESSIONAL SOCIETIES

American Society of Civil Engineers
Society of Mining Engineers of AIME
International Society for Rock Mechanics

PUBLICATIONS

Author of 8 publications on soil and rock mechanics, environmental engineering, construction, and coal mining.

TIMOTHY W. ZEIGLER
PUBLICATIONS

1. "Determination of Rock Mass Permeability," USAE Waterways Experiment Station Tech. Report TRS-76-2, Vicksburg, MS, January 1976.

2. "Design and Construction of Compacted Shale Embankments, Vol. 2, Evaluation and Remedial Treatment of Shale Embankments" (with G. H. Bragg, Jr.), Federal Highway Administration Research and Development Report FHWA-RD-75-62, Washington, DC, August 1975.

3. "Design and Construction of Compacted Shale Embankments, Vol. 5, Technical Guidelines" (with W. E. Strohm et al), Federal Highway Administration Research and Development Report FHWA-RD-78-141, Washington, DC, December 1978.

4. "Habitat Development Field Investigations Windmill Point Marsh Development Site, James River, Virginia" (with J. Lunz et al), USAE Waterways Experiment Station Tech. Report D-77-23, Vicksburg, MS, August 1978.

5. "Detailed Design for Dyke Marsh Demonstration Area, Potomac River, Virginia" (with M. Palermo), USAE Waterways Experiment Station Tech. Report TR D-77-13, Vicksburg, MS, October 1977.

6. "Feasibility Study for Dyke Marsh Demonstration Area, Potomac River, Virginia" (with M. R. Palermo), USAE Waterways Experiment Station Tech. Report TR D-76-6, Vicksburg, MS, November 1976.

7. "Practices and Problems in the Confinement of Dredged Material in Corps of Engineers Projects" (with W. L. Murphy), USAE Waterways Experiment Station Tech. Report D-74-2, Vicksburg, MS, May 1974.

8. "In Situ Tests for the Determination of Rock Mass Shear Strength," USAE Waterways Experiment Station Tech. Report TR S-72-12, Vicksburg, MS, November 1972.

SWAPAN BHATTACHARYA
Mining Engineer

EXPERIENCE

1980-Present: Engineers International, Inc., Downers Grove, IL.
Mining Engineer: Participates in a wide variety of projects in the field of rock mechanics and mine ventilation including studies of block caving drift support and production practices, investigation and design of the tunnel and shaft for the Rocky Mountain Pumped Storage Project in Georgia, Beavertail Highway Tunnel in Colorado, and ventilation surveys in underground mines. Mr. Bhattacharya has a background in finite element modeling using digital computers which has him carrying out supporting studies for many projects.

1970-1980: Virginia Polytechnic Institute & State University, Blacksburg, VA.
Graduate Teaching Assistant, Department of Mining and Mineral Engineering: Mr. Bhattacharya taught courses and laboratory classes in rock mechanics and mineral beneficiation and worked on several research projects for the department. As part of his graduate thesis he carried out finite element computer analyses of coal mine entries in tectonic stress fields.

Summer 1977: Hindusthan Zinc, Ltd., and Salgaonkar Iron Ore Mine, India.
Engineering Trainee: Carried out studies of mining methods and equipment and supervised the execution of a large underground blast using 10 tons of high explosives.

Summer 1976: Kolar Gold Fields and Singareni Collieries, India.
Engineering Trainee: Carried out studies of mining methods, equipment, rock bursts, and sandfilling of underground gobs.

Summer 1975: Iron Ore Mine, India.
Engineering Trainee: Carried out studies of operations in an open pit mine.

EDUCATION

MS (Mining Engineering) Virginia Polytechnic Institute and State University, Blacksburg, VA, 1980.

B. Tech. (Mining Engineering) Indian Institute of Technology India, 1978.

CERTIFICATION

Engineer-in-Training, Virginia, 1981.

Certification for Mine Safety Training by MSHA for Surface and Underground, Coal, Metal and Nonmetal Mining, 1980.

SWAPAN BHATTACHARYA (continued)

REGISTRATION

Engineer-in-Training, Virginia (No. 8499), 1980.

Certification for Mine Safety Training by MSHA for Surface and Underground, Coal, Metal and Nonmetal Mining, 1980.

PROFESSIONAL SOCIETIES

Society of Mining Engineers of AIME.

PUBLICATIONS

Author of technical papers and reports on finite element modeling, selection of underground equipment and safety analysis at crushers.

SWAPAN BHATTACHARYA
PUBLICATIONS

"Finite Element Analysis of Coal Mine Entries in Tectonic Stress Fields" (with C. Haycocks and M. Karmis), Proc of the Symp on Implementation of Computer Procedures and Stress-Strain Laws in Geotechnical Engineering.

"A Comparison of Different Finite Element Methods in a Practical Coal Mine Rock Mechanics Problem" (with F. S. Kendorski), to be presented at the 17th International Symposium on Computer Applications in the Mineral Industry, Golden, CO, April 19-23, 1982.

SANDIP K. MUKHERJEE
Senior Mining Engineer

EXPERIENCE

1980-Present: Engineers International, Inc., Downers Grove, IL.
Senior Mining Engineer: Participates in a wide variety of projects in the mining field. Project Engineer on US BuMines project on Guidelines for Water Spray Systems for Dust Control in Underground Mines and also Project Engineer on Cost Effectiveness of Increasing Airflow in Underground Coal mines. He has been involved with studies of underground multiple seam coal mining techniques and economic analysis of mining methods. Mr. Mukherjee is also especially qualified in computer simulation techniques and this background leads to his carrying out supporting studies for many projects.

1979: Foster-Miller Associates, Inc., Waltham, MA.
Mining Engineer: Mr. Mukherjee carried out several studies in the fields of coal mining equipment and safety, including dust control in room and pillar and longwall mining, self-rescuer evaluations, rescue chamber quidelines, and ventilation. His work in these projects, most involving underground work, gave him a broad background in the mining and safety problems of the industry.

1976-1978: The Pennsylvania State University, State College, PA.
Graduate Research Assistant, Department of Mineral Engineering:
Mr. Mukherjee taught courses in Mine Production Engineering, and carried out studies of longwall simulation, and operational constraints in conventional and continuous mining.

Summer 1974: Hindustan Zinc, Ltd., India,
Engineering Trainee: Carried out a study of shrinkage and sublevel stoping methods, ore reserves estimation, operation and maintenance of tower mounted Koepe cage and skip winding system, Alimak Raise Climber, Cavo loader, and Simba Junior ring drilling machine.

Summer 1973: Coal India, Ltd., India.
Engineering Trainee: Carried out studies of operations on a longwall face, including shearer, props, and sand-stowing of the gob.

EDUCATION

MS (Mining Engineering) - The Pennsylvania State University, State College, PA, 1978.

B. Tech. (Mining Engineering) - Institute of Technology, Banaras Hindu University, India, 1975.

Certification for Mine Safety Training by MSHA for surface and Underground, Coal, Metal, and Nonmetal Mining (1980).

SANDIP K. MUKHERJEE (continued)

PROFESSIONAL SOCIETIES

Society of Mining Engineers of AIME.
Mining, Metallurgical and Geological Institute of India.

PUBLICATIONS

Author of several technical papers and reports on coal mining management, operational simulation, and operational constraints.

SANDIP K. MUKHERJEE

PUBLICATIONS

1. "Inventory Control in Mining," with B. B. Dhar and B. S. Verma, the New Sketch Republic Day Special Issue (India), Jan. 1976.

2. "A Longwall Simulation Model," presented at SME Fall Meeting, Florida, 1978.

3. "Evaluation of Operational Constraint in Continuous Mining Systems - A Dynamic Simulation Model of Longwall Mining Systems," US BuMines Rept on Contract No. G0166028, 1978.

4. "Analysis of Operational Constraints in Conventional Mining Systems," presented at the Int'l Symp. Mining Res. Tech. and Instr., Banaras Hindu University, India, 1979.

