Kimballton DUSEL Appendices

Appendix A: Existing Surface Infrastructure

DUSEL kimballton

**PRELIMINARY INFRASTRUCTURE STUDY
PROPOSED DUSEL SITE
GILES COUNTY, VIRGINIA**

Prepared for:

**Kimballton Deep Underground Science and
Engineering Laboratory**

Kimballton DUSEL Team

Prepared by:

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DAA Project Number: B04298-01

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INTRODUCTION

The purpose of this site infrastructure study is to provide the Kimballton Deep Underground Science and Engineering Laboratory (DUSEL) Team with a document that summarizes information obtained in a preliminary infrastructure study. This study is based on preliminary information obtained to date in the project area and is intended as a guide for more detailed, subsequent infrastructure studies.

Draper Aden Associates completed a preliminary review of available infrastructure information for the proposed DUSEL portal locations at Kimballton, Hoges Chapel, and the Mountain Top Sites.

Draper Aden preformed the following tasks before beginning a site evaluation:

- Data Gathering – Gathered readily available information from Giles County: USGS and other topographic data, Virginia Base Mapping Program data, accessibility, utility availability, natural gas, and electric services.

- Field Reconnaissance – Conducted field investigations to identify points of interest, constraints, and assets of the site.

The information gathered in the tasks above is included in the attached appendix.

GENERAL SITE LOCATION INFORMATION

The proposed DUSEL site is located under Butt Mountain in Giles County, Virginia. It is located near the towns of Kimballton, Pembroke, Ripplemead, and Hoges Chapel. Access to the proposed site is attained via U.S. Route 460, a four-lane road which extends between Interstate 81 in Christiansburg, Virginia to Interstate 77 in Princeton, West Virginia. The proposed DUSEL location is approximately 27 miles west of I-81 on U.S. Route 460 West, approximately 18 miles beyond Virginia Polytechnic Institute and State University in Blacksburg, Virginia. The site is located approximately 33 miles east of I-77 in Princeton, West Virginia on U.S. Route 460 East. A vicinity map and the approximate portal locations can be found in Appendix A, Figures A1 and A2.

The location of the proposed portal locations in proximity to the Jefferson National Forest Area can be found in Appendix A, Figure A3. The general topographic features of the

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study area consist of rolling hills, karst terrain and mountains, which is typical of areas located within the New River Valley of southwestern Virginia. The two portal sites are comprised of generally rolling hills with heavily forested areas interspersed with some clearings.

KIMBALLTON PORTAL SITE

The proposed Kimballton portal site is located on the north slope of Butt Mountain. The general location of the site in proximity to surrounding land features is located in Appendix B, Figure B1.

SITE LOCATION

The Kimballton portal site is located on the south side of State Route 628 approximately 5 miles north of the intersection of U.S. Route 460 and State Route 635. The portal is approximately three-tenths of a mile east of Chemical Lime Company's Olean mining operation.

ACCESS

A general access road map is included in Appendix B, Figure B2.

Roads

U.S. Route 460 is a primary, four-lane highway connecting I-81 in Christiansburg and Blacksburg, Virginia with I-77 in Princeton, West Virginia. Route 635 is a secondary two-lane, state highway that connects the rural communities of Kimballton, Goldbond, and Olean to Route 460. This road currently accommodates heavy truck traffic to and from Chemical Lime's mining operations at Kimballton and Olean. Route 628 is a local road surfaced with compacted gravel sufficient in width to accommodate construction traffic.

Rail Service

Norfolk Southern Railroad currently serves Chemical Lime's Kimballton Mine operation. A siding is currently in place with capacity to accommodate approximately 15 rail cars. Norfolk Southern has indicated it has the infrastructure in place to provide service for DUSEL construction and operation. Specific available rail capacity will be determined by the amount of service required during construction and operation.

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AVAILABLE UTILITIES

A general Kimballton Site map indicating existing and proposed utility information collected to date is included in Appendix B, Figure B3.

Water

The Giles County Board of Supervisors (GCBOS) and the Giles County Public Service Authority (GCPSA) provided a study of the existing water supply at the Kimballton site. The study was completed in order to determine the feasibility of extending existing water service from near U.S. Route 460 to residents of the State Route 635/Chemical Lime study area. This has been addressed in a Preliminary Engineering Report (PER) dated July 2004. The purpose of the PER was to identify, investigate and evaluate the alternative methods of extending public water service to the upper reaches of the State Route 635/Chemical Lime area of Giles County, Virginia. Preliminary project costs were developed for two alternatives, and conclusions were presented regarding selection of the recommended alternative.

The study area includes the environs adjacent to State Route 635 from approximately 1 mile north of the intersection of U.S. Route 460 and State Route 635 to the boundary of the Jefferson National Forest, approximately 0.6 mile north of the intersection of State Route 635 and State Route 628 (Olean Road). It was noted in the PER that residents above an elevation of 2,050 feet cannot be served by the existing GCPSA Riverbend and Bostic water storage tanks, which provide storage for the existing State Route 635 water distribution system.

Currently, the majority of the State Route 635/Chemical Lime Study area relies upon private wells and springs. However, there are two water distribution systems currently operating within the proposed study area: (1) the GCBOS State Route 635 system, and (2) the Chemical Lime Company's private system.

The GCBOS system consists of a 6-inch water line, which is connected to the GCPSA water main along U.S. Route 460 and extends approximately 1 mile north of the intersection of U.S. Route 460 and State Route 635. The GCPSA Riverbend and Bostic water storage tanks supply this portion of the GCBOS water distribution system.

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The Chemical Lime Company's water distribution system consists of a spring, a 32,300-gallon concrete reservoir, chlorination equipment and various amounts of 3-inch and 4-inch water line necessary to service a maximum of 130 employees and 13 residential connections.

The existing GCBOS State Route 635 water system is supplied from a 2.0 million gallon per day (MGD) water treatment plant operated by the GCPSA. The GCPSA Water Treatment Plant is currently operating at approximately 60% of its capacity. The demands projected for the State Route 635/Chemical Lime study area will result in the GCPSA Water Treatment Plant operating at approximately 63% of its current capacity. Additionally, the Riverbend and Bostic water storage tanks provide storage capacity for this portion of the water distribution system, and water is transferred to the tanks from the GCPSA water treatment plant through the Bluff City and Wal-Mart pump stations.

Two alternatives were reviewed for the PER as follows:

Alternative I

In this alternative, a proposed water main would bypass the high point along State Route 635 by connecting to the County's existing State Route 635 water system approximately 0.65 mile north of the intersection of U.S. Route 460 and State Route 635, paralleling the existing 6-inch water line to the intersection of State Route 626 (Klotz Road). The proposed line would extend northwest along State Route 626 to State Route 684 (Norcross Road), then run northeast to State Route 635 near Kimballton, and then parallel State Route 635 to the limits of the project area. Existing tanks would provide the necessary storage capacity for this alternative.

Preliminary cost estimates for this alternative detail a total project cost of approximately 2.41 million dollars. It is anticipated that this alternative may not provide adequate service to the proposed Kimballton DUSEL site due to the proposed elevation at the surface of approximately 2,050 feet at the site location.

Alternative II

In this alternative, a proposed water main would connect to the County's existing State Route 635 water system approximately 1 mile north of the intersection of U.S. Route 460 and State Route 635. From this point the proposed line would extend north along State Route 635 to the limits of the project area at a location approximately 1 mile from the intersection of State Routes 635 and 626. Routing of the water main along the higher elevations of the service area

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would require the construction of a water storage tank at an elevation greater than that of the GCPSA Riverbend and Bostic tanks, as well as the addition of a booster pump to supply water to the new storage tank.

Preliminary cost estimates for this alternative detail a total project cost of approximately 2.6 million dollars. Depending on the elevation of the proposed 100,000-gallon storage tank and required anticipated future demand for this study area, this alternative will likely provide adequate service to the proposed Kimballton DUSEL site.

A recommendation was provided in the PER to proceed with Alternative I due to the needs and relative cost of the project. Upon discussions with Giles County officials, other means for service can be investigated, such as Alternative II, in the event that a need for additional service is anticipated in this study area, particularly the development of the DUSEL site. Alternative I is scheduled to begin construction in Spring 2006.

Sewer

The nearest known service provider for sewer lies approximately 1 mile outside the Town of Pembroke and approximately 8 miles from the proposed Kimballton Site. A 10-inch gravity main located at Pembroke Street and U.S. Route 460 in Pembroke provides this service. Currently, the Kimballton Mine uses a septic and treatment system to treat its waste material.

Electric

Electric service is available to the site, however existing lines are not immediately adjacent to the site. American Electric Power (AEP) will charge for extending that service based on the potential usage of the services.

Existing 3-phase electric service is available from AEP at the Chemical Lime Mine approximately 0.25 mile from the proposed site. AEP has the capacity to serve the project at the proposed site location (Goldbond area / Butt Mountain). Assuming a 9MW load, the two possible service scenarios are outlined below and include the initial pro-forma cost estimates for serving the Kimballton project DUSEL site:

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Improvements to Existing Sub-Station

The improvements required to serve the proposed load from the existing 34.5 KV distribution source and provide 34.5 KV delivery will cost approximately $250,000. The estimate could be higher if a separate breaker and circuit originating out of the existing Kimballton Station are required.

Construction of New Sub-Station

The approximate cost to provide a 138 KV tap and a 138/34.5 KV substation on site is approximately $4,000,000. This estimate is based on wood pole construction and would be higher if steel poles or towers are used. Cost estimates were determined using 34.5 KV to be consistent with the existing distribution system, which is somewhat flexible. If the load estimate increases, this may become the best choice, and alternatives will need to be reviewed as the project evolves in order to present the most advantageous response to the project needs. The advantage of this type of system is the significant increase in reliability, greater service range, and increased redundancy as the main power source to the facility.

Once KW demand and KWH / month load information is obtained, AEP will be better able to determine more accurate development costs that would then be relayed to the project developer.

Telecommunications

Pembroke Telephone Cooperative (PTC) provides telephone, internet, and cable television service to the area. Discussions with PTC have revealed that service availability can only be determined after a customer makes a formal request for service to identify their needs. It has been determined that PTC has an existing size 12 fiber optic cable extending along State Route 635 to the Chemical Lime facility. Representatives from PTC have indicated that adequate service can be provided to the proposed Kimballton site. The level of upgrades, if needed, and the associated cost would depend upon the anticipated use for the facility. Currently, PTC has indicated that there are approximately 3 fibers available for use.

Gas

There is currently not a gas provider in the area.

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HOGES CHAPEL PORTAL SITE

The proposed Hoges Chapel portal site is located on the south slope of Butt Mountain. The general location of the site in proximity to surrounding land features is shown in Appendix C, Figure C1.

Site Location

The Hoges Chapel portal site is located on the north side of U.S. Route 460 approximately 3 miles east of the Town of Pembroke, Virginia and approximately 18 miles west of the Virginia Tech campus in Blacksburg, Virginia. This site is a portion of the property currently under consideration for a proposed Giles County Industrial Park.

Access

A general access road map is included in Appendix C, Figure C2.

Roads

Hoges Chapel Portal will be accessed directly from U.S. Route 460, a four-lane primary highway. A right deceleration and turn lane would be required to be constructed to the Virginia Department of Transportation (VDOT) standards. The proposed commercial entrance would be constructed at the current entrance to the Giles County Industrial Park. It is not anticipated that sight distance issues at this location would preclude the construction of one or more entrances to the proposed site.

An access drive alignment following an appropriate and efficient route from the proposed site entrance on U.S. Route 460 to the portal site produces an access drive of approximately 2,400 linear feet in length.

AVAILABLE UTILITIES

A general Hoges Chapel Site map indicating existing and proposed utility information collected to date is included in Appendix C, Figure C3.

Water

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A study of the existing water supply at the Hoges Chapel site was investigated. General information was provided by Giles County in regard to existing water lines in the service area. Currently, the site is serviceable via an existing 8-inch water line that parallels U.S. Route 460. Representatives from Giles County have indicated that the service to the proposed Hoges Chapel site is adequate from this location, with appropriate upgrades to the system to accommodate growth from the proposed development.

Sewer

The nearest known provider for the sewer service is the Giles County Board of Supervisors (GCBOS). An existing 14-inch gravity sewer line lies approximately 0.5 mile outside the Town of Pembroke, approximately 1.5 miles from the proposed site location.

GCBOS received approval on June 26, 2000 from the Department of Environmental Quality (DEQ) for the Eastern U.S. Route 460 Corridor Sewer System Extension, based on a Preliminary Engineering Report (PER) dated June 2000. This report outlined the preliminary design for a regional sewer expansion from the existing Pembroke service area to Newport, Virginia. Phase I of the preliminary design includes the addition of service to the Giles County Industrial Park lying adjacent to Eastern Elementary / Middle School, which also includes the Hoges Chapel DUSEL Site. Currently, sewerage treatment for the Eastern Elementary / Middle School area is provided by a septic and treatment system. Upon completion of Phase I of the sewer system extension by the GCBOS, it is anticipated based on preliminary design efforts that the capability to provide sewer service to both the proposed Hoges Chapel DUSEL Site and Eastern Elementary / Middle school will be in place.

Electric

Electric service is available to the site, however existing lines are not immediately adjacent to the site. American Electric Power (AEP) will charge for extending that service based on the potential usage of the services.