DOUGLAS F. HAMBLEY
Senior Mining Engineer

EXPERIENCE

1980-Present: Engineers International, Inc., Downers Grove, IL.
Senior Mining Engineer: Participates in underground mining and tunneling projects involving rock mechanics, blasting, and stress measurement. Especially well qualified in work in hard rock or deep environments. Project Engineer on the investigation and design of the 40 ft diameter Beavertail Tunnels in thinly bedded sedimentary rock in Colorado. Project Engineer on the design of shaft and tunnels for the Rocky Mountain Pumped Storage Scheme, Georgia. Project Engineer on US BuMines Contract on Open Pit Ore Pass Design Manual. The tunnel design work involved extensive studies of rock mass behavior and the design of innovative rock reinforcement and support systems for these large diameter tunnels in variable geologic environments.

1977-1980: Denison Mines Ltd., Elliot Lake, Ont., Canada.
Project Engineer: As a member of the Long Range Planning Group and later as the Rock Mechanics Engineer in the Engineering Services Department, Mr. Hambley was responsible for a number of major projects including a Regional Stability Study considering district-wide interactions and items such as barrier pillars and rockbursts; backfill program, the scheduling study for the initial underground test pour, and design of the piping system for the hydraulic transport of the backfill; Stanrock Mine reactivation including dewatering investigations, pumping calculations, preparation of bid documents and review of contractors bids for that work; rock fall investigations, mine pillar design, and approval from a structural standpoint of all mine layouts. He has also designed several large underground garage openings and their ancillary service systems. Studied the water supply system for the mine and made recommendations for present and future improvements and extensions.

1975-1976: Harrison Bradford and Associates, Ltd.,
St. Catharines, Ontario, Canada.
Mining Engineer: Performed shaft and tunnel support and ventilation studies for the Strait of Belle Isle Cable Crossing, and also studies on Shaft Tunnel Station design and cable take-off into the tunnel. Performed investigation on hydraulic coal mining.

1974-1975: Falconbridge Nickel Mines. Ltd.,
Falconbridge, Ontario, Canada.
Mining Engineer Trainee: Participated in planning of development headings for post-pillar stopes, stope back support and mining method modification studies. Also carried out underground mine surveying and ventilation work, as well as assisting on diamond drilling.

1972-1973: Iron Ore Company of Canada, Schefferville, Quebec.
Junior Engineer: Responsible for all field engineering and pit geological mapping at an open pit mine, and carried out design of dumps, accesses, and pole lines for a projected mine.

Summer 1971: INCO Metals Ltd., Copper Cliff, Ont., Canada.
Junior Engineer: Surveying, layouts, and office work.

Summer 1970: Falconbridge Nickel Mines. Ltd.,
Falconbridge, Ontario, Canada.
Mine Beginner: Underground labor including timbering, tramming, and chute pulling.

Summer 1969: Kam-Kotia Mines, Ltd., Timmins, Ontario, Canada.
Mine Helper: Diamond drillhole grouting and blasthole loading.

EDUCATION

BS (Mining Engineering) Queen's University, Kingston, Ontario, Canada, 1972.

Short Courses: CPM Scheduling (1972), Supervisory Safety Training (1972), First Aid (1972, 1978), Rock Engineering (1978), Underground Opening Support Principles (1978), Supervision (1978), Rockburst Causes and Control (1979).

Fluent reading, writing, and speaking knowledge of French.

REGISTRATION

Professional Engineer, Illinois, No. 062-039201, 1981.
Professional Engineer, Ontario, Canada, No. 18026013, 1975. Certification for Mine Safety Training by MSHA for Surface and Underground Coal, Metal, and Nonmetal Mining, 1980.

PROFESSIONAL SOCIETIES

Society of Mining Engineers of AIME.
Canadian Institute of Mining and Metallurgy.
Mine Ventialtion Society of South Africa.
Society of Explosives Engineers.
Engineering Institute of Canada.
Canadian Geotechnical Society.
Canadian Rock Mechanics Group.
International Society for Rock Mechanics.
International Association of Engineering Geologists.
Colorado Mining Association.

PUBLICATIONS

Author of several publications concerning Mechanical Excavation, Computer Modeling, and Rock Mechanics.

DOUGLAS F. HAMBLEY

PUBLICATIONS

1. "Robbins 61R Raise Borer vs. Conventional Methods: A Cost Comparison" Unpub. BS Thesis, Queen's University, Kingston, Ont., May 1972, 34 p.

2. "Use of Analog and Computer Models in the Elliot Lake Uranium Mines" (with D. G. F. Hedley and G. M. Morgan). Underground Rock Engineering, Special Vol. No. 22, CIM, Montreal, p 151-161. Also CANMET, Minerals Research Program, Mining Research Laboratories, Division Report MRP/MRL 80-5 (OP), 1980, 24 p.

3. "Regional Stability in the Elliot Lake Mines." Part 1: The Denison-Quirke Boundary; Part 2: The Dension-Panel Boundary; Part 3: Pillar Recovery at Denison (with D. G. F. Hedley and G. M. Morgan). Report to the Mining Health and Safety Branch, Ministry of Labour, Government of Ontario, 1979.

MUHAMMAD O. RAHIM
Mining Engineer

EXPERIENCE

1981-Present: Engineers International, Inc., Downers Grove, IL.
Mining Engineer: Mr. Rahim participates in EI projects in mining equipment evaluation and design and ventilation studies. He has carried out detailed surveys in both coal and nonmetal underground mines of the effectiveness of main and auxiliary ventilation. On other projects, Mr. Rahim has evaluated various mining methods and equipment of their suitability to particular requirements.

1978-1981: College of Mineral and Energy Resources, West Virginia University, Morgantown, WV.
Graduate Assistant and Mining Engineer: Mr. Rahim carried out research on ventilation network analyses by computer, and assisted in the field in research projects in mine ventilation.

1975-1977: Mineral Development Corporation, Bangladesh.
Mining Engineer: Worked in various phases of planning and economic evaluation of coal and limestone mining projects.

1971-1972: Associated Consulting Engineers, Ltd., Bangladesh.
Assistant Engineer: Carried out subsoil investigations and involved in project feasibility studies.

1970-1971: International Engineering Company, Inc., Bangladesh.
Assistant Geotechnical Engineer: Work included preparation of a groundwater drilling program, supervision of drilling, and preparing technical reports.

EDUCATION

MS (Mining Engineering) - West Virginia University, Morgantown, WV, 1981.

M. Tech. (Mining) - Indian School of Mines, Dhanbad, India, 1975.

BS (Mining Engineering) - University of Engineering and Technology, Lahore, Pakistan, 1970.

PROFESSIONAL SOCIETIES

Society of Mining Engineers of AIME.
Mining, Metallurgical and Geological Institute, India.

PUBLICATIONS

Author of several papers and reports on mine ventilation and mining methods.

ROBERT A. CUMMINGS
Senior Geological Engineer

EXPERIENCE

1979-Present: Engineers International, Inc., Downers Grove, IL.
Senior Geological Engineer: As a Project Engineer, Mr. Cummings has performed a wide variety of geological and geotechnical investigations. He has organized and carried out several projects requiring extensive field work, including geological mapping, the design and installation of instrumentation arrays, the employment of various rock classification systems, and engineering studies, as well as both conventional and novel laboratory tests. An investigation in an underground block caving in the Southwest required detail line mapping and rock testing to characterize the behavior of a jointed intrusive rock mass. A project in a longwall coal mine in the Southeast involved geologic mapping, rock classification, measurement of mine roof convergence and pillar stresses, and in-situ jacking tests, for an improved entry design. A field project in a remote area in Utah determined the effect of proposed blasting on a nearby National Park. The geology, structure and seismic response of the principal rock formations were determined by means of conventional methods and test blasting; a field camp was set up and helicopter support was required. He conducted an inventory of the geologic and mineral resources of three geologically recent lava fields in Oregon. Mr. Cummings is Project Geologist on a highway tunnel design project in Colorado that involves a core drilling program, extensive rock testing, and statistical interpretation of results. Mr. Cummings employed novel techniques and tests in an investigation of the deterioration of shale coal mine roof in the humid regions of the United States.

1977-1979: University of Arizona, Tucson, AZ.
Research Assistant: Responsible for field and office research on thorium mining and recovery practices with the Department of Nuclear Engineering. This project involved inspecting and reviewing thorium mining techniques, assessing environmental impacts, and recommending suitable methods for future development of this promising energy resource. Involved in teaching formal classes in mining geology in surface and underground mines of various sizes, and short courses in mine valuation and mineral exploration.

Summer 1977: U. S. Borax, Spokane, WA.
Crew Chief: Helicopter supported reconnaissance for molybdenum and other base metal exploration in Southeastern Alaska. Included setting up a base camp for detailed development drilling of major molybdenum find.

Summer 1976: Duval Corporation, Tucson, AX.
Geologic Assistant: Carried out regional exploration, and exploration core drilling programs, for base metals in New Mexico and related office studies in Tucson.

ROBERT A. CUMMINGS (continued)

Winter 1975-1976: Elliot Geophysics, Tucson, AZ.
Field Assistant: Participated in magnetic survey exploration in the Southwestern United States.

Spring and Fall 1975: University of Arizona, Tucson, AZ
Technician for the Geomechanics Laboratory: Ran direct shear, uniaxial compression and Brazilian Tension tests of rock for engineering projects.

Summer 1975: AMAX Exploration, Tucson, AZ.
Field Assistant: Participated in base metals reconnaissance exploration using geochemical methods in New Mexico.

Summer 1974: Newmont Exploration, Tucson, AZ.
Sampler: Worked in the core lab as splitter and sampler at the San Manuel Copper Mine in Arizona.

EDUCATION

MS (Geological Engineering) University of Arizona, Tucson, AZ, 1979.

BS (Geological Engineering) University of Arizona, Tucson, AZ, 1976.

REGISTRATION

Engineer-In-Training, Arizona, (No. 1933), 1978.
Certification for Mine Safety Training by MSHA for Surface and Underground, Coal, Metal and Nonmetal Mining (1980).

PROFESSIONAL SOCIETIES

Society of Mining Engineers of AIME.
Association of Engineering Geologists.

TECHNICAL COMMITTEES

Society of Mining Engineers of AIME, Geological Engineering Committee.

ROBERT A. CUMMINGS
PUBLICATIONS

"Methods of Environmental Factors in the Production of Thorium from Vein Deposits," M. S. Thesis, University of Arizona, 1979.

"Assessment of Environmental Impact and Analysis of Control Technologies for Radioactive Materials Associated with Thorium/Uranium-233 Nuclear Fuel Cycles;Volume III--Mining, Milling, and Refining," report to DOE, SR/0970-T3, UC-83, Dept. of Nuclear Engineering, University of Arizona.--With A. Bronson and L. Klejbuk.

"Evaluation of Resources on Public Land in South-Central Oregon," Presented at the SME-AIME Fall Meeting, Minneapolis, Minnesota, 1980.

"Effect of Atmospheric Moisture on the Deterioration of Coal Mine Roof Shales," with M. M. Singh and N. N. Moebs, AIME Annual Meeting, Chicago, Illinois, 1981.

"Control of Shale Roof Deterioration with Air Tempering," Final Report on US BuMines Contract No. J0188028, "Evaluation of Air Conditioning Chambers for Prevention of Moisture-Induced Disintegration of Shale Roof," 1981. With M. M. Singh.

MANDEV S. REHAL
Civil/Structural Engineer

EXPERIENCE

1981-Present: Engineers International, Inc., Downers Grove, IL.
Civil/Structural Engineer: Participates in projects in which structural design is required.

1979-1981: Power Design Services, Inc., Lombard, IL.
Chief Structural Engineer: Responsible for direction and administration of structural engineering and design for all projects.

1971-1979: Sargent and Lundy, Engineers, Chicago, IL.
Structural Supervising Design Engineer: Supervised structural design for several oil-fired power stations including: Collins Station, Commonwealth Edison Company, Chicago, IL; Reading Station, Israel Electric Corporation, Haifa, Israel.

Structural Lead Design Engineer: Carried out complete structural design and analysis for a number of power stations including: Columbia Station, Unit No. 1, Wisconsin Power and Light Company, Madison, WI; Beckjord Station, Unit No. 3, Cincinnati Gas and Electric Company, Cincinnati, OH; Kincaid Station, Commonwealth Edison Company, Chicago, IL.

1968-1971 Pioneer Service and Engineering Company, Chicago, IL.
Structual Design Engineer: Carried out layout, grading, foundation design and complete structural design work for a number of power plants and heating units including: Sabrooke, Joliet and Calumet Stations, Commonwealth Edison Company, Chicago, IL; Boiler No. 1, University of Chicago, Chicago, IL; Pathfinder Nuclear Power Plant, Northern States Power Company, Minneapolis, MN; South Bay Power Plant, Unit No. 4, and Encina Power Plant, Unit No. 4, San Diego Gas and Electric Company, San Diego, CA.

1967-1968: Campbell Engineering, Inc., Detroit, MI.
Structural Designer: Carried out design of industrial buildings, foundations and steel, and grading and layout design of crane columns and girders.

1965-1966: John G. Hoad and Associates, Ypsilanti, MI.
Structural Designer: Carried out drafting and design of heavy industrial buildings, foundations and steel.

EDUCATION

Diploma	(Civil Engineering) - Thepar Institute of Engineering and Technology, India, 1961.
BS	(Civil Engineering) - University of Michigan, Ann Arbor, MI, 1965.
MS	(Civil Engineering) - University of Michigan, Ann Arbor, MI, 1967.

MANDEV S. REHAL (cont.)

REGISTRATION

Structural Engineer, Illinois, No. 81-3633

PROFESSIONAL SOCIETIES

American Society of Civil Engineers

ROGER C. CLEMENS
Mechanical Engineer

EXPERIENCE

1981-Present: Engineers International, Inc., Downers Grove, IL.
Mechanical Engineer: Participates in projects requiring mechanical design, especially well-qualified in piping and ductwork designs.

1980-1981: Power Design Services, Inc., Lombard, IL.
Project Engineer: Responsible for direction of multi-discipline groups for engineering and design of steam, generating stations and associated facilities including a Study to Upgrade Coal Conveyors at Powerton Station, Commonwealth Edison Company, Chicago, IL.

Mechanical Engineer: Responsible for mechanical engineering and design for a number of projects including a) sizing of miscellaneous service pumps for Units 17 and 18, R. M. Schahfer Generating Station of Nothern Indiana Public Service Corporation (Subcontractor to FMC Corp.); b) Feasibility studies of low-head hydroelectric power plants in Illinois for State of Illinois, Department of Natural Resources; c) Turbine water induction prevention system for Allen S. King Station, Northern States Power Company, Minneapolis, MN; d) Rehabilitation of stack emissions control systems, Utilities Center Building, University of Illinois, Chicago Circle Campus, Chicago, IL.

1975-1980: Sargent and Lundy, Engineers, Chicago, IL.
Mechanical Engineer: Responsible for mechanical design, engineering and analysis of piping systems and equipment for coal-fired generating stations. Sized and selected main station and miscellaneous pumps and sized and did layout at flue gas ducts and related equipment. Projects included: East Bend Station, Unit No. 2 and Beckjord Station, Units Nos. 1, 2 and 6, Cincinnati Gas and Electric Company, Cincinnati, OH.

EDUCATION

BS (Mechanical Engineering) - University of Illinois, Urbana, IL.

REGISTRATION

Professional Engineer, Illinois

PROFESSIONAL SOCIETIES

American Society of Mechanical Engineers
Illinois Society of Professional Engineers

THEODORE S. HENDZEL, JR.
Electrical Engineer

EXPERIENCE

1981-Present: Engineers International, Inc., Downers Grove, IL.
Electrical Engineer: Participates in projects requiring electrical engineering and design. Especially well-qualified in design of and specification writing for switchgear, motor control centers, and load centers.