Existing 3-phase electric service is available from AEP on U.S. Route 460. AEP has the capacity to serve the project at the proposed Hoges Chapel site location. Assuming a 9MW load, the two possible service scenarios are outlined below and include the initial pro-forma cost estimates for serving the Kimballton project DUSEL site:

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Improvements to Existing Sub-Station

The improvements required to serve the proposed load from an existing 34.5KV distribution source and provide 34.5KV delivery will cost approximately $250,000. The estimate could be higher if a separate substation, breaker and circuit are required.

Construction of New Sub-Station

The approximate cost to provide a 138 KV tap and a 138/34.5 KV substation on site is $4,000,000. This estimate is based on wood pole construction and would be higher if steel poles or towers are used. Cost estimates were determined using 34.5 KV to be consistent with the existing distribution system, which is somewhat flexible. If the load estimate increases, this may become the best choice, and alternatives will need to be reviewed as the project evolves in order to present the most advantageous response to the project needs. The advantage of this type of system is the significant increase in reliability, greater service range, and increased redundancy as the main power source to the facility.

Once KW demand and KWH / month load information is obtained, AEP will be better able to determine the more accurate development costs that would be the relayed to the project developer.

Telecommunications

Pembroke Telephone Cooperative (PTC) provides telephone, internet, and cable television service to the area. Discussions with PTC have revealed that service availability can only be determined after a customer makes a formal request for service to identify their needs. It has been determined that PTC has an existing size 24 fiber optic cable extending along U.S. Route 460 to the Eastern Elementary / Middle School. Representatives from PTC have indicated that adequate service can be provided to the proposed Hoges Chapel site. The level of upgrades, if needed, and the associated cost would depend upon the anticipated use for the facility.

Gas

There is currently not a gas provider in the area.

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MOUNTAIN TOP SITE

The proposed Mountain Top Site is located on the top of Butt Mountain. The general location of the site in proximity to surrounding land features is shown in Appendix D, Figure D1.

SITE LOCATION

The Mountain Top Tower is an out of service National Forest Service fire tower located in the north-central portion of Giles County. At an elevation of 4,200 feet above sea level, the Mountain Top Site rises approximately 2,600 feet above the New River at Ripplemead, Virginia.

ACCESS

A general access road map is included in Appendix D, Figure D2.

Roads

The Mountain Top Site is accessed by way of state secondary roads and National Forest Service roads. Approximately 1 mile west of the Hoges Chapel Portal entrance on U.S. Route 460, State Route 613 (Doe Creek Road) is a paved road constructed to secondary highway standards. Route 613 gains approximately 1,250 feet in elevation (to about 3,300 feet above sea level) over the 3.7 miles traveled to State Route 714.

State Route 714 is a compacted gravel road that is 13 feet wide with 3-foot wide shoulders on the cut side and 5-foot wide shoulders on the fill side. This road continues for 2.8 miles at which point state maintenance ends in the vicinity of Little Stony Creek. Along the way, Route 714 first climbs to an elevation of 3,600 feet above sea level, then descends to 3,050 feet at Little Stony Creek.

From the end of Route 714, a National Forest Service road (shown as Butt Mountain Road on Forest Service maps) crosses Little Stony Creek by way of a concrete bridge and begins the 1,150 foot climb over 4.4 miles to the Mountain Top Tower at elevation 4,200 feet above sea level. Butt Mountain Road is an "open" loose-gravel road that varies in width from 10-feet wide with 3-foot shoulders, to 12-feet wide with 2-foot shoulders. The road conditions are generally fair to good with isolated portions of extremely rutted segments requiring high-clearance vehicles and, in wet weather conditions, 4-wheel drive vehicles.

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AVAILABLE UTILITIES

A general Mountain Top Site map indicating existing and proposed utility information collected to date is included in Appendix D, Figure D3.

Water

A study of the existing water supply at the Mountain Top Site was investigated. General information was provided by Giles County in regard to water lines that exist in the service area. The site is not serviceable by an existing potable water system. It is anticipated that service can be provided via a well and storage system.

Sewer

A study of the existing sewer system at the Mountain Top Site was investigated. General information was provided by Giles County in regard to sewer lines that exist in the service area. The site is not serviceable by an existing sewer system without significant upgrades to the existing system. It is anticipated that service can be provided by an on-site septic system, or other means, depending on demand.

Electric

Existing single-phase electric service is available from AEP near the existing fire tower location at the Mountain Top Site. Existing power easements can be incorporated, or built upon, in order to provide the service necessary. AEP has the capacity to serve the project at the proposed site location, assuming a 9MW load. Once KW demand and KWH / month load information is obtained, AEP will be better able to determine the more accurate development costs that would be then relayed to the project developer.

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Telecommunications

Pembroke Telephone Cooperative (PTC) provides telephone, internet, and cable television service to the area. Discussions with PTC have revealed that service availability can only be determined after a customer makes a formal request for service to identify their needs. It has been determined that PTC has an existing fiber optic cable in the project area. Representatives from PTC have indicated that adequate service can be provided to the proposed Mountain Top site with new construction of additional fiber optic cable depending upon the required demand for the facility. The level of upgrades, if needed, and the associated cost would depend upon the anticipated use for the facility.

Gas

There is currently not a gas provider in the area.

SUMMARY

In summary, it is anticipated at this time that all three sites can be serviced with adequate utility needs. Items to note:

- The Kimballton, Hoges Chapel, and Mountain Top Sites can be serviced via a highly reliable 138 KV power source at a very reasonable cost due to the close proximity of the existing transmission line.
- The Kimballton, Hoges Chapel, and Mountain Top Sites can be serviced with phone, internet, and cable television via an existing fiber optic cable in the near vicinity to each site.
- The Kimballton site may be serviceable from a community water source based on an existing Preliminary Engineering Report with upgrades to the proposed preliminary design. The Hoges Chapel Site may be serviceable with upgrades to existing community water systems lines in the near vicinity as well.
- The Hoges Chapel Site is serviceable with construction of proposed Phase I of the Preliminary Engineering Report as approved for design of a regional sewer system.
- Further discussions and confirmation with Giles County officials is warranted to ascertain the schedule for water system upgrades and the feasibility in proceeding with proposed water system Alternative II to plan for possible future DUSEL developments.

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- Further investigation is recommended to determine the available capacity of the surrounding town's sanitary sewer systems and to discuss possible plans for future expansion.
- Once potential usage levels are established, demand information should be forwarded to water, sewer, gas, electric and high-speed broadband providers to confirm appropriate availability.

REFERENCES

- *Preliminary Engineering Report for the State Route 635/Chemical Lime Water Line Extension Project* by Thompson & Litton dated July 2004.
- *Virginia Base Mapping Program* of Montgomery County State of Virginia dated 2002.
- *Preliminary Engineering Report for the Eastern U.S. Route 460 Corridor Sewer System Extension* by Thompson & Litton dated June 2000.

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APPENDIX A

General Vicinity Maps

National Location Plan

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N

Site
Location

VA

0   420   840
Miles

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Figure A1

State Location Map

N

Washington DC

Site
Location

64

66

95

81

85

77

Commonwealth of Virginia

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0   75   150
                              Miles

Figure A2

Kimballton Portal Overview Map

Proposed
Kimballton
Portal

Limits of Jefferson
National Forest

Proposed
Mountain Top Site

635

613

460

New River

Proposed Hoges
Chapel Portal

18 Miles to
Va Tech

460

N

0   1   2
Miles

National Forest boundary from USFS GIS website.
USGS 7.5' Topographic Maps: Lindside, Pearisburg,
Interior, Eggleston

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Figure A3

APPENDIX B

Kimballton Site Maps

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Kimballton Portal Area Map

N

635

626

Approximate Location of Proposed Kimballton Portal

Mine Property

Existing Kimballton Mine

635

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0   1,000   2,000
                              Feet

Aerial Imagery Copyright 2002 Commonwealth of Virginia

Figure B1

Kimballton Portal Access Map

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Approximate Site Access Location

Approximate Location of Proposed Kimballton Portal

Existing Rail Service

Existing Kimballton Mine

Approximate Boundary of Mine Property

National Forest Boundary

25 Miles to Va Tech

```
0          2,100         4,200
                              Feet
```

National Forest boundary from USFS GIS website.
USGS 7.5' Topographic Maps: Lindside, Pearisburg
Parcel Information provided by Giles County.

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Figure B2

Kimballton Portal Utilities Map

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635

626

N

Approximate Location of
Proposed Kimballton Portal

Goldbond

Existing
Kimballton
Mine

Proposed 8" Water Line

Existing Fiber-Optic Line

635

Existing 138 kV and 345 kV
Transmission Lines

······· Fiber Optic
─ · ─ Electric
▬ ▬ Water - Proposed

0   2,000   4,000
                              Feet

Figure B3

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Utility Information provided by Giles County.
Fiber optic information provided by Pembroke Telephone Co-op.

APPENDIX C

Hoges Chapel Site Maps

Hoges Chapel Portal Area Map

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Approximate Location
of Proposed Hoges
Chapel Portal

Moore Property

Eastern Elementary /
Middle School

460

0   1,000   2,000
Feet

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Aerial Imagery Copyright 2002 Commonwealth of Virginia

Figure C1

Hoges Chapel Portal Access Map

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613

8 Miles to Top of Mountain

N

Approximate Boundary of J.Moore Property

Approximate Location of Proposed Hoges Chapel Portal

Approximate Site Access Location

Eastern Elementary School

460

18 Miles to Va Tech.

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0   2,000   4,000
Feet

USGS 7.5' Topographic Maps: Eggleston.
Parcel Information provided by Giles County.

Figure C2

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Hoges Chapel Portal Utilities Map

613

Existing 138 kV Transmission Line

Approximate Location of Proposed Hoges Chapel Portal

Existing Fiber-Optic Line

Existing Water Line

Proposed Sewer Line

460

⋯⋯⋯	Fiber Optic
— ⋅ —	Electric
——	1" - 4" Water
——	6" Water
——	8" - 12' Water
— —	Sewer Proposed

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0   2,000   4,000
Feet

Utility Information provided by Giles County.
Fiber optic information provided by Pembroke Telephone Co-op.

Figure C3

APPENDIX D

Mountain Top Site Maps

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Mountain Top Site Area Map

N

Forest Service
Fire Lookout
Tower

**Approximate Location of
Proposed Mountain Top Site**

National Forest Boundary

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0   1,000   2,000
Feet

Aerial Imagery Copyright 2002 Commonwealth of Virginia

Figure D1

Mountain Top Site Utilities Map

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Approximate Location of
Proposed Mountain Top Site

8 Miles to
Hoges Chapel

National Forest Boundary

Existing Telephone
and Electrical Line

Existing 345 kV
Transmission Lines

Existing Fiber-Optic Line

Existing 138 kV
Transmission Lines

▪▪▪▪▪	Fiber Optic
▬ · ▬ · ▬	Electric
———	Telephone / Electric

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0   2,000   4,000
                              Feet

Utility Information provided by Giles County.
Fiber optic information provided by Pembroke Telephone Co-op.

Figure D2

Appendix B: Kimballton Geology

Introduction

Since the beginning of the 2004 Fall semester an interdisciplinary team at Virginia Tech has been working to develop a comprehensive proposal for a national research laboratory to be based at the Chemical Limestone Corporation's Kimballton mine in nearby Giles County. This Appendix summarizes geologic information about the Kimballton site. Geotechnical and rock mechanics information is provided in a separate appendix (Appendix C). For comparison with the other candidate sites, a general geologic map showing the locations of all eight potential DUSEL sites is shown below (Fig. 1).
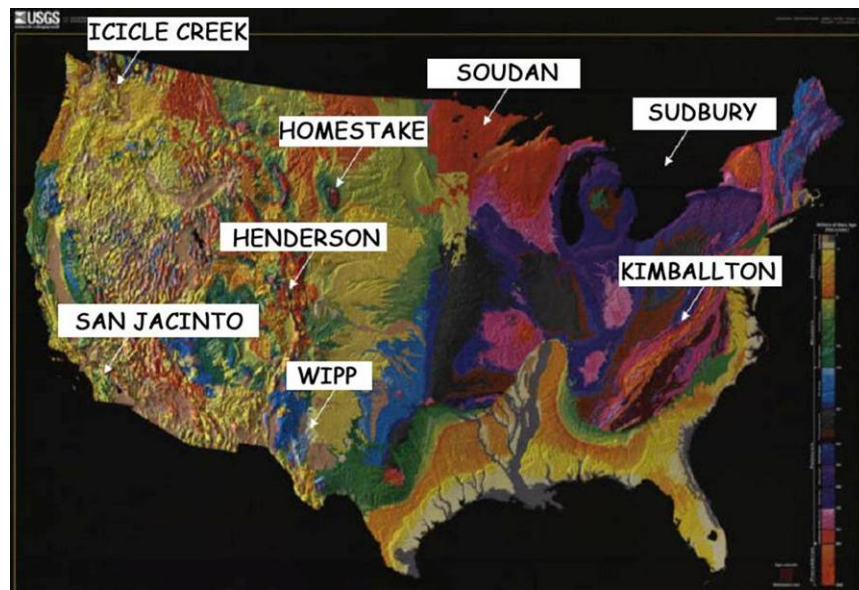
Figure 1: Map showing potential DUSEL locations.