1979-1981: Power Design Services, Inc., Lombard, IL.
Chief Electrical Engineer: Responsible for direction and administration of electrical engineering and design for all projects.

1979: Teletype Corporation, Skokie, IL.
Plant Electrical Engineer: Responsible for electrical engineering and design for remodeling of plant and factory electrical facilities.

1973-1979: Brown and Root, Inc., Oak Brook, IL.
Project Electrical Engineer: Performed review and approved issuance of design drawings, change orders, material requisitions, and specifications for construction, procurement, or subcontracting, as well as bid analysis and recommendations for purchase for major power projects including Manatee and Martin Plants of Florida Power and Light Company.

Start-Up Engineer: Worked on switchgear, motor control centers, load centers, equipment control and operation.

Electrical Design Engineer: Developed specifications for motor control centers, load centers, power and control cable, cable tray, station battery, and other electrical systems. Engineered and designed control schematics for the above systems. Performed various calculations of electrical engineering for the plants.

1969-1973: ITT-Harper, Inc., Morton Grove, IL.
Mechanical Draftsman: Worked part-time while going to college and full-time on semester and quarter breaks. Worked on tooling and special projects.

1969: H. K. Porter Company, Chicago, IL.
Mechanical Draftsman: Worked as draftsman and with application engineering in the power connector division.

EDUCATION

AA (Engineering Science) - Wright College, 1971

BS (Electrical Engineering) - University of Illinois, 1973

MS (Engineering Management) - Midwest College of Engineering, in progress.

TECHNICAL SOCIETIES

Institute of Electrical and Electronic Engineers

6.2 CONSULTANT RESUME

M. ASHRAF MAHTAB
Consultant

EXPERIENCE

1980-Present: Associate Professor of Mining, Henry Krumb School of Mines, Columbia University, New York.

1975-1979: Senior Rock Mechanics Engineer, Acres Consulting, Ltd, Niagara Falls, Canada. Rock mechanics design and analysis of radioactive waste repository concepts for AECL, including effects of heat generation and mining construction on rock failure, spalling, room stability and emplacement. Development of ventilation and sealing systems for rooms, shafts and adits. Analysis of site geology and mechanics of hydraulic fracturing for feasibility of injecting radioactive waste in hydro-fractured shale at West Valley, New York. Development of a program for in-situ and laboratory testing of dam foundation and construction materials for feasibility study of Karun development, Iran. Assessment of geology, chimney foundation conditions, and pump house and forebay excavation stability, Atikokan thermal power project, Ontario. Assessment of stability of a near-surface tunnel at Sault Ste. Marie during construction of a proposed powerhouse in the vicinity. Assessment of stability of Ironton limestone mine for oil storage. Geotechnical feasibility of Weeks Island salt mine for storage of crude oil. Assessment of long-term performance of natural/artificial crust on abandoned tailings ponds in U.S. and Canada. Planning of investigation and design for underground storage chambers for the U.S. Federal Energy Commission.

1970-1975: Mining Engineer/Physical Research Scientist, U.S. Bureau of Mines, Denver Mining Research Center, Denver, CO. Project leader on several in-house projects for investigating problems of stability of underground openings in jointed rock mass, influence of jointing on caving of porphyry coppers, oil shale, and coal-mine roof. Technical Project Officer on U.S. Bureau of Mines contract, "Engineering Study of Structural Geologic Features of the Herrin (No. 6) Coal and Associated Rocks in Illinois". A principal objective of this investigation was to determine roof support requirements and, in particular, to establish guidelines for the design of roof bolt patterns.

1965-1969: Research Assistant/Teaching Assistant, Department of Civil Engineering, University of California, Berkeley, with participation in
- Three-Dimensional Finite Element Analysis of Jointed Rock Slopes (USBR)
- Borehole Jack Experiment for Deformation Modulus of Rock Mass (NASA)
- Stresses at the Bottom of a Wellbore in Nonlinear Rock (AIME)
- Geologic Factors in Design of Blast Resistant Tunnels, including unsupported and rock bolted openings in jointed rock (U.S. Army)

- Finite Element Analysis of Borehole Jacking Test (University of California).

1964-1965: (Summers) Senior Engineer, Iron Ore Company of Canada, Labrador City, Newfoundland.

1963-1965: Research Assistant, Department of Mining and Geophysics, McGill University, Montreal, Quebec. Research and thesis on "Field Stress Distribution Around an Elliptic Hole Under Different Loading Conditions".

1959-1963: Lecturer, Mi[illegible] Department, Engineering University, Lahore, Pakistan. Mine Design, Mining Methods, Surveying.

EDUCATION

University of California, Berkeley, California, Ph.D. Civil Engineering (Geological Engineering), 1970.
McGill University, Montreal, Quebec, M. Eng. Mining Engineering (Rock Mechanics), 1965.
Montana University, Butte, Montana, B.S. Mining Engineering, 1959.
Engineering University, Lahore, Pakistan, B.Sc. Engineering, 1957.
Punjab University, Lahore, Pakistan, S. Sc. Physics and Mathematics, 1954.

PROFESSIONAL SOCIETIES

Association of Professional Engineers, Ontario - Member
Society of Mining Engineers of AIME - Member
Association of Engineering Geologists - Member

M. ASHRAF MAHTAB
PUBLICATIONS

1. "A Study of the Field Stress Distribution Around an Elliptic Hole Under Different Loading Conditions," M. Eng. Thesis, Dept. of Mining Eng. and Geophysics, McGill University, Montreal, 1965.
2. "Stresses Around Wellbores in Nonlinear Rock," (with R.E. Goodman), Soc. of Pet. Eng. Jour., V. 8, No. 3, September 1968, pp. 304-312.
3. "Three-dimensional Finite Element Analysis of Jointed Rock Slopes," Ph.D. Diss., Dept. of Civil Engineering, University of California, Berkeley, 1970, 97 p.
4. "Three-dimensional Finite Element Analysis of Jointed Rock Slopes," (with R.E. Goodman), Proc. 2nd Int. Cong. Rock Mechanics, Belgrade, September 1970, paper 7-12.
5. "Analysis of Fracture Orientations for Input to Structural Models of Discontinuous Rock," (with D.D. Bolstad, J.R. Alldredge, and R.J. Shanley), BuMines RI 7669, 1972, 76 p.
6. "Analysis of the Geometry of Fractures in San Manuel Copper Mine, Arizona," (with D.D. Bolstad, and F.S. Kendorski), BuMines RI 7715, 1973, 24 p.
7. "Procedures Used for Sampling Fracture Orientations in an Underground Coal Mine," (with D.D. Bolstad, J.R. Alldredge), BuMines RI 7763, 1973, 9 p.
8. "A Computer Program for Clustering Data Points on the Sphere," (with J.R. Shanley), BuMines IC 8624, 1973, 58 p.
9. "A Bureau of Mines Direct Reading Azimuth Protractor," (with D.D. Bolstad), BuMines IC 8617, 1973, 7 p.
10. "Determination of Attitudes of Joints Surveyed with a Borescope in Inclined Boreholes," (with D.D. Bolstad and R.R. Pulse), BuMines IC 8615, 1973, 12 p.
11. "Influence of Natural Jointing on Coal Mine Stability and the Preferred Direction of Mine Layout," BuMines Technology Transfer Seminar, Lexington, March 1973, BuMines IC 8639, 1974, pp. 70-78.
12. "Statistical Analysis of Axial Data," (with J.R. Alldredge and L.A. Panek), Journal of Geology, V. 8, No. 4, July 1974, pp. 519-524.
13. "Sampling , Mapping, and Analysis of the Geometry of Rock F actures," (with D.D. Bolstad), AIME's Annual Intermountain Minerals Conference, Vail, Colorado, August 1974.

14. "Influence of Rock Jointing and Block Boundary Weakening on Cavability," (with J.D. Dixon), Transactions Society of Mining Engineers, AIME, Vol. 260, March 1976, pp. 6-12.

15. "FRACTAN: A Computer Code for Analysis of Clusters Defined on the Unit Hemisphere," (with R.J. Shanley), BuMines IC 8671, 1975, 49 p.

16. "A Method for Computing Stabilization Pressures for Excavations in Incompetent Rock," (with L.A. Panek, J.D. Dixon), 16th U.S. Symposium on Rock Mechanics, University of Minneapolis, September 1975.

17. "Delineation and Analysis of Clusters in Orientation Data," (with R.J. Shanley), Jour. Int. Soc. of Mathematical Geology, V. 8, No. 1, 1976.

18. "Fracture Patterns and Anisotropy of San Manuel Quartz Monzonite," (with F.S. Kendorski), Bulletin Association of Engineering Geologists, V. 13, No. 1, 1976, pp. 23-52.

19. "A Method for Computing Stabilization Pressures for Excavations in Incompetent Rock with Computer Use Information," (with J.D. Dixon). BuMines RI 8128, 1976, 41 p.

20. "Stability of [illegible]ctive Waste Repository in the Canadian Shield," (with J.L. Ratigan and D.R. McCreath, 18th U.S. Symposium of Rock Mechanics, Colorado School of Mines, June 1977, Paper 4B4.

21. "National Strategic Crude Oil Storage in the Weeks Island Dome Salt Mine: I. Geotechnical Evaluation," (with Lamb, Van Sambeek, and Gill), ASME Journal of Energy Resource Technology, March 1979 (ASME Paper 78-Pct-75).

22. "National Strategic Crude Oil Storage in the Weeks Island Dome Salt Mine: II. Rock Mechanics Evaluation," (with Van Sambeek, Hansen, Gnirk), ASME Journal of Energy Resource Technology, March 1979 (ASME Paper 78-Pct-64).

23. "Geologic Engineering Factors in the Design of a Radioactive Waste Repository in Hard Crystalline Rock," (with Charlwood, Burgess, McCreath, Gnirk, and Ratigan), Geol. Soc. America, Geol. Assoc. Canada, Mineral. Assoc. of Canada Meeting, Toronto, Ontario, October 1978.

24. "Design Concepts for Underground Disposal of Irradiated Candu Fuel and Reprocessing Wastes in Crystalline Rock," (with others), Canadian Nuclear Associations, 19th Annual International Conference, Toronto, June 1979.

M. ASHRAF MAHTAB
PUBLICATIONS (Cont'd)

25. "Geological Engineering Aspects of the Conceptual Design of a Radioactive Waste Vault in Hard Crystalline Rock," (with others), Canadian Institute of Mining and Metallurgy, 18th Annual Meeting, Montreal, April 1979.

26. "Design Concepts for Underground Disposal of Irradiated Candu Fuel and Reprocessing Wastes in Crystalline Rocks," (with others), International Symposium on the Underground Disposal of Radioactive Wastes, Otaniemi, Finland, July 1979.

7.0 FACILITIES

7.1 GENERAL FACILITIES

Engineers International, Inc. offices and laboratories occupy over 10,000 square feet of space in a newly constructed industrial park in Downers Grove, about 25 miles west of downtown Chicago. These are readily accessible via interstate highways from O'Hare Airport and downtown. The EI facilities include conference rooms, reproduction facilities, drafting areas, word processing units, and a computer terminal.

A computer terminal, linked to the Control Data Corporation (CDC) computers in Rockville, MD, is in use at EI, which facilitates computational work on projects. Programs on file include geologic data analysis, structural design techniques, and sophisticated modeling routines. The terminal is also used by EI management for project cost control.

EI maintains an excellent, up-to-date library related to the mining and geotechnical engineering fields. The library contains texts, monographs, proceedings of symposia and conferences, handbooks, technical reports, government documents, commercial literature, theses, and other pertinent publications. It regularly receives all major periodicals and journals on mining, civil engineering, and geology, including foreign publications. EI staff have close contacts with the research and academic communities, and many papers are sent by the authors as soon as they are published.

The print shop is equipped with an offset machine, with appropriate mastermaking and accessory equipment. It has automatic collating equipment and facilities for binding of reports. These permit EI to maintain quality control and ensure confidentiality of client data.

Fully equipped laboratories and shop in the building provide support to EI's design, investigation, and field projects.

7.2 REGULATION LIBRARY

Contained within the EI library is an up-to-date and comprehensive collection of both United States and international mining and industrial regulations. The United States collection includes copies of federal regulations from MSHA, OSHA, BLM, OSM, and mining laws from all state agencies. Mining regulations from foreign countries such as Canada, Britain, and other European and Asian countries are also available. In addition, EI regularly receives all recent releases of MSHA Fatalgrams and Bulletins, EPA Environmental News, MSHA Policy Memoranda, U. S. Department of Labor News, Mine Safety Sense, and other relevant literature, as well as constant updates of all state mining regulations. There are very few such comprehensive mining regulations and industrial regulations libraries in existence, thus making EI's collection and organization of this material virtually unique.

7.3 LABORATORIES

The laboratories at EI are high-bay areas with a loading dock capable of accommodating full-sized trucks. Thus, deliveries of heavy equipment, rock and soil samples, instruments, and other items can be made without any difficulty. EI routinely perform field instrumentation investigations, and have the requisite space and facilities to calibrate and check these devices prior to use on and upon their return from a field project. Also because of the nature of these programs, EI is adequately equipped with safety clothing and other supplies required for such jobs. EI has a number of general instruments such as voltmeters, hydraulic pressure gauges, hydraulic jacks, and so forth.

Specific equipment in the various laboratories pertinent to this program are described in detail later in this proposal.

Rock Mechanics Laboratory

Equipment in the Rock Mechanics Laboratory includes:

- Seismic Analyzer, SBEL 2007-H
- Compression Testing Machine, Forney Model OC-200-DR with dual range (up to 30,000 lb and 400,000 lb), and special platens for rock testing
- Triaxial Load Cell, equipped for pore pressure measurements and outlet for strain gage leads, Soiltest Model T-8160
- Direct Shear Machine, for shear along a selected plane and controlled vertical load, complete with hydraulic jacks, SBEL Model RM 101
- Double Shear Device for Intact Core
- Rock Saw, SBEL Model SS-18
- Vibratory Lap, SBEL Model VL-20
- Strain Indicators, Vishay Model P0350A-K
- Gantry Crane with 3-ton Chain Hoist, Jet Model L-30, for moving large rock specimens
- Slake Durability Apparatus, EL77-051
- Point Load Tester, EL77-010
- Signal Conditioners, Sensotec 5A-10D
- Deformation Jacket, SBEL DJU Series
- XYZ Plotter, Hewlett Packward
- Goodman Jack, Slope Indicator Co

Special Equipment for Roof Bolt Testing

- Complete Roof Bolt Drilling and Testing System, with hydraulic drillhead and motor (Fletcher 51844), with hydraulic feed cylinder (Lynair H-R 3.0.2-48), pump (Fletcher 42042), 25 hp GE totally enclosed motor, custom built drill stand and platform, and a dust collection system. The system can drill for and install overhead bolts, similar to a mine

- Complete pull-test equipment for use in the laboratory or mine, with center-hole hydraulic jack and dial gage for measuring bolt head displacement

- Roof Bolt Load Cells, Ailtech Model 401

- Roof Sensing Bolts, Strainsert Model FB58

- Frame for tesing bolts in tension

EI is always adding new equipment and capabilities to its laboratories to meet the requirements of the programs that it undertakes. Hence the enumeration of equipment above is only intended to indicate that suitable facilities for a given program are generally available. EI makes a concerted effort to acquire appropriate equipment for new projects.

Soils Laboratory

The Soils Mechanics Laboratory contains the following equipment:

- Precision Motorized Compression Tester, Soiltest Model U-164
- Motorized Liquid Limit Device, Soiltest Model CL-205
- Hydrometer Analysis Set, Soiltest Model CL-279
- Motorized Sieve Shaker, Soiltest Model CL-305B, with timer, and 8-in. dis. Standard Sieve Set
- Oven, Sargent-Welch Model S-64620
- Plastic Limit Equipment
- Balance, O'Haus Model 2610
- Desiccators, Cylinders, Evaporating Dishes, Spatulas, Sample Cans, and other miscellaneous items

Engineers International, Inc. is continually upgrading and acquiring new equipment for its laboratories as the need arises. The above listing is merely indicative of the types of tests that we have had to perform to date. If other devices are required for a program, EI is generally able to accommodate these.