Among the eight candidate sites, Kimballton is unique in that it offers the capability for hosting the DUSEL facilities in sedimentary rock, at the full depth of 7,500 ft (WIPP is also in sedimentary rock, but is not proposing to develop laboratories at the full depth.) The geology at Kimballton is characterized by hard, strong sedimentary rocks, primarily limestone and dolostone, in ancient overlapping thrust sheets. The imbricate thrust faults give rise to repeated stratigraphy, and good surface exposure of the Kimballton rock units, allowing excellent stratigraphic control. Access tunnels and shafts at Kimballton will begin in limestone and dolostone within the Narrows thrust sheet, and then cross the Narrows fault into limestone and dolostone of the St. Clair thrust sheet. Access tunnels and underground laboratories will be within competent rock formations with strengths comparable to that of granite. Karst features are expected in the uppermost few hundred feet, but both karst and fracture intensity are expected to decrease significantly with

depth. Evidence from the existing Kimballton mine, which has large, unsupported chambers at depths over 2000 ft., suggests that the geomechanical properties of Kimballton rocks are well suited to the creation and maintenance of large scale, long term underground openings.

Because of its sedimentary setting, Kimballton-DUSEL is particularly well-suited for significant research on hydrocarbon recovery and carbon sequestration. It also offers many advantages for bioscientists studying deep and ancient life. Kimballton-DUSEL will provide direct access to the core of the classic Appalachian foreland fold-thrust belt, the locus of ongoing studies on tectonics and orogenesis. Because of proximity to both east coast and mid-America seismic zones, it will provide valuable insight into earthquake hazard. Due to a wide range of scale of hydraulic pathways (from grain scale to major thrust faults), Kimballton will be a unique research facility for studying groundwater flow. Finally, Kimballton can serve as a primary center for studies on geomechanics of layered rock under high stress, with a major impact on future development of underground space in sedimentary host rocks.

Additional geologic characterization, beyond that discussed in this appendix, will be conducted as part of the S-2 process to further reduce uncertainty and to plan for facility design and construction. These additional geologic characterization studies are described in a later section.

Geological Setting of Kimballton

The Kimballton Mine and Butt Mtn are located in the Allegheny Mountains of southwestern Virginia, near the western edge of the Appalachian Valley and Ridge Physiographic Province. This region is characterized by linear ridges held up by tilted strata of resistant sandstone with limestone and shale in fault line valleys. Geologically, Kimballton lies in the classic Appalachian foreland fold-thrust belt. The bedrock consists of folded sedimentary rock of Paleozoic age arranged in overlapping thrust sheets (Figure 2). Structurally, the proposed Kimballton DUSEL laboratory site lies within the St. Clair thrust sheet, beneath the Narrows thrust fault, and above the St. Clair thrust sheet. The Appalachian foreland fold-thrust belt has been studied for more than 150 years. Several fundamental concepts related to the evolution of continental crust and mountain chains were formulated here. Those concepts have been applied in other mountain chains, such as the Jura Mountains and the Canadian Rockies, but opportunities exist to expand and develop new concepts based both on current knowledge and the unique opportunities afforded by being able to conduct experiments at depth.

Valley and Ridge topography (Figure 3) reveals some 300 million years of geological history. The Valley and Ridge overthrust structure reflects intense compression along the proto- Atlantic Continental margin during the Alleghenian collision event between North America and Africa. The collision created the Pangean super continent some 300 million years ago. Our present mountains are much younger, having formed by erosion in the post-Cretaceous Era.
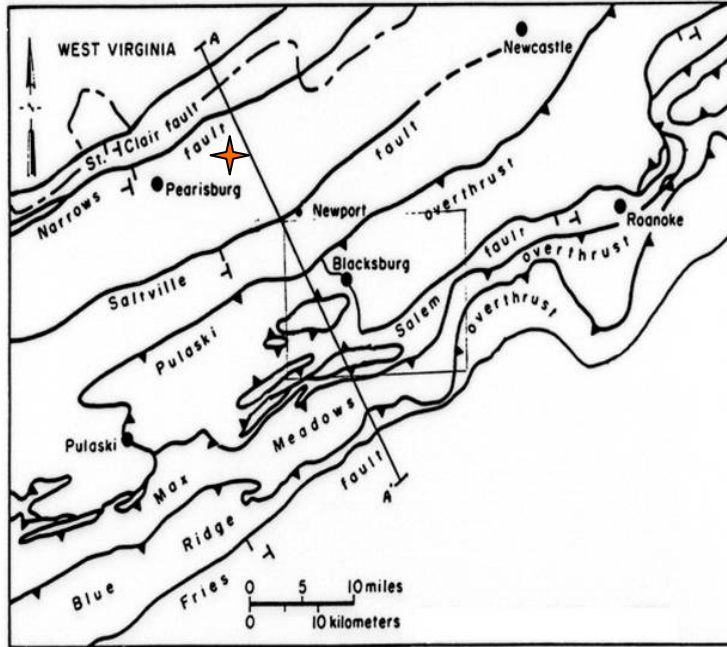
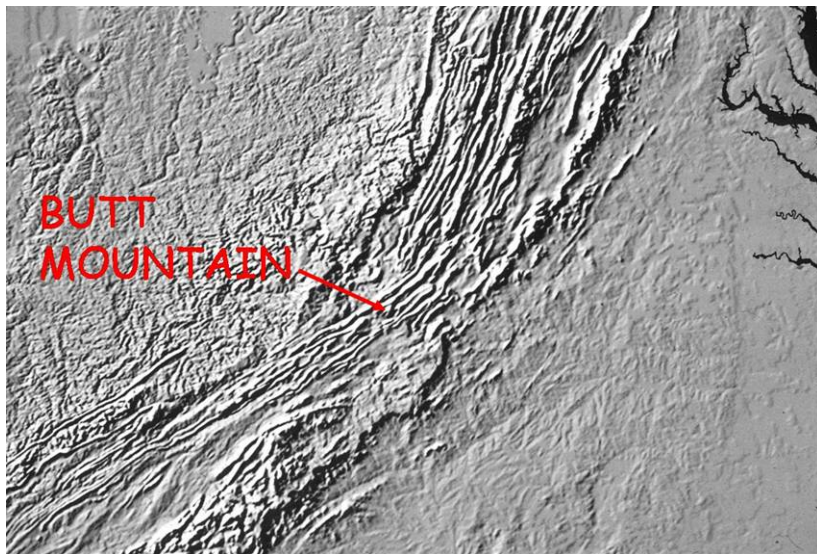Figure 2: Map showing overlapping thrust sheets and location of DUSEL.

Figure 3: Hillshade showing Valley and Ridge Topography.

The break up of Pangea began in the Triassic Period about 245 million years ago and by the Jurassic Period continental rifts forming the Atlantic and Gulf of Mexico Ocean basins were well established (Figure 4). The modern Appalachian Mountains are forming by gentle uplift, rejuvenation and entrenchment of rivers along the eastern flanks of the Atlantic Basin (Figures 4 and 5). Butt Mountain is located along a passive continental margin. Moderate seismic activity has been localized in basement rocks several kilometers below the site (Figure 6).
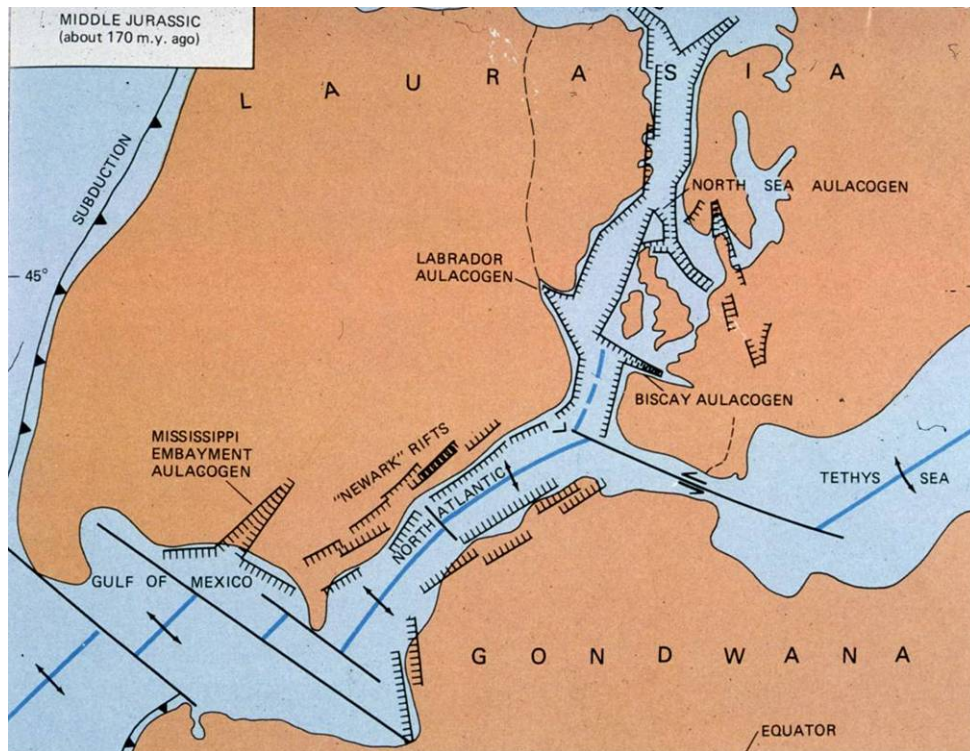
Figure 4: Jurassic Period continental rifts forming Atlantic and Gulf of Mexico ocean basins

Figure 5: Location of Butt Mountain along passive continental margin. Source: National Geographic
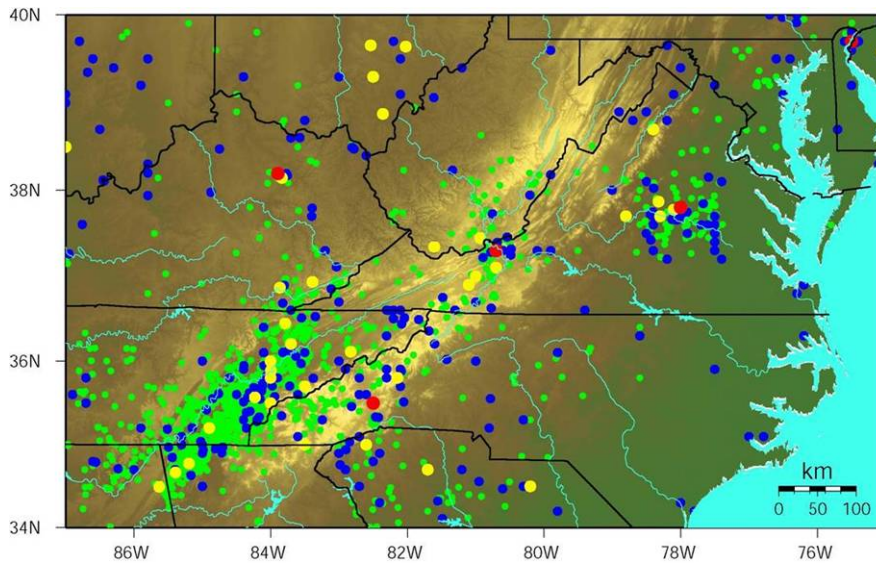
Figure 6: Regional seismic activity (moderate). Source: M. C. Chapman, Virginia Tech

Previous Work

The Kimballton area was studied first by Charles Butts in a landmark synthesis of regional stratigraphy and structural geology (1932, and 1941). Wartime needs for strategic minerals including high calcium limestone provided the impetus for VPI professor of geology Byron Cooper (1944) to map and describe details of the valuable Middle Ordovician Limestone sections in the Kimballton area. Photographs of the plant and original entrance to the underground mine workings beneath Butt Mountain published in 1944 (Virginia Geologic Survey Bulletin 62, Plate 6) give testimony to the long- term geologic stability in this area.

The well-exposed fold and thrust structures along the Appalachian Structural Front (Figure 1) were major exploration targets during the post-World War Two oil and gas exploration boom. A wildcat exploration well 1,443 deep that was drilled by the California Company on the Bane Dome southwest of the Kimballton Mine in 1948 was the first attempt to explore the Appalachian Thrust Belt of SW VA (Perry et al., 1979). The Straler well penetrated the nearly flat lying Narrows thrust fault on the crest of the Bane dome but was abandoned in massive Knox dolomite that was misidentified as the older Cambrian Shady Dolomite. This wild cat well helped to trigger a 30-year controversy on the nature of thin-skinned deformation in the Appalachians.

In preparing the geological model for the NSF proposal, the team has revisited the previous 60 years of geological and geophysical research by Virginia Tech faculty and graduate students. Surface and subsurface mapping by Thomas Gathright II, William Ekroede, Art Schultz, Chuck Stanley, Robert McDowell, and Jerry Bartholomew have proven invaluable in fleshing out Cooper's original stratigraphic studies of the Middle Ordovician limestone formations in the New River- Roanoke River District published in Virginia Geological Survey Bulletin 62, in 1944.