Concrete Testing Laboratory

The Concrete Laboratory is equipped to perform most routine tests on concrete samples. Among the facilities available are:

- Compression Testing Machine, Forney Model QC-200-DR, with dual range (up to 30,000 lb and 400,000 lb), capable of accepting 6-in. dia., 12-in. high specimens
- Rock Saw, SBEL Model SS-18
- Capping molds and material
- Laboratory Warming Pot, with variable heat control
- Classification (Schmidt) Hammer, Soiltest Model CT-320
- Strain Indicator, Vishay Model P-350-A-K
- Strain Gages for determination of Young's modulus and Poisson's ratio
- Oven, Sargent-Welch Model 64620
- Facilities for determining the linear thermal co-efficient of expansion

EI is continually upgrading the facilities in all its laboratories to be able to perform new and more efficient tests. The above listing is, therefore, not complete or extensive, but merely indicative of the type of work that EI can perform.

7.4 COMPUTATIONAL FACILITIES

EI is directly linked to a very powerful and sophisticated computer system - The Control Data Corporation's Cybernet Services. To offer a wide range of processing flexibility, Cybernet Services operates more than 30 control data computer systems at 17 centers worldwide. The computer systems range from high capacity and reliable CDC CYBER 174 and 175 for average day-to-day computing needs, and CYBER 76 and 176 for improved data processing and data management needs, to the CYBER 203 - currently the fastest computer available.

EI carries out interactive processing by means of a full size, 1200 baud TI Model 820 KSR remote terminal which is connected via telephone lines to the central computer facilities in Rockville, MD. The computer services provide a comprehensive set of programming language and utilities - FORTRAN, COBOL, BASIC, ALGOL, PASCAL, COMPASS, APL, IMSL, SORT/MERGE, FORM, XEDIT, and others.

In addition, EI maintains an excellent library of computer programs on disk for geologic data analysis, structural design techniques, and sophisticated modeling and simulation. Cybernet Services supplements the library with a wide range of geologic and mining applications available for CDC users. A partial list of the computer programs and packages available for use at EI is included in this section.

EI also has access to IBM 370/158 computers through the Oak Brook Data Center, located close to our Downers Grove Offices. This facility is generally used only when specific computational needs are not available through CDC.

Partial List of Computer Programs on Disk

CONTUR

Developed at EI, CONTUR is a generalized program for plotting data contours. The program accepts data values and their locations in space, subdivides the data in grid fashion and generates CALCOMP plots of contours at a user-specified interval.

CONVRT and WNDPLT

Developed by CANMET, these two routines are designed to interact with one another. CONVRT coverts field data on discontinuities in a rock mass collected on a straight line traverse to a form suitable for subsequent processing. WNDPLT produces an orientation diagram on a Schmidt equal-area projection of a sphere with a dense array of counting locations.

FEM2D

Developed at the Virginia Polytechnic Institute and State University, FEM2D is a relatively simple, finite element, computer code limited to linear, elastic, plane strain or plane stress analysis of isotropic bodies.

FRACTAN

Developed by the USBM Denver Research Center this program isolates naturally occurring clusters of data plotted on the unit hemiphere and tests these clusters against a probability distribution which admits elliptical symmetry about its mean. Output consists of a point plot, cluster statistics, a point plot of points belonging to a given cluster, and a summary of cluster statistics.

LABTEST

Developed at EI, this routine analyzes laboratory rock testing data from uniaxial, triaxial, Brazilian, direct shear and dynamic tests, computes material strength properties, conducts statistical analysis on computed data and generates stress-strain curves on the line printer.

OPMHS (Open Pit Materials Handling Simulator)

Developed at the Pennsylvania State University, OPMHS is a generalized materials handling simulator for coal stripping operations. The simulator consists of a number of interrelated subassemblies which represent various entities of a complete mining operation. These include bucketwheel excavator, shovel, dragline, truck haulage, conveyor, and train subassemblies. User inputs desired subassembly and the program computes the particulars of the complete material handling system.

PATCH

Developed by the USBM Denver Research Center, and modified by EI staff, this routine identifies and analyzes clusters (preferred orientations) of fracture data. Output consists of a percent plot, cluster statistics, and a plot of the cluster blown up to its diameter and centered on the plot. The plots are upper hemisphere plots.

SCHMIDT

Developed by Dr. R. D. Call at the University of Arizona, this program analyzes 3-D rock fracture orientations and outputs a point-count plot and a percent plot on a Schmidt stereographic projection.

STRESS AND STRAIN

Developed at EI, these two programs are designed for use in conjugation with the finite element routines. Both programs accept output data from the finite element programs and generate CALCOMP plots for the magnitudes and directions of the principal stresses and strains within the finite element model.

UGMHS (Underground Materials Handling Simulator)

Developed at the Pennsylvania State University, UGMHS is a simulation package incorporating a method of modeling phenomena that ensures computer compatibility and provides a means of moving the model through time on a computer and recording its behavior. This program gives a technique for describing and classifying sets of pieces of equipment and moves and then a technique for simulating their interations as the material handling system operates. User inputs data on equipment and layouts and the computer analyzes and designs the entire material handling system.

UTAH-2

Developed at the University of Utah, UTAH-2 is a 2-D finite element computer code which has been modified and extended to account for some of the complexities associated with practical rock mechanics. Program capabilities include arbitrary assignment of element properties without regard to element ordering, anisotropic elastic, plastic and brittle rock properties that may be time dependent, arbitrary mining sequences and provision for the effects of artificial support on adjacent strata.

VENTSIM

Developed at the Pennsylvania State University, this program is designed for simulation of underground mine ventilation networks. Program capabilities include mesh selection, free splitting, internal or external fans, natural ventilation pressure and fixed quantity branches. The computer produces, the quantities and head losses in the branches and the fan operating point.

ZONE-2

Developed at the Virginia Polytechnic Institute and State University, ZONE-2 is a computer model of subsidence prediction, based on the "zone area" method. This routine is capable of handling uniform as well as non-uniform extraction patterns and can be used for subsidence prediction over both room-and-pillar and longwall panels.

Partial List of Mining Software Available through Control Data's CYBERNET Services Networks

ADINA

A structural analysis system consisting of two finite element programs - ADINA for structural analysis and ADINAT for heat transfer analysis.

FCPO (Floating Cone Pit Optimizer)

This program package yields a practical solution to define optimum economic open-pit mining limits. The principle of operation involved is the technique of superimposing the frustum of an inverted cone into a computerized block model of the orebody. The economic mineral content of the material falling within the boundaries of the cone is then calculated.

MEGAS (Multi-Elemental Geochemical Analysis System)

MEGAS is an integrated, geochemical analysis system used to evaluate geochemical data. It incorporates geochemistry, mineralogy and statistical knowledge in an analysis system that is easy to use.

MINECAN (Mineral Economic Analysis Program)

MINECAN, a generalized cash flow modeling program, evaluates potential mine projects within a specific tax structure. The program is general enough to analyze many types of minerals and to examine different levels of complexity.

MINEVAL (Mineral Evaluation System)

MINEVAL uses a three dimensional matrix of blocks for evaluating deposits of massive, homogenous or thickly layered commodities such as copper, molybdenum, iron, gold, alunite,asbestos, limestone and uranium.

MIVENDES (Mine Ventilation Design System)

The MIVENDES module is a unique mine ventilation computer software program designed to model all types of mine ventilation systems. Besides the standard mine ventilation situations encountered, mines with heat problems, mines utilizing mechanized diesel equipment and gassy mines can be modeled and effective mine ventilation and air conditioning systems engineered.