Geologic Map

A geologic map of the Kimballton area is shown as Fig 7. Lines AA', BB', CC', DD', EE' HH' and I-I' are cross sections developed as part of the initial geologic investigations for Kimballton-DUSEL which will be presented in Figs. 8 and 9. The proposed deep laboratories are to be located beneath Butt Mountain., approximately under the intersection of cross section lines I-I' and H-H'. Following Fig 7 are detailed lithologic descriptions, which also serve as the legend for the geologic map.
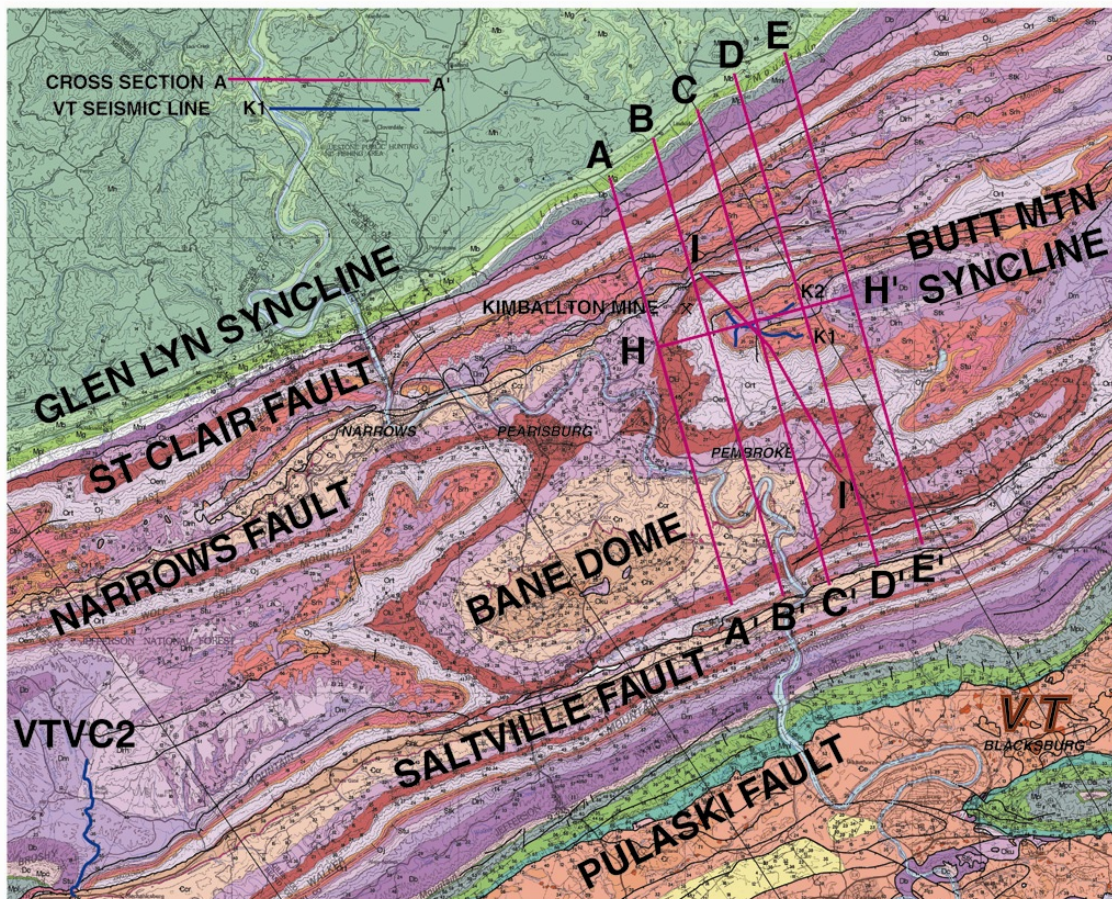
Figure 7: Geologic map of Kimballton area. The geologic cross sections are shown in Figs. 8 and 9

Lithologic Descriptions

MISSISSIPPIAN

Hinton Formation – Mh

Mh

Dark-gray, greenish-gray, and reddish-gray mudstone, gray siltstone, and dark- to light-gray, fine- to medium-grained sandstone; basal Stony Gap sandstone member is a resistant, 10-30-m thick, pebbly quartzite (Cooper, 1961). About 200 m of the lower Hinton is exposed in the northwestern part of this quadrangle within the Allegheny Plateau.

Bluefield Formation – Mb

Mb

The lower 200 m of the Bluefield Formation consists of interbedded medium- to dark-gray, argillaceous calcilutite and medium-gray calcareous mudstone. Total thickness of the Bluefield is about 600 m in the Allegheny Plateau; 420 m was measured by Humphreville (1981) near Glen Lyn.
The upper 400 m of the Bluefield Formation consists of interbedded gray to greenish-gray to reddish-gray mudstone, medium- to light-gray, fine- to medium-grained sandstone, and light-gray siltstone with minor dark-gray to black coal beds.

Greenbrier Group (undivided) – Mg

Mg

The basal 40 m consists of interbedded medium- to dark-gray, fine-grained, argillaceous limestone and medium- to dark-gray mudstone. The basal unit is overlain by about 10 m of medium- to dark-gray, massive-bedded, fine-grained limestone with black chert lenses. The upper 210 m consists of interbedded dark-bluish-gray, thick-massive-bedded, fine-grained limestone, dark-gray argillaceous fine-grained limestone, and light-gray oolitic and bioclastic, medium-grained limestone, with minor dark-gray mudstone interbeds.. Total thickness of the Greenbrier is about 260 m but along most of its outcrop length on the overturned limb of the Glen Lyn syncline, beneath the St Clair thrust sheet, it is tectonically thinned to about 60 m.

Maccrady Formation – Mmcl

Mmcl

The lower marine member consists of cyclic deposits of sandstone overlain by mottled grayish-red and grayish-green mudstone. The mottled mudstone is in units that are commonly 8-15 m thick and are interbedded with 15-100 cm thick beds of medium-gray, thin-bedded, fine- to medium-grained sandstone and crossbedded, medium- to coarse-grained sandstone. In a few localities, sandstone cycles contain dark-gray to black mudstone with thin coal seams. The sandstone typically consists of 6-10 m of thick (30- 120 cm) dark-grayish-red, crossbedded, or medium-gray, medium- to coarse-grained, feldspathic and/or micaceous, quartzose sandstone. The base of the Maccrady is placed at the base of the lowest thick bed of dark-grayish-red sandstone Total thickness: about 300 m in the Saltville thrust sheet in Pulaski and Montgomery counties and about 10 m along the overturned limb of the Glen Lyn syncline beneath the St Clair thrust in Giles and Monroe counties.

Price Formation – Mpru

Mpru

(upper member) – A coal-bearing, dark-gray to black mudstone forms the basal 20-40 m of the upper member (Bartholomew and Lowry, 1979). One to six (locally) coal beds, present within this basal mudstone unit, have been mined (Bartholomew and Brown, 1992). Rank of the coal ranges from semi-anthracite to low-volatile bituminous (Lewis and Hower, 1990; Campbell and others, 1925). The coal occurs in 0.5-6 m thick beds and is black, commonly laminated, bright and dull coal and is interlayered with dark-gray to black, thinly laminated, commonly rooted mudstone (Brown, 1983); plant fragments are abundant and locally upright lycopod tree stumps are present (Locality 5) (Bartholomew and Brown, 1994). The basal mudstone unit is overlain by a nonmarine cyclic clastic sequence of sandstone, siltstone, and mudstone. Scour channels are common and coarse-grained, lithic arenites form the basal part of each sequence and fine upward into dark-gray laminated siltstone (Brown, 1983). The arenites are medium-gray, thick-bedded (30-120 cm), crossbedded, uncommonly rippled (Kreisa, 1972), coarse- to medium- to fine-grained arenite with lithic clasts of mudstone common near the base of coarser beds. Mottled grayish-red and green mudstone locally caps sequences. The thickness and amount of mottled mudstone increases upward so that the uppermost 30-50 m of this member is predominantly mottled mudstone with minor fine-grained sandstone-interbeds Total thickness: about 350 m in the Saltville thrust sheet.

Mprl

Mprl (lower member) – dominantly marine, interbedded sandstone, siltstone, and mudstone with 3-15 m-thick beds of quartz-pebble conglomerate and orthoquartzite locally; member coarsens eastward to interbedded medium- and coarse-grained sandstone. The sublitharenites are medium-gray, fine- to medium-grained, platy, well laminated or crossbedded with lithic fragments of quartz, feldspar, and mica (Brown, 1983). The siltstones are medium-gray, platy, well laminated and are sometimes associated with clayball conglomerates. Thin (10-20 cm) sandy quartz-pebble conglomerates occur locally near the base and are typically massive-bedded with 0.5-1 cm, well rounded, well sorted milky-quartz-pebbles, gray-chert-pebbles and other rock fragments in a siliceous cement Total thickness; about 200 m in the Saltville thrust sheet west of New River and about 300 m east of New River; and about 130 m along the overturned Glen Lyn syncline.

Mprc

Mprc (Cloyd Conglomerate member) – The Cloyd Conglomerate, at its type locality (Butts, 1940) on Cloyd Mountain near New River is white to light-gray, massive-bedded to crossbedded (on a scale of several meters), graded, 3-6 m-thick sequences of quartz-cobble, quartz-pebble and sandy quartz-pebble conglomerate. Milky quartz-clasts, with 2-10 cm long axes, are the dominant clast type with minor chert-clasts typically present. Predominantly siliceous cement; although Kreisa (1972) noted some hematite-cement locally. Twelve to 20 m of this lithology predominate from about 7.5 km southwest of Virginia Route 100, northeastward along Little Walker Mountain, Cloyds Mountain, and Brush Mountain to the vicinity of the U.S. Highway 460 gap. In eastern Montgomery, Roanoke, and Botetourt counties the Cloyd is predominantly light-gray to white, coarse-grained, conglomeratic quartz arenite with thin (0.3-1 m) beds of sandy, quartz-pebble conglomerate (Bartholomew and Brown, 1992). At the New River and Poverty Creek water gaps and the Virginia Route 100 wind gap the Cloyd thins and undergoes a rapid facies-change. At these gaps the member consists of coarse-grained, light- to medium-gray or reddish-gray quartz arenite with thin (0.3-1 m) sandy, quartz-pebble conglomerate lenses (Brown, 1983). Similar sandstones are found interbedded with reddish-gray siltstone just below classic

Cloyd at the U.S. Highway 460 gap where Cooper (1961) included them in his Parrott Formation and also appear to be interbedded with reddish-gray siltstone on the eastern end of Fort Lewis Mountain, where Rossbach and Dennison (1994) identified Hampshire Formation just below the Cloyd. Total thickness: 2-20 m in the Saltville thrust sheet.

DEVONIAN

Chemung Formation (of Cooper, 1961) – Dch

Dch

Fossilferous sandstones which overlie Brallier lithologies and underlie sandstones of the Mississippian Price Formation were termed Chemung Formation by Cooper (1961), although this designation has not been formalized for this region and Rossbach and Dennison (1994) have suggested subdividing the Chemung into the Foreknobs and Hampshire formations. Predominantly cyclic clastic sequences of medium-gray, medium-grained sandstone fining upward to medium-gray siltstone, locally capped by black mudstone with sharp contacts. Scour channels and fossil-debris mark the base of each sequence (e.g., Bartholomew and others, 1982; Randall, 1984; Bartholomew and Brown, 1992). Sandstones are medium-gray, thick, massive-bedded, slightly calcareous, medium- to fine-grained, lithic sandstone. The base of the Chemung is placed at the base of the lowest thick beds of sandstone containing abundant fossil-debris. The upper 5-15 m of the Chemung contains abundant 0.5-2 m-thick beds or lenses of sandy conglomerate and conglomeratic sandstone. Total thickness: about 500 m on Fort Lewis Mountain in the Catawba thrust sheet; 150-300 m in Saltville thrust sheet.

Brailler Formation – Db

Db

Predominantly interbedded cyclic sequence of 5-15 cm thick, dark-gray to black claystone and mudstone beds and 5-15 cm, medium-gray siltstone and medium-gray, commonly crossbedded, fine-grained sandstone. Sandstone and siltstone percentage increases upward in section. The base of the Brailler generally is placed at the base of the lowest thin beds of interbedded siltstone and fine-grained sandstone. The base in the western part of the map area is the base of a laterally extensive, 3 m-thick section of medium-gray, massive, thick-bedded (15-60 cm), medium- to fine-grained sandstones.   Total thickness: about 500 m on Fort Lewis Mountain in the Catawba thrust sheet; about 1000 m elsewhere.

Millboro Formation – Dm

Dm

Dark-gray to black, thin-bedded, fissile claystone with a few interbeds of mudstone. Locally, thin (0.5-2 m), dark-gray, fine-grained limestone beds are present near the base. Abundant zones of concretions, calcite-filled vugs, calcite-coated fracture surfaces and disseminated sulfides occur throughout the formation which is sparsely. Total thickness: about 100 m.

--Disconformity--

Undivided Devonian Limestones, Rocky Gap Sandstone and Huntersville Chert

Dlrh (Undivided Devonian Limestones) – Poorly exposed only in northeastern portion of quadrangle; bluish-gray, thick-bedded, coarse-grained, crystalline limestone and thinly laminated, fine-grained, argillaceous limestone

Dlrh

Dlrh (Rocky Gap Sandstone) – Medium-gray to locally dark-green (glauconitic), medium- to coarse-grained, commonly iron-oxide cemented, subgraywacke and medium-gray, locally crossbedded, subquartz arenite, which weather to brownish-gray to yellowish- or reddish-gray; at Fagg (Locality 18), the base is a sandy, lithic-cobble conglomerate; weathered crinoid and brachiopod molds; iron and manganese ores occur along joints and filling voids or as cement. Butts (1940) measured 11 m along Virginia State Highway 311 on Catawba Mountain.

Dlrh (Huntersville Chert) – Light- to dark-gray, fine-grained chert in irregular, 2-10 cm-thick beds separated by 0.5-1 cm lenses of dark-gray to black mudstone with chert beds somewhat nodular to irregularly layered tabular lenses 1-4 cm thick with shaly partings; as much as 10 m of chert is common in northwestern part of area.

SILURIAN

Tonoloway Limestone and Keefer Formation

Stk (Tonoloway Limestone) – upper siliceous clastic sequence, medium-gray, calcareous, thinly laminated siltstones, light-gray, very fine-grained, crosslaminated sandstones and dark-gray calcareous, finely laminated shales with minor, gray, fossiliferous and intraclastic conglomeratic calcilutites and dark-gray, calcareous silty shale; dark-gray, thin-bedded, limestone dominant in the lower sequence, cyclic, brachiopod and ostracod-rich calcilutites and calcisiltites, dark-gray, fissile, silty calcareous shales and dark-bluish-gray, massive, fine-grained calcilutites.

Stk

Stk (Keefer Formation) – light- to dark-gray, fine- to medium-grained sandstone and quartzite; crossbedded and crosslaminated, rippled, mudcracked, and burrowed. Includes some very light-gray, grayish-red and minor medium-red siltstone and shale, Total thickness: ranges from 65-70 m;

Rose Hill Formation – Srh

Dark-reddish-gray (hematitic), fine- to medium-grained, quartz sandstone irregularly interbedded with lesser amounts of dark-reddish-gray to occasionally bright-grayish-green shale; sandstone has prominent low-angle crossbedding and laminations. Clay galls and lenses of quart-pebble, lithic-fragment and fossil-hash conglomerate occur within the sandstone. Grayish-red, massive-bedded, burrowed, fine-grained sandstone and light-olive-gray, fissile shale is interbedded with the sandstone. Thickness of the Rose Hill Formation varies. Ranges include: Johns Creek Mountain -50 m; Cascades -45 m; White Rocks Mountain (Eckroade, 1962) -63 m; the Narrows (Hale, 1961) -59 m; Mill Creek area (Whitman, 1964) -82 m; Catawba Mountain (Butts, 1940) -32 m.

Srh

Tuscarora Formation – Stu

Stu

Lower transitional zone (with the underlying Juniata Formation) -greenish-gray to medium-light-gray, medium- to coarse-grained sandstones with interbedded medium-light-gray orthoquartzite and quartzarenite; crossbedding and crosslaminations are common; local conglomeratic beds. Middle quartzite zone - very light-gray, resistant, ledge-forming, exceptionally well sorted and well indurated, thick-bedded, fine- to coarse-grained orthoquartzite. Upper transitional zone - alternating medium-light- to dark-gary, fine- to medium-grained sandstones with medium-gray quartzites. Worm burrows are the only fossils. West of the Pulaski thrust, thickness varies from 15 m near the Cascades (Eckroade, 1962) to 60 m on Walker Mountain (Butts, 1940); the average thickness is about 35 m; Within the Catawba thrust sheet the Tuscarora varies from about 1.5 m at Fagg (Locality 18), where it is bounded by unconformities (Tillman, 1963), to 5 m near Hanging Rock (Amato, 1974) to 15 m where U.S. 311 crosses Catawba Mountain (Tillman, 1963).

ORDOVICIAN

Juniata Formation – Oj

Oj

Lower part is dominantly grayish-red and pale reddish-brown, fine-grained sandstone interbedded with minor grayish-red shale. Reduction spots, crossbedding, and brachiopod fragments are common in the fine-grained sandstones. Formation grades upward into interbedded light-gray quartzites and grayish-red to dusky-red, finely crosslaminated, fine- to medium-grained sandstones with minor grayish-red, fissile siltstone. Medium- to thin-bedded (5-15 cm). Kreisa (1980) reports Lingula in the lower 22 m along county road 738 on Walker Mountain south of Mechanicsburg (Locality 19), in the lower 80 m along New River north of Narrows (Locality 20), and in the lower 11 m along New River at Gap Mountain (Locality 21). Total thickness: about 100 m (Hale, 1961; Eckroade, 1962; Whitman, 1964); Butts measured 65 m north of Narrows.

Martinsburg Formation – Omb

Omb

Upper portion is dominantly interbedded dark-gray to black mudstone and medium-gray, massive-bedded to well laminated, fine-grained sandstone.The lower portion is composed of interbedded medium- to dark-gray, coarse-grained, 2-15 cm-thick beds of limestone with abundant bioclastic debris, and light- to medium-gray, calcareous mudstone (Kreisa, 1980). Locally this unit is intensely deformed with well developed solution-cleavage. Butts (1940) measured a thickness of 445 m and Kreisa (1980) a thickness of 407 m.

Eggleston Formation and Moccasin Formation (St Clair, Narrows, and Saltville thrust sheets)

Oem

Oem (Eggleston) - Interbedded light-gray, fine- to medium-grained sandstone and siltstone and medium- to dark-gray, silty limestone with yellowish-green, waxy, translucent bentonite beds; Butts measured 45 m along New River north of Narrows.

Oem (Moccasin) - Interbedded maroon mudstone and medium-gray limestone form gradational contact with underlying Middle Ordovician limestone, pink to gray, thin-bedded, argillaceous calcilutite and dark reddish-gray, laminated,

calcareous mudstone and siltstone; mudcracks are common; middle part of unit is a gray calcilutite with minor mudcracks; upper part of the unit is interbedded medium-reddish-gray, laminated, calcarious mudstone and siltstone and minor gray to pink, argillaceous calcilutite. Thickness ranges from 15 to 35 m (Kreisa, 1980). The Eggleston and Moccasin Formations of the Saltville, Narrows and St Clair thrust sheets are laterally equivalent to the Bays Formation of the Pulaski thrust sheet.)

Bays Formation (Catawba and Saltville thrust sheets, Draper Mountain and Christiansburg allochthons)

Oba

Oba - Interbedded light-gray, fine-grained quartzite and light-gray or reddish-gray quartzose sandstone and greenish-gray or reddish-gray siltstone and mudstone and dark-yellowish-green, waxy, translucent bentonite. Thickness varies, in the Catawba thrust sheet from 30 m near Catawba (Kreisa, 1980) to 300 m near Ellett (Tillman and Lowry, 1968) where Butts (1940) measured 268 m. On State Highway 311 near Catawba (Locality 28), Kreisa (1980) reports Lingula throughout the Bays Formation.

In the Narrows thrust sheet just beneath the Saltville thrust, the thickness of a coarse-grained, conglomeratic sandstone varies from about 1 to 3 m and this Bays unit is included in the Eggleston Formation. In the Saltville thrust sheet, where the Bays sandstone and conglomerate are also included in the uppermost part of the Eggleston Formation, the Bays lithologies pinch out northeastward about 2 km west of New River in the northeastern corner of the Staffordsville quadrangle (Locality 29).

Undivided Limestones of Middle Ordovician Age – Olu

Olu

Lower dolomite and dolomitic limestone sequence: medium- to light-gray, dolomitic limestone sequence with a basal, medium- to light-gray dolomitic calciolutite with angular chert and dolomite clasts both rounded and angular (e.g., Localities 35, 36, 37); overlying beds are medium-light-gray, massive-bedded, calcareous dololutites with numerous fenestry and scattered medium-gray chert. Also overlying the lowermost beds are argillaceous dolomites, medium- to light-gray with wavy anastamosing stylolites and medium-gray calcite blebs. Thickness ranges from about a meter to greater than 40 m (Frieders, 1975).

Middle cherty, fossilferous limestone sequence: medium-light-gray to medium-dark-gray calcilutite and calcisiltite interbedded with coarse-grained calcarenite are dominant lithologies. Dark-gray and black nodular and bedded chert is abundant and characteristic. Fossil-hash zones containing brachiopods and bryozoans are scattered throughout the unit. Thickness is about 120 m.

Upper argillaceous limestone sequence: medium- to dark-gray, irregularly to planar-bedded, argillaceous calcilutites and calcisiltites with interlaminated and interbedded, thin, olive-gray shales; abundant fossil fragments.Thickness is about 75 m.

Knox Group (Undivided Kingsport, Mascot, Longview, and Chepultepec Formations) (St Clair, Narrows, and Saltville thrust sheets) – Oku

Oku

Medium-dark-gray to light-gray, massive-bedded to poorly styolitic, thick-bedded fine- to medium-grained, crystalline dolomite with lenses and nodules of light-gray to black chert; dark-reddish-brown argillaceous dolomite and lenses of laminated to crossbedded, fine-grained, siliceous clastics are present in the basal

part; algal laminations and domal structures are common; abundant cherty residuum obscures this unit; laterally equivalent to Beekmantown Group. Thickness is about 165 m along New River north of Narrows (Gustafson, 1981).

CAMBRIAN

Copper Ridge Formation – Ccr

Ccr

Dolomite, sandy dolomite, minor sandstone, and thinly laminated, argillaceous dolomite (near the base). Dolomite is light- to medium-gray, thin- to medium-bedded dololutites and dolosiltites. Stromatilitic and flat algal laminations common in dololutites, with minor flat-pebble conglomerates. Typical thinly "ribbed" weathered dololutites formed from differential weathering of quartz-silt laminations. Sandy units include light-brown to grayish-orange, thinly-laminated to massive-bedded, carbonate-cemented, fine- to coarse-grained sandstone and light-gray, thin-bedded, sandy dolosiltites. Cross laminations, crossbedding and small-scale channels are prevalent in sandstones and sandy dolosilltites. Minor, dark-gray, siliceous, oolitic dololutites, dark-gray to black chert and very light-gray "cauliflower" chert scattered throughout the section. Copper Ridge Formation is about 300 m thick.

Elbrook Formation (Pulaski and Catawba thrust sheets and associated allochthons) – Ce

Ce

The uppermost part of the formation is characterized by interbedded sandy, commonly crossbedded, fine-grained dolomite containing thin (1-10 cm) lenses of fine- to medium-grained sandstone and 30-120 cm thick ribbon-banded limestone/dolomite. The amount of quartzose sand decreases and the percentage of limestone increases, downward. Below the upper part, the dominant Elbrook lithology consists of cyclic sequences of medium-gray, thinly laminated, fine-grained dolomite with crossbedding, scour channels, and edge-wise, dolomite-conglomerates; bioturbated, fine-grained dolomite with burrowed areas filled with slightly coarser grained dolomite; and ribbon-banded, slightly burrowed, fine- to very fine-grained dolomite and/or micritic limestone. Limestone units are up to 15 m thick. The percentage of limestone decreases downward so that dolomite overlies the basal 7-15 m of light-greenish-gray, thinly laminated, fine-grained phyllitic, dolomitic mudstone and interbedded dolomite. In the Salem synclinorium the exposed thickness is about 500 m. The soil is characteristically a light orangish brown color.

Nolichucky Formation (St Clair, Narrows and Saltville thrust sheets) – Cn

Cn

Grayish-brown to medium-gray, thin- to medium-bedded, argillaceous dololutites to dolosiltites with numerous olive-gray shale partings; yellowish-gray to olive-gray, fissile, calcareous, and thinly laminated mudstone with dark-gray to black, phosphatic fossil-fragments, and light- to medium-gray, thin- to medium-bedded, dolomite-clast, flat-pebble conglomeratic dololutites. Thickness is about 15-30 m in Narrows and Saltville thrust sheets. Markello (1979) measured 20 m of Nolichucky in the new road cuts along Virginia Highway 100 between Bane and Staffordsville.

Honaker Formation (St Clair, Narrows and Saltville thrust sheets) – Ch

Ch

Light- to dark-gray, thin- to massive-bedded dololutites and dolosiltites; in the lower part of the Honaker, bedding surfaces are highly irregular due to stromatalites and thrombolites; thick bedding-parallel stylolites are common; oolitic dolosiltites occur in the upper part of the formation, interbedded with massive-bedded, chert-bearing, dark-gray dololutites. Weathered, rusty-brown, spongy chert is abundant on slopes below the Nolichucky-Honaker contact. In the Bane dome area of the Narrows and Saltville thrust sheets, the Honaker Formation is about 300 m thick.

Rome Formation – Cr

Cr

In the Pulaski thrust sheet, consists of mottled maroon, green and yellow, phyllitic, mm- to cm-laminated mudstone with interbeds of red siltstone (3-8 m thick), light-gray to pinkish-gray to red, fine-grained, well sorted, sandstone and orthoquartzite (up to 5 m thick) with hematite-cement in the red units and silica-cement in the orthoquartzites, dark-gray, massive-bedded, crystalline dolomite (up to 16 m thick) with irregular styolites and vugs, and light- to medium-gray, thinly (mm - cm) laminated, fine-grained, silty dolomite (up to 10 m thick). Micaeous minerals impart a poor to well developed parting parallel to bedding which is commonly cut by a younger, poor to well developed cleavage. The rock is extensively fractured and calcite-coated and/or slickensided surfaces are common. Neither the top nor base of the Rome is exposed and intensive deformation characterizes the unit throughout the region; thickness is not determinable although it probably exceeds 300 m.

In the Bane Dome on the Narrows thrust sheet, consists primarily of interbedded, mottled, brownish-red to pink to greenish-gray mudstone and dark-gray, thinly laminated, fine-grained dolomite and dolomitic mudstone (0.1-1 m). The upper part of the Rome is highly deformed and is truncated by the Narrows fault in the core of the Bane Dome.

Structural Model

Geophysical data gathered processed and modeled by Mark Gresko (1985), W.J. Demoracki, J.K. Costain and C. Coruh (1989) and Moses and Robinson (1991) during the Appalachian overthrust exploration boom of the late 70s and early 80s has been useful in understanding the regional structure. The working model for the area is that of a major anticline-syncline pair, including the Bane Dome- Butt Mountain Syncline. These regional structures were produced by subsurface imbrication beneath the Saint Clair and Narrows overthrust faults that outcrop in elongate valleys between the long Allegheny ridges west of the mine. Examination of several published cross sections in the area (McDowell, and Schultz, 1990), led to the initial use of the ABIA sponsored cross section by N. Woodward and D. Gray with modifications west of the St. Clair Fault based on a cross section submitted with the 100,000 Radford Geologic Map (Bartholomew and others in Schultz and Henika, 1994, Bartholomew and others, 2000).