MSCDEC (Multi-Seam Coal Deposit Evaluation System)

MSCDEC is designed for modeling and mining a multi-seam coal deposit. It produces plan and cross-section plots of data, statistical histograms, summaries of coal quality by seam, reserve estimate and contour plots for thickness of overburden and coal.

POLYGON

The Uranium/POLYGON mine planning system produces 3-D mathematical models of deposits. It is made up of four principal subsystems: data preparation and display and grade calculation, data interpretation and statistical analysis, disequilibrium analysis and economic analysis.

SLOPE-II

SLOPE-II is a computer program which utilizes the limit equilibrium theory to solve for the factor of safety of an earth slope.

SPSS

SPSS is an integrated system of statistical procedures such as regression, cross tabulation and analysis of variance.

SPSTRESS

A batch or interactive program for the linear analysis of elastic, statically loaded framed structures.

STARDYNE

This package consists of both static and dynamic finite element structural analysis capability. The static analysis predicts stresses and deflections resulting from pressure, temperature and concentrated forces. Dynamic analysis predicts the node displacements, velocities, accelerations, element forces and stresses from transient, harmonic, random or shock excitations.

7.5 FIELD EQUIPMENT

EI owns full field equipment necessary for the pursuit of work in either underground mines and tunnels or remote field locations. The underground equipment includes:

- Mine lamps and chargers
- Self-rescuers
- Wet gear
- Permissable photographic flash unit
- Mine air velocity measuring equipment
- Clock-drive mine air monitoring equipment (temperature, pressure, humidity)
- SF_6 tracer gas analyzing equipment
- Complete rock mechanics field testing laboratory

the field gear includes:

- 4 Wheel drive pickup truck with weather-proof shell
- 2 Standard pickup trucks, one with high security shell
- Tent and camp facilities for up to 10 persons
- Water coolers
- Gasoline and diesel fuel cans
- Brunton compasses
- Field surveying equipment
- 4 Cameras of various types with different lenses and one with a data-recording back
- Water level monitor
- Weather monitors
- Rain gauges

Thus EI can mobilize and support a full field effort from available equipment in order to carry out entirely self-sufficient underground and remote field projects.

7.6 SPECIFIC PROJECT REQUIREMENTS

This project requires no special materials and equipment except for office supplies, and documents which are readily available.

8.0 SUPPORTING DATA

8.1 REPORTING CONCURRENCE

The reporting and delivery requirements for this program have been comprehensively discussed in the Program Plan. It is evident that all the requirements specified in the Solicitation will fully be complied.

However, as required by the suggested proposal format in the RFP, it is specifically stated that all reporting requirements outlined in the Request for Proposals will be met by EI.

8.2 GOVERNMENT CONTRACTS

A list of federal government contracts awarded to Engineers International, Inc., giving the agency, contract numbers, amount of contract, contracting offices, and phone numbers are listed in Table 8.1.

In addition to these, the Principal of the firm, Dr. Madan M. Singh, has been involved in a number of federal contracts prior to founding Engineers International, Inc. These are presented as Table 8.2.

Table 8.1
LIST OF FEDERAL CONTRACTS

SPONSOR/CONTRACT No.	PROJECT	AMOUNT	EFF. DATE	CONTRACT OFFICER
1. National Science Foundation APR 76-15229	Cost Comparison Study of Impact Methods of Rock Excavation	$ 49,200	June 1976 to June 1977	Washington, DC W. B. Cole, Jr. 202/632-5892
2. U. S. Bureau of Mines H0166096	Field Test of Roof Bolt Tension Indicating Devices	$ 154,164	June 1976 t0 Oct. 1977	Washington, DC A. G. Young 202/634-4700
3. U. S. Dept. of Energy ET-76-C-01-9040 (Formerly USBM J0166130)	Technical Assessment of Patents Related to Underground Coal Mine Haulage	$ 140,854	June 1976 to Nov. 1978	Washington, DC E. F. Callaghan 202/376-911
4. U. S. Bureau of Mines J0274031	Analysis of Inclined Roof Bolt Data in Coal Mines	$ 18,364	June 1977 to July 1978	Denver, CO L. Rock 303/234-4421
5. U. S. Bureau of Mines H0272022	Testing and Evaluation of Self-Drilling Roof Bolts	$ 161,240	Aug. 1977 to Apr. 1979	Denver, CO D. J. Askin 303/234-4421
6. U. S. Dept. of Energy W-31-109-38-4157	Consultation to Geothermal Task Group	$ 3,000	Jan. 1978 to Mar. 1978	Argonne, IL L. A. Hoornbeck 312/972-7075
7. U. S. Bureau of Mines H0282011	Improved Highwall Stability by Improved Blasting Techniques	$ 191,993	Aug. 1978 to Aug. 1980	Denver, CO D. J. Askin 303/234-4421
8. U. S. Bureau of Mines J0188028	Evaluation of Air Conditioning Chambers for Prevention of Moisture Induce Disintegration of Shale Roof	$ 243,601	Aug. 1978	Washington, DC J. P. Connelly 202/634-4700

Table 8.1 (cont'd)

	SPONSOR/CONTRACT NO.	PROJECT	AMOUNT	EFF. DATE	CONTRACT OFFICER
9.	National Park Serv. PX20008D167	Zion-Mt. Carmel Tunnel Inspection	$ 3,910	Sept. 1978 to Sept. 1978	Denver, CO E. W. Simpson 303/234-4308
10.	U. S. Bureau of Mines J0285011	Criteria for Determining When a Body of Surface Water Constitutes a Hazard to Mining	$ 79,634	Sept. 1978 to Aug. 1979	Denver, CO D. J. Askin 303/234-4421
11.	Bur. of Land Management OR910-CT9-16	Geological Investigation and Mineral Inventory of Devils Garden, Four Craters and Squaw Ridge in Lake County, Oregon	$ 9,800	May 1979 to June 1980	Portland, OR L. Parrish 503/231-6942
12.	U. S. Bureau of Mines J0295060	Laboratory Experiments to Determine the Roof Behavior of Auger Mining with Aerostatic Support	$ 125,432	Sept. 1979	Denver, CO B. G. Horton 303/234-4421
13.	U. S. Department of Energy DE-AC01-79ET14242	Investigation of Problems and Benefits of Underground Multiple-Seam Coal Mining	$ 121,394	Sept. 1979	Washington, DC S. L. Lake 202/373-9111
14.	U. S. Bureau of Mines J0100007	Improved Techniques for Boulder Blasting at the Crusher	$ 71,546	Nov. 1979	Washington, DC D. W. Teets 202/634-4700
15.	U. S. Bureau of Mines P3300486	Collection of Data on Small Scale Drilling Machines Used in Underground Non-Coal Mines	$ 3,675	Jan. 1980 to June 1980	Minneapolis, MN E. A. Allison 612/725-4520
16.	U. S. Bureau of Mines J0308017	Design Guidelines for Improved Water Spray Systems	$ 89,803	Feb. 1980	Pittsburgh, PA A. G. Bolton, Jr. 412/675-6400

Table 8.1 (cont'd)

SPONSOR/CONTRACT NO.	PROJECT	AMOUNT	EFF. DATE	CONTRACT OFFICER
17. National Park Service CX-1200-0B033	Blasting and Erosion Study, Bryce Canyon National Park	$ 79,559	April, 1980 to August 1980	Denver, CO David L. Olson 303/234-2792
18. U. S. Bureau of Mines J0308044	Reverse Performance Characteristics of Main Mine Fans	$ 154,845	May 1980	Pittsburgh, PA A. G. Bolton, Jr. 412/675-6400
19. U. S. Bureau of Mines J0205041	Open-Pit Ore Pass Design Manual	$ 121,809	July 1980	Denver, CO David J. Askin 303/234-4421
20. U. S. Bureau of Mines J0100066	Cost-Effectiveness of Increasing Airflow at Any Location in Underground Coal Mines	$ 140,864	Aug. 1980	Washington, DC F. M. Naughton 202/634-4700
21. U. S. Bureau of Mines J0100103	Mine Support Requirements Based on Rock Quality Indices	$ 136,641	Sep. 1980 to Sep. 1981	Washington, DC D. W. Teets 202/634-4700
22. U. S. Bureau of Mines J0318015	Testing Jet Fans in Metal/Nonmetal Mines with Large Cross-Sectional Airways	$ 165,396	Feb. 1981 to Feb. 1983	Pittsburgh, PA A. G. Bolton, Jr. 412/675-6400
23. U. S. Bureau of Mines J0318095	Mine Demonstrations of Longwall Dust Control Techniques	$ 347,002	Aug. 1981 to Jan. 1984	Pittsburgh, PA A. G. Bolton, Jr. 412/675-6400