In preparing the model a series of cross sections across the mine area was constructed (Figure 8) using the stratigraphic framework and measured thicknesses presented by McDowell, and Schultz, 1990. These differed significantly in detail from the generalized units used in the ABIA regional sections. Structural contour maps prepared from the initial models were used to constrain the positioning of the proposed lab sites beneath the Butt Mountain Syncline. Major issues in developing the structural model and dependent sub-thrust research proposals included identifying the depth and extent of the Narrows thrust zone, and the predicted structure and stratigraphy beneath the St Clair fault as well.

The Narrows Zone is a regionally important, southeast dipping imbricate fan that seems to double or triple the Martinsburg shale and limestone beds dipping beneath the Butt Mountain syncline in the existing model. Petroleum prospect scenarios circulated through industry circles in the 1980s showed a sub-thrust projection of the prospective Upper Ordovician through Lower Devonian clastic and carbonate section extending as far to the southeast of the frontal St. Clair thrust as the crest of the sub-thrust anticline beneath the Bane Dome. Bartholomew's section (1994, 2000) allowed for space in the sub-thrust section beneath the Butt Mountain Syncline for this prospective clastic section whereas the Woodward and Gray model showed the Silurian and Devonian portion of the prospective section truncated against the St Clair Thrust along the northwestern Limb of the Butt Mountain Syncline. The current interpretation is shown as Fig. 9.
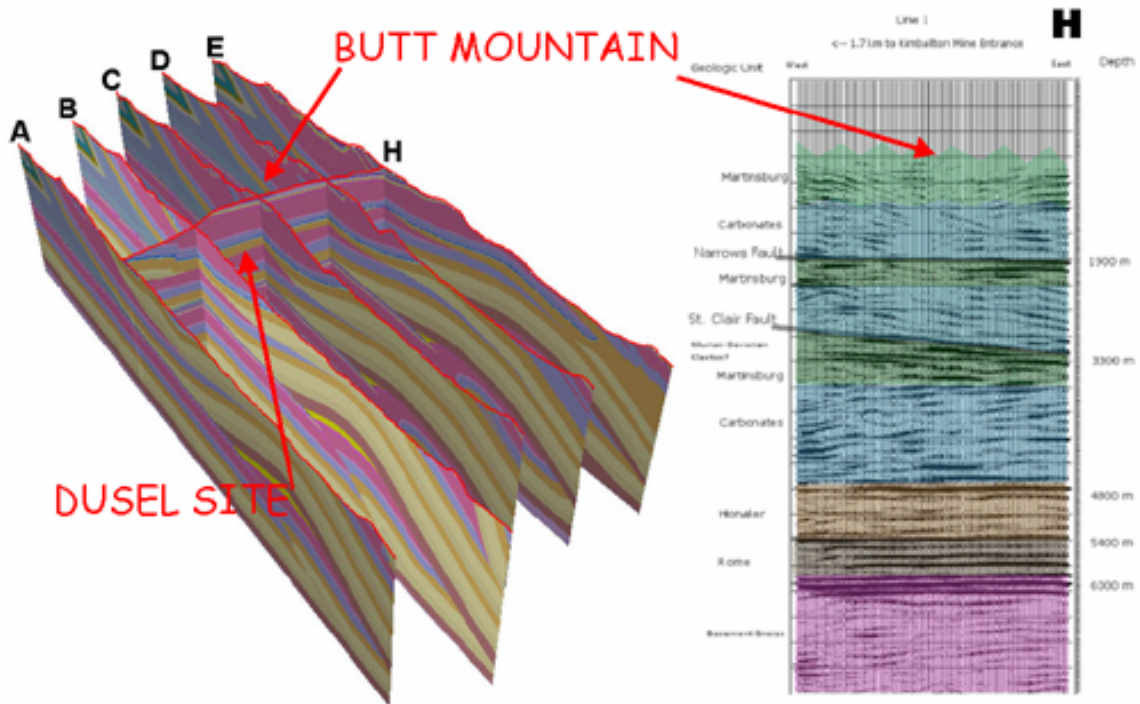
Figure 8: Geologic cross sections using stratigraphic framework and measured thicknesses.
A detailed report on the seismic survey is presented in a separate appendix.
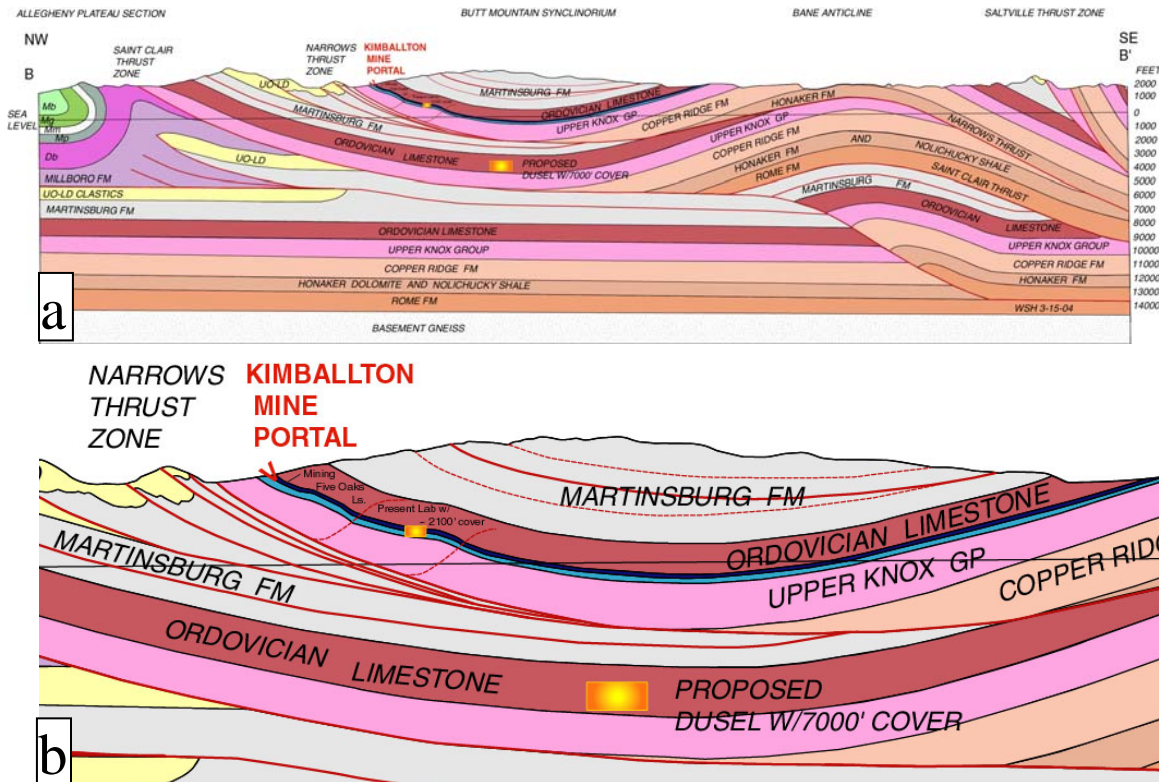
Figure 9: (a) Current interpretation based on Woodward & Gray structural model; (b) detail

Testing the Structural Model Using Seismic Profiling

During the late 1970s and early 1980s, Vibroseis profiling had previously been used to outline the general structure of the Bane Dome – Butt Mountain Syncline both by the Chevron Oil Exploration Company and to a lesser extent by a Virginia Tech Seismic Crew supervised by Dr. John Costain. Costain's group (Domoracki and others 1989) recognized the essential style of multistack imbricate trusting and delineated a consistent seismic stratigraphy within the St Clair and Narrows thrust sheets on Virginia Tech Seismic Line VTVC2A (Figure 10). It was conceived that a test of the Butt Mountain structural model could be accomplished by seismic profiling in the Jefferson National Forest land above the Kimbalton Mine. Two dynamite seismic lines K-1 and K-2 (Figure 7) were located generally along the projection of cross section H-H', a strike cross section drawn along the ridge of the mountain. These lines recognized a similar seismic stratigraphy to the previous Industry and Virginia Tech Vibroseis profiles.

While they general supported the multistack-overthrust style beneath Butt Mountain previously recognized in published cross sections, close inspection of the K-1 and K-2 seismic records showed that the highly prospective upper Ordovician- Lower Devonian Clastic-carbonate unit does not appear beneath the Saint Clair thrust in the Butt Mountain Syncline as depicted in the initial cross sections drawn using Bartholomew's Cross Section B-B' as a model. Instead of the tight and persistent "railroad track" seismic reflection zone marked "Clinch sandstone "above the Ordovician Martinsburg on VT line

C2 line model, lines K-1 and K-2 show broad zone of weaker reflections thought to be deformed limestone and highly calcareous shale beds in the Martinsburg beneath the Narrows Thrust (Figure 10). A report on the Seismic Site Characterization Program for the proposed DUSEL site below Butt Mountain is attached to this appendix.
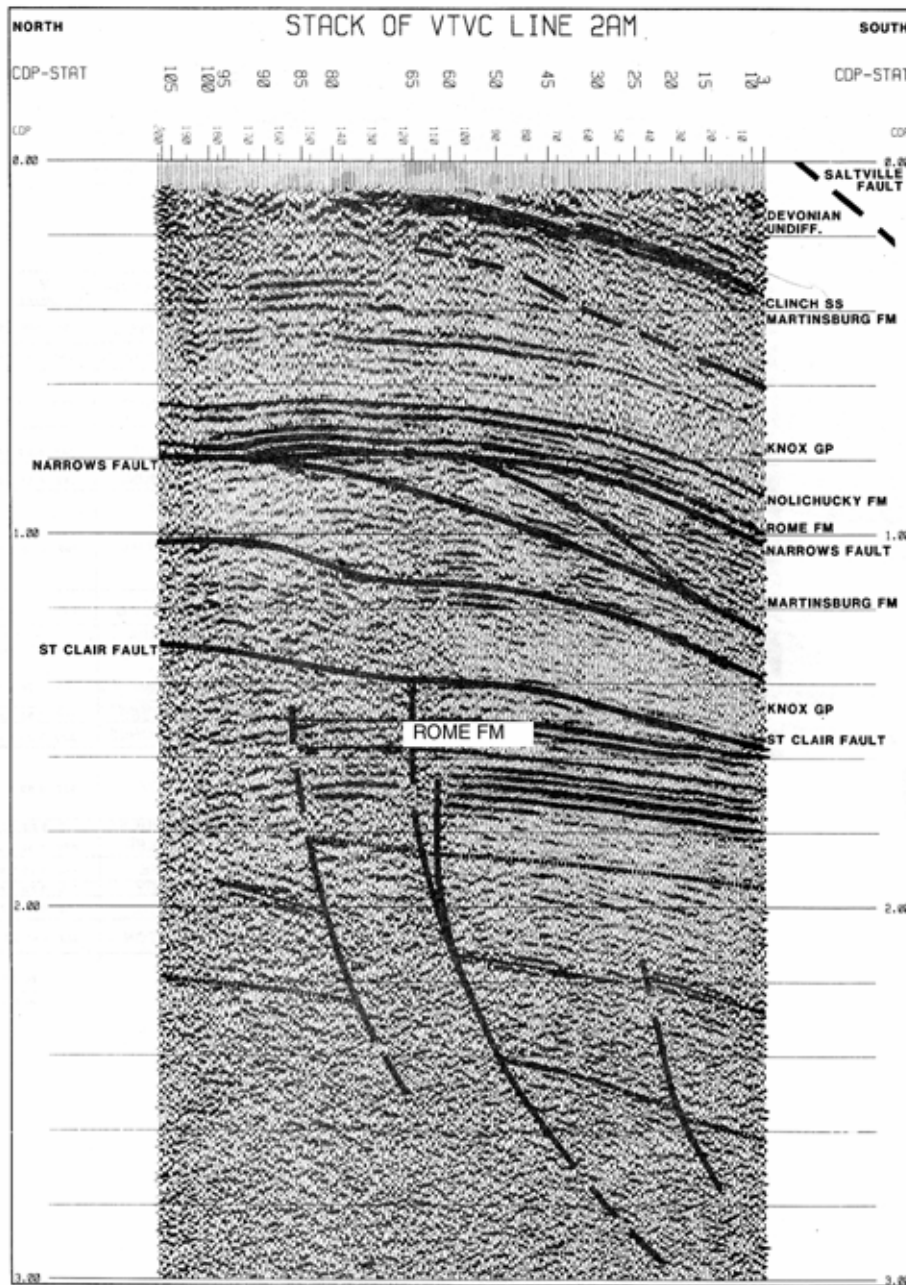
Interpreted stack of Line VTVC2A (unmigrated): Three major fault slices are interpreted to occur between the St. Clair and Narrows faults.
Modified from Domoracki,W.J. , Costain, J.K, and Coruh, C., 1989

Figure 10: Virginia Tech seismic line VTVC2A.