Table 8.2

PRIOR EXPERIENCE WITH FEDERAL CONTRACTS
(Dr. Madan M. Singh)

Contract No. U. S. Bureau of Mines	Program Title
Program Manager:	
H0111789	Feasibility of Mining Coal With High-Pressure Water Jets
H0133119	Design of a Hydraulic Jet Coal Miner
H0220012	Metallic and Nonmetallic Mining in the United States
H0210009	The Effect of Specimen Size on Confined Compression Testing of Rock Cores
H0210057	Feasibility of Pneumatic Stowing for Ground Control in U. S. Coal Mines
Major Contributor:	
H0111881	Evaluation of Present Shotcrete Technology For Improved Mine Ground Control
H0252071	Test of Inclined Roof Bolts and Analysis of Their Effectiveness in Roof Control in Coal Mines
U. S. DEPARTMENT OF TRANSPORTATION	
Program Manager:	
DOT 3-0171	Rock Breakage by Light Gas Gun Projectiles
DOT 3-0171 (Cont'd)	Rock Breakage by Pellet Impact
FR-9-0031	Rock Fracture by High Speed Water Jet
PO 40201	Water Jet Tests to Establish a Specific Energy Curve for Rocks
DOT-FR-11-8082	Determination of the In-Situ State of Stress in Soil Masses

PRIOR EXPERIENCE WITH FEDERAL CONTRACTS (Continued)

(Dr. Madan M. Singh)

Contract No.	Program Title
U. S. DEPARTMENT OF DEFENSE	
Program Manager:	
F33615-69-C1349	Aircraft Landing Gear Dynamic Load Induced by Soil Landing Fields
F29601-73-C-0020	Dynamic Response of Soil/Concrete Interfaces at High Pressure
Major Contributor: F29601-69-C-0016	Experimental Investigation of Small Scale Lined and Unlined Cylindrical Cavities in Rock
NATIONAL SCIENCE FOUNDATION	
Program Manager:	
GI-41307	Survey of Excavation Research Facilities in the United States
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION	
Major Contributor:	
NAS8-20820 Sub:510-60042H	Lunar Drill Bit and Cuttings Conveyor Mechanism
NASW - 1953	Application of NASA Technology to Mine Safety Problems

8.3 LETTER FROM CONSULTANT

On the following page is reproduced a letter from the project consultant indicating his willingness to serve on this project.

Columbia University in the City of New York | *New York, N.Y. 10027*

HENRY KRUMB SCHOOL OF MINES

Seeley W. Mudd Building

November 9, 1981

Engineers International, Inc.
5107 Chase Ave.
Downers Grove, IL 60515

Attention: F.S. Kendorski

Ref: Proposed Project in response to RFP No. RS-NMS-82-030, "Technical Assistance for Design Reviews"

Gentlemen:

This is to indicate my consent to work with Engineers International, Inc. on the proposed project. I shall be available to consult with you as specified in your proposal and up to 10 weeks per year.

Yours sincerely,

M. Ashraf Mahtab
Associate Professor of Mining

MAM/kh

9.0 CONFLICTS

Engineers International, Inc. has no present or past contractual or organizational relationships, including its staff consultant, Dr. M. Ashraf Mahtab, which might give rise to an apparent or actual conflict of interest in the event of contract award.

We believe that this position of total non-conflict puts EI into an extremely valuable objective position in that while the staff, firm, and consultants are very technically capable and experienced in all required fields for this project, we have not directly or indirectly worked on any nuclear waste repository studies or designs that could possibly pose a conflict of interest.

EI's experience in rock mechanics, mine design, and ventilation is all up to date and pertinent, and has been gained in projects with the same geologic and geometric considerations as waste repositories, without having actually been waste repositories.

Thus, the EI project team could not be suspected of reviewing their own work in any way and would be truly objective.

10.0 . CLOSURE

Engineers International, Inc. is pleased to submit this proposal to NRC in response to RFP No. RS-NMS-82-030 "Technical Assistance for Design Reviews."

This proposal has demonstrated that EI has highly competent personnel and adequate facilities to complete such work to the satisfaction of NRC.

The RFP listed several evaluation criteria which we have endeavored to cover comprehensively in the body of the proposal, and are reiterated here:

- The outline of the work to be completed that has been presented in this proposal demonstrates the complete understanding EI has of all elements of the Statement of Work and that an approach has been presented that demonstrates our thoroughness by completely thinking the project through, including the logistics, the soundness by the concise, clear, plan presented, and the comprehension of the work by completely detailing all required tasks, eliminating none and adding none.

- The Technical Discussion of this proposal, we believe, adequately demonstrates EI's thorough comprehension of the Scope of Work of this RFP. We believe that we fully understand all the requirements of this program, since EI staff and consultant have worked on similar contracts in the past involving shaft design for mining and civil projects, backfill design, rock mechanics, and design and evaluation of cementitious materials. EI has recognized the difficulties involved, but feels that these can be readily overcome by sound prior planning and experience. Hence, we are convinced that the approach suggested toward the completion of this project is quite sound and viable.

- The indicated key personnel are clearly dedicated to serving on the project, should it be awarded to EI.

- Due to the closing out of several successfully completed projects during 1981 and early 1982, EI is in an excellent position to perform the proposed work during the indicated time frame of the project. Experience on past quick-response projects has allowed us to develop the expertise to carry out such tasks efficiently.

- The regularly-instituted project management and control techniques enable EI to closely monitor costs, schedules, and technical quality, and thus assure that corrective actions, if needed, are imposed early.

- The project organization and management structures have been carefully designed to allow rapid and efficient reviews of submitted technical materials.

- The personnel proposed for this work have specific pertinent experience in the technical fields required, including mining and civil design, rock mechanics, mine systems, mechanical engineering, electrical engineering, safety engineering, thermomechanical analysis, and human factors engineering, and the management of government contract work. The personnel have numerous publications and committee work in the proposal area and are considered experts in their fields. The resumes of the individuals concerned demonstrate this experience gained through extensive industry design work for mining and tunneling, including uranium mining, and in engineering activities related to nuclear requirements.

- The proposed key personnel committed to the project have experience in design and analysis of proposed systems for high-level radioactive waste disposal through a thorough understanding of the technology involved from peripheral fields.

- EI has a well-rounded, multi-disciplinary staff which has experience in both research and design, and are fully qualified to undertake such work.

- The proposed work is comparable to projects already undertaken and successfully completed or underway at EI since we have carried out major geotechnical and mining technology projects for industry and government.

- EI and its retained consultant have no actual or apparent conflicts that might alter their objectivity on this work.

- EI has an excellent track record of performing work for the government and for private industry and details of these projects have been presented.

- This proposal adequately demonstrates, we feel, our comprehension of the proposed work from both a technical and managerial standpoint.

- We believe the thoroughness and completeness of this proposal, as well as the published technical interests of the management, demonstrates the interest of EI in providing these services.

- This proposal has demonstrated our responsiveness to all of the RFP requirements and our appreciation of the importance of each.

Engineers International, Inc. would be pleased to discuss the scope of these proposed services, and would appreciate having the opportunity to carry it out for the Nuclear Regulatory Commission.

Respectfully submitted,

E. NEERS INTERNATIONAL, INC.

Michael F. Dunn

Michael Dunn
Projec ineer

Approved by:

Francis S. Kendorski

Francis S. Kendorski
Project Manager