Lineament, Karst and Fracture Trace Study

Over 60 years of underground mining at the Kimballton mine has provided a detailed localized fracture study of massive carbonate units on the Narrows Thrust sheet. In order to get a qualitative look at regional fracture sets, a topographic and aerial photography based fracture trace study was conducted by members of the Kimballton team. A statistical approach to delineate only longer, more persistent lineaments using a linear mask (straight edge) was used. The lineaments produced in this study are correlated with the major karst features (Figure 11) mapped in the published Giles County Karst Map by Hubbard (Miller, E.V. and Hubbard, D. A. Jr., 1986). The major fracture systems are relatively widely spaced, northwest and southeast trending, nearly vertical features that correspond to joints and fractures mapped in the Kimballton Mine (Figure 12).
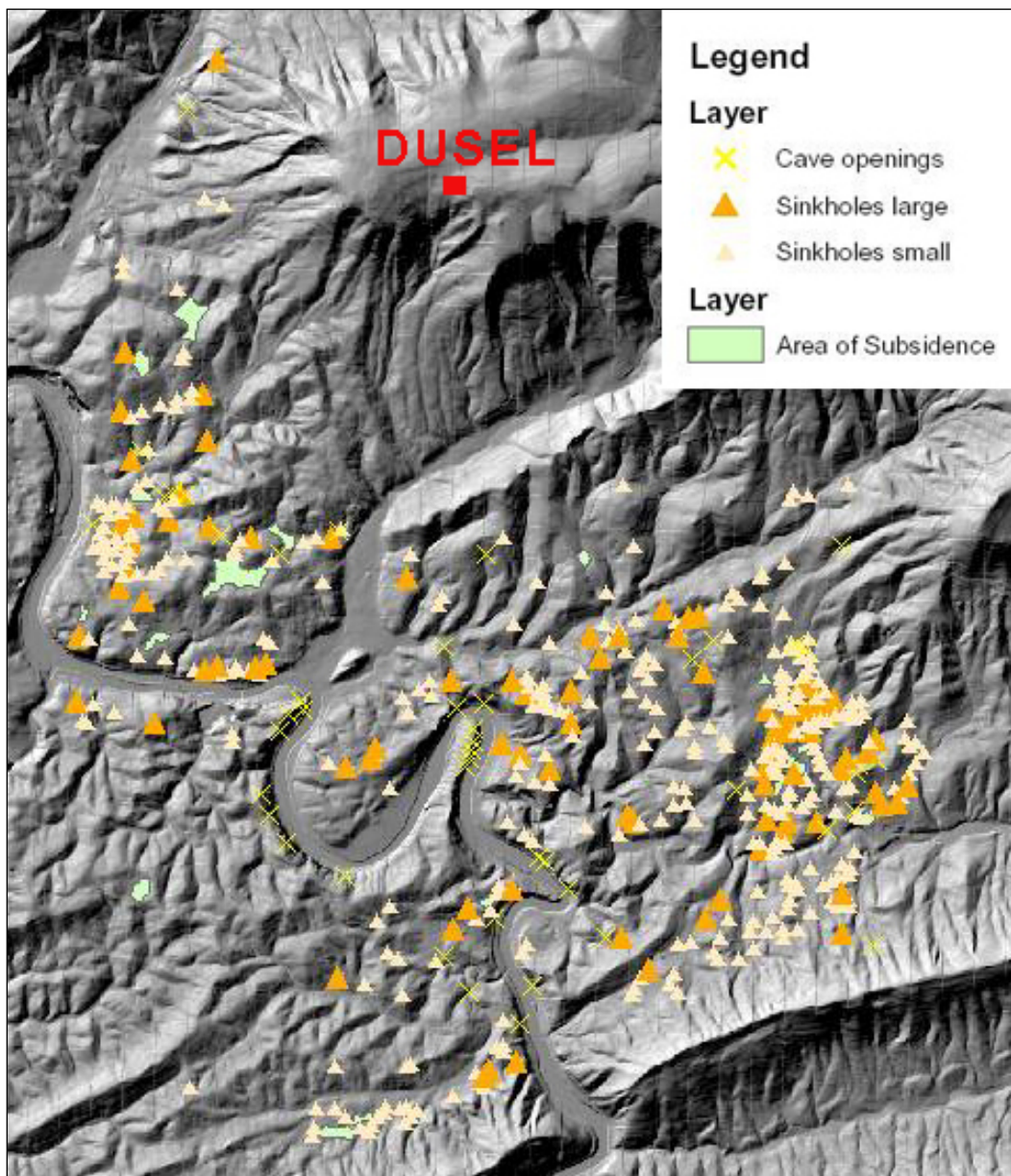

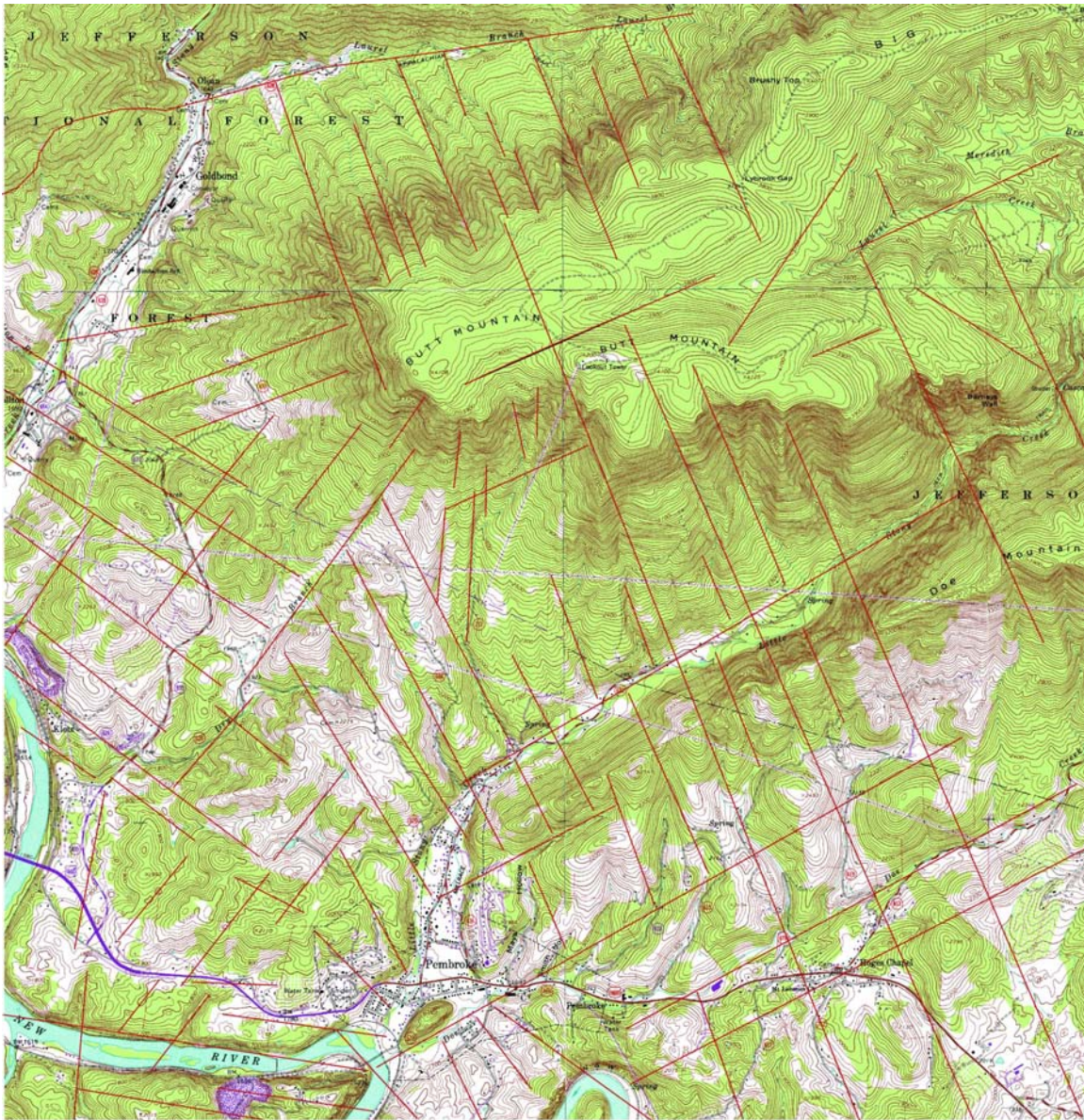Figure 11: Local karst features from published Giles County karst map.

Figure 12: Lineament study of Kimballton area. Widely spaced fractures separated by unfractured blocks.

Seismic Site Characterization

Two seismic lines, each approximately 3 km in length, were acquired in 2004 to image the faults, thrust sheets, and repeated sections of rock at the Kimballton site. The results are consistent both with previous seismic work and the structural model derived from surface outcrops. All data indicate that the geology of the Kimballton area is composed of repeated sequences of Paleozoic dolomite, limestone, and clastic rocks. No faults excepting the thrust sheets were detected on the seismic data. The proposed facilities at 1500 m and 2200 m depth would lie in competent carbonate formations.

A detailed report is posted as a separate file.

Additional Proposed Site Characterization:
Geology & Rock Mechanics

A major focus of the S-2 effort will be to better characterize the geology, tunneling conditions and rock mechanics properties in the vicinity of the laboratory in order to minimize uncertainty during construction. The surficial geology of the Kimballton site has been studied in considerable detail and the layered and folded nature of the host rocks result in abundant outcrops that permit extrapolation into the subsurface, resulting in a high level of confidence in our current understanding of the overall geology. Limited deep seismic investigations recently completed in preparation for the S-2 submission have confirmed the basic configuration of the conceptual model. However, additional geologic and engineering characterization will be conducted as part of the S-2 process to further reduce uncertainty and to better plan for facility design and construction.

The overall S-2 geological characterization task will be led by Mr. William (Bill) Henika. Mr. Henika is recently retired from the Virginia Division of Mineral resources and holds an Adjunct Faculty position in the Department of Geosciences at Virginia Tech. He is widely recognized as a leading expert in the geology of the southern Appalachians. Geoscientists, engineers and engineering geologists with the Kimballton Team will work closely with Mr. Henika to plan and implement the geological characterization process. The Kimballton Team includes Robert Hatcher, Junior, a PI, and perhaps the world's leading expert in the geology of fold-thrust belts such as the Appalachians. Sub-tasks of this process will be led by members of the Kimballton Conceptual Design Team.

The S-2 process will involve several related studies that will serve to better characterize the geology and rock mechanics / tunneling conditions at depth and to provide input for uncertainty analyses associated with Kimballton-DUSEL. Work to be accomplished as part of this process is summarized below

1. A deep core hole will be drilled from the top of Butt Mountain to the deep campus location to obtain geologic and geomechanical information over the entire 2100 m from the surface to the deep campus. Sonic logging and resistivity logging will be conducted to better constrain rock strength and lithologic variability at depth. Temperature and fluid conductivities will be investigated under ambient and pumping conditions to identify active fracture networks, and an optical televiewer will provide information on individual fracture apertures and orientations. This information is critical to assessing changing conditions that might be encountered during tunneling and cavern excavation. Borehole flow meters will be used to measure the quantity of water that may be encountered during construction – this information will be used to design the optimum tunneling methodology and operational criteria. Specific subtasks include:
    a. Retrieval of full or partial rock core for petrographic examination and engineering testing of areas where tunnels and laboratory spaces are sited
    b. Sonic logging to examine depths to reflectors and calculate the elastic modulii of the rock types encountered

      c. Resistivity logging to further characterize lithologic properties
      d. Examination of temperature and fluid conductivities under ambient and pumping conditions to identify fractures and to characterize active fracture networks in greater detail
      e. Exploration to depth with optical televiewer for visual identification and examination of fracture zones, individual fracture apertures, and for determination of fracture orientations
      f. Characterization of water bearing zones and evaluate flow rates using borehole flow meters to identify and address issues relating to the quantity of water that may be encountered during construction

The drilling effort will be coordinated by Dr. Burbey of the Department of Geosciences and Dr. Mauldon of the Department of Civil and Environmental Engineering, both at Virginia Tech.

2. The proposed laboratory design involves excavating a tunnel adjacent to the operating Kimballton Mine, with the portal located on mine property and with a cross tunnel (or tunnels) connecting to the existing mine workings. To confirm the feasibility of this model, one or more shallow drill holes will be located in the vicinity of the proposed portal site and to identify potential ground entry challenges. These holes will additionally provide information on lithology, rock quality, fracture characteristics and the potential to intersect water-bearing zones during construction, providing critical data to reduce design uncertainty. Specific subtasks include:
      a. Approximately three cored drill holes to more fully examine and document rock types, rock quality, fracture patterns, and fracture characteristics
      b. Retrieval of full or partial rock core for petrographic examination and engineering testing
      c. Characterization of water bearing zones to identify and address the possibilities of encountering water during construction

The shallow drilling effort will be coordinated by Dr. Burbey of the Department of Geosciences and Dr. Joseph Dove of the Department of Civil and Environmental Engineering, both at Virginia Tech, in collaboration with geologists at the Kimballton Mine.

3. Fracture data from within the existing Kimballton mine will be collected and analyzed in order to supplement data already collected from nearby quarries and road cuts. The data will include trace lengths and orientations. Preliminary results are presented in Appendix C. Fracture data reduces design uncertainty by allowing ultimate design of the laboratory and access routes to be designed such that known fracture orientations are intersected with the most stable geometry possible, reducing uncertainties associated with tunnel construction. This will be coordinated by Dr. Matthew Mauldon of the Department of Civil and Environmental Engineering at Virginia Tech and by Dr. Watts of Radford University

4. Measurements to determine the *in situ* stress field will be made from the corehole at the depths of the middle and deep campuses. These measurements will use the borehole breakout method, recently incorporated at the San Andreas Fault Observatory at Depth (SAFOD), to determine regional *in situ* stress. Knowledge of the *in situ* stress field will allow the tunnels and caverns to be aligned so that ground instability is minimized. This typically occurs when the long axis of underground openings is aligned parallel to the primary horizontal stress. Determination of the *in situ* stress field will be overseen by Dr. Erik Westman of the Mining and Minerals Engineering Department at Virginia Tech.

5. A preliminary interpretation of aerial photography and the analysis of digital elevation models indicate the presence of widely-spaced lineaments representing steeply dipping fractures. In order to reduce the uncertainty associated with tunnel construction in the vicinity of these lineaments we will conduct studies to help constrain our estimates of the depths to which they extend, and their dips (orientations) in the subsurface. Electrical resistivity studies will be conducted to image these features in the near-surface, and these will be extrapolated to greater depths based on information obtained from other characterization studies. As with the fracture data from item 3, identification of lineaments reduces design uncertainty by allowing ultimate design of the laboratory and access routes to be designed such that major features are avoided, and known fracture orientations are intersected with the most stable geometry possible. Specific subtasks associated with the resistivity studies include:
   a. Examine characteristics of these features to depths of approximately 40 meters.
   b. Interpolate the near surface lineament orientations and characteristics to depths greater than 40 meters to assist in portal and tunnel design
   This work will be conducted by Dr. William Seaton of ATS, Inc and will be coordinated by Dr. Watts of Radford University.

6. A deep seismic survey conducted during the summer of 2004 provided confirmation of the subsurface geology in the vicinity of the proposed lab. Additional seismic studies are not currently included in our S-2 geological characterization plans, but may be conducted if results of the deep drilling program indicate inconsistencies with our inferred subsurface geology. If such studies are required, the task will be led by Drs. Imhof and Hole of the Department of Geosciences at Virginia Tech.

7. Additional geomechanical testing
   Additional rock mechanical testing will be performed, as needed, on core obtained from the boreholes and from inside the Kimballton mine. The suite of additional tests will be established based on specific needs for design of the tunnels and laboratories. Testing might includes additional strength testing and determination of elastic properties. Testing will be coordinated by Dr. Matthew Mauldon of Civil and Environmental Engineering and Dr. Erik Westman of the Mining and Minerals Engineering Department, both at Virginia Tech.

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Appendix B: Kimballton Geology (seismic imaging)

I. Introduction

The objective of this study was to acquire, process, and interpret two seismic reflection lines on top of Butt Mountain in Giles County, Virginia, as part of an integrated site characterization for the Deep Underground Science and Engineering Laboratory (DUSEL) at Kimballton. Both lines, approximately 3 km in length, are standard multifold seismic reflection data aimed at imaging faults, thrust sheets, and repeated sections of rock in the vicinity of the proposed Kimballton site. Results from this survey support the existing structural model and suggest that the proposed DUSEL facility would lie in competent limestone units.

II. Data Acquisition

Both seismic lines (Fig. 3) were collected in June 2004 along strike of the Butt Mountain Synclinorium (Figs. 4, 5, and 6). Seismic explosion charges were used to record 111 and 84 shots at 20 m spacing along Lines 1 and 2, respectively. Shot holes were drilled to 6 m depth and contained 2 kg of seismic explosive. Two 10 kg shots were used near the end of each line and were drilled to a depth of 12 m. Shot holes penetrated a shallow weathering layer of compacted sand into bedrock with the exception of a short segment on the east end of Line 1 where the weathering layer was exceptionally thick and bedrock was not reached.

This survey consisted of 180 stationary geophone stations. 70 geophones were spaced at 10 m on the western end of Lines 1 and 2, and 110 geophones were spaced at 20 m throughout the rest of the lines. Acquisition parameters may be found in Table 1.

III. Data Processing

The processing of Lines 1 and 2 (table 2) was done at Virginia Tech and was directed towards producing the strongest reflectors in the upper 2 km to image rock structures of interest to the DUSEL project. Experimentation indicated that 15 m CDP bins provided the best trade-off between reflector continuity and spatial resolution. The stack fold ranged between 40 and 120. Two-dimensional median filters directed between 330 m/s and 2000 m/s were effective at removing the effects of airwaves and ground roll that remained after bandpass filtering. It was noted that shallow reflectors were better imaged at far offsets, and receivers less than 500 m from the source were not stacked in the section.

NMO stacking velocities were chosen to maximize the continuity of reflections in the stacked section. Iterative velocity analysis provided nominal signal improvement beyond the first pass of residual statics. The residual statics time gate focused the

strongest reflectors in the section, which were between 1600 ms and 2100 ms. Migration was attempted, but created an over-smeared image because of the short line compared to the target depths. Interpretation was done on stacked sections only.

IV. Regional Geology and Previous Seismic Work

The study area lies in the Valley and Ridge Province, which is the result of thin-skinned deformation during the Alleghanian orogeny. Regional structure is dominated by the Saltville, Narrows, and St. Clair thrust faults. The Butt Mountain Synclinorium (Figs. 4, 5, and 6) lies in the Narrows thrust sheet, which is composed of numerous imbricate faults.

The stratigraphy of the study area consists of Cambrian through Ordovician carbonates and Ordovician through Silurian sandstones, claystones, and shales. The section is dominated by massive dolostones, which are capped by a thin, mildly metamorphosed clastic package.
.

Surface geology, regional borehole data, and balanced cross sections have been integrated into a regional geologic model first published by Woodward and Gray (1985) and modified by Henika (personal communication 2004). This model indicates that detachment zones originate at the base of the Cambrian carbonate package and propagate into imbricate structures in the Ordovician Martinsburg formation. Stacked thrust sheets triplicate sections of rock in the vicinity of the Butt Mountian Synclinorium (William Henika, personal communication 2004).

Previous regional seismic work by Costain and others (1988) near the Bane Dome (Figs. 2 and 7) shows structures such as regional overthrusts and imbricate faults in the Martinsburg formation. Seismic data acquired in the region has been poor due to sub-surface dissolution of carbonates and poor impedance contrast across rock boundaries.

V. Interpretation of Seismic Data

Seismic interpretation (Figs. 8 and 9) was guided by the balanced cross sections from Henika (Figs. 5 and 6). Conversion of travel time to vertical depth based upon a borehole will be necessary to confirm the identification of formation boundaries.

The most identifiable feature in both Lines 1 and 2 is the robust reflection at 6000 m, which is interpreted to be the boundary between the Rome formation, a mudrock unit, and the crystalline basement. A strong reflector at 5000 m is interpreted as the Nolichucky-Honaker boundary.

Mildly dipping events at 3100 m on Line 1 are interpreted to be truncations of the Millboro shale at the base of the St. Clair detachment. Line 2 is more parallel to strike and has a flatter reflection at 3000 m. Reflections between 2000 m and 2400 m on Lines 1 and 2 are interpreted to be internal reflectivity in the Martinsburg formation. These reflections may be caused by imbricate fault slices or by the interbedding of mudstone and limestone. The top of the Martinsburg formation is interpreted as the Narrows fault.

Much of the section is discontinuously reflective, as might be expected in thick sequences of dolostones and limestones where impedance contrasts are poor between juxtapositions of similar rock units. In addition to the better constrained stratigraphic and major fault boundaries, the character of remaining reflectivity consistent with Henika's model. Moreover, no secondary faults were detected, which suggests the construction of DUSEL at Kimballton should not be hampered by complicated geology.

VI. Anticipated Refraction Analysis

Travel time tomography will be used to build a near surface velocity model of Lines 1 and 2 from the first arrival times of refracted acoustic waves. Preliminary investigation shows that refracted rays should penetrate to a depth of 300 m to 500 m and will constrain near surface rock structure. A refined velocity model may be used in the reprocessing of Lines 1 and 2 to improve resolution at shallower depths.

Travel time tomography results will also be aimed at imaging bedrock joints and fracture systems. Drilling conditions and arrival times in shot gathers indicate that an anomalously thick weathering layer exists in conjunction with a low velocity zone towards the east end of Line 1 (Fig. 10). This low velocity zone is coincident with surface lineaments derived from topographic maps (Fig. 11) (Henika, personal communication 2005). Presence of a low velocity zone might confirm the interpretation of topographic lineaments as bedrock joints and fracture systems, which may affect the construction of DUSEL structures on top of Butt Mountain.

VII. Summary

Results from seismic Lines 1 and 2 are consistent both with previous seismic work and Henika's structural model derived from surface outcrops. All data indicate that the geology of the Kimballton area is composed of repeated sequences of Paleozoic dolomite, limestone, and clastic rocks. No faults excepting the thrust sheets were detected on seismic data. Proposed facilities at 1500 m and 2200 m depth would lie in competent carbonate formations. Further analysis of travel time data will help map shallow bedrock joints and lineaments.

VIII. Acknowledgements

William Henika is gratefully acknowledged for contributing his unpublished cross sections, surface lineament maps, and vast knowledge of regional geology.

IX. References

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X. Figures and Tables

Table 1: Acquisition Parameters for Line 1 and 2
Table 2: Processing Sequence

Figure 1: Location Map
Figure 2: Regional Map with Bane Dome and Butt Mountain Seismic Lines
Figure 3: Index Map for Lines 1 and 2.
Figure 4: Cross Section Index Map
Figure 5: Cross Section H-H'
Figure 6: Cross Section I-I'
Figure 7: Bane Dome Stacked Seismic Section
Figure 8: Line 1 with and without Interpretation
Figure 9: Line 2 with and without Interpretation
Figure 10: Shot Gather with Low Velocity Zone
Figure 11: Lineament Map of Butt Mountain

Table 1
Acquisition Parameters for Line 1 and Line 2

Date Recorded	June 2004
Spread Type	End-on/Shoot through
Number of Channels	180
Geophone Spacing	70 at 10 m / 110 at 20 m
Geophone Type	10 Hz single / 4.5 Hz array
Shot Spacing	20 m
Small Charge Size	2 kg
Large Charge Size	10 kg
Charge Depth	6 m (small shots) / 12 m (large shots)
Recording Instrument	24 bit Geometric StrataView
Sample Rate	2 ms
Record Length	15 s
Record Format	SEG 2
Number of Shots Line 1	111
Number of Shots Line 2	84

Table 2
Processing Sequence

1	Read SEG 2 data – 15 s
2	CDP crooked line sort – 15 m
3	Pick first breaks
4	Static shift traces with shot delay – (125ms)
5	Spherical divergence correction 1/r
6	Elevation statics – 4000 m/s 1300 m datum
7	Bandpass filter 15-25-75-120 Hz
8	Velocity filter – median method, remove 2000 m/s and 330 m/s
9	Surface consistent spiking deconvolution
10	Sort by offset – exclude channels < 500 m
11	Sort to CDP domain
12	Velocity analysis – constant velocity stacks
13	NMO correction
14	Max power autostatic – 500 ms gate at 1600 ms
	Allow 25 ms shift
15	Bandpass filter 15-25-75-120 Hz
16	Coherency filter
17	Trace display with single trace scaling
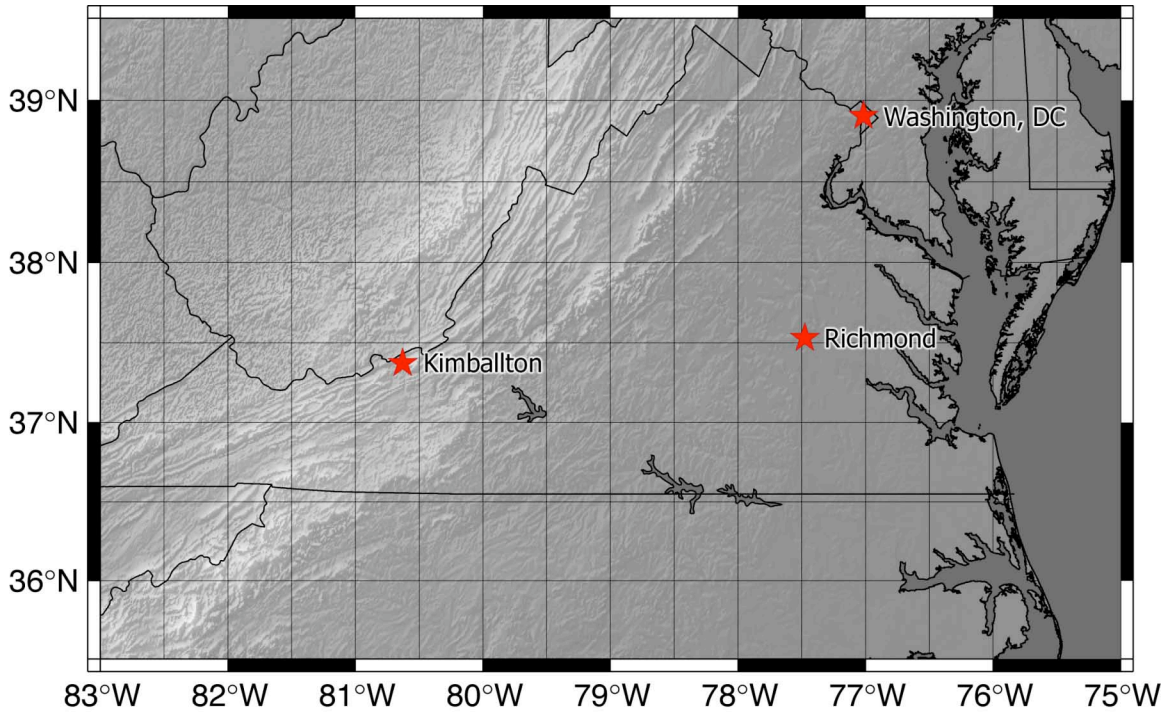
Figure 1. Location of the Kimballton site.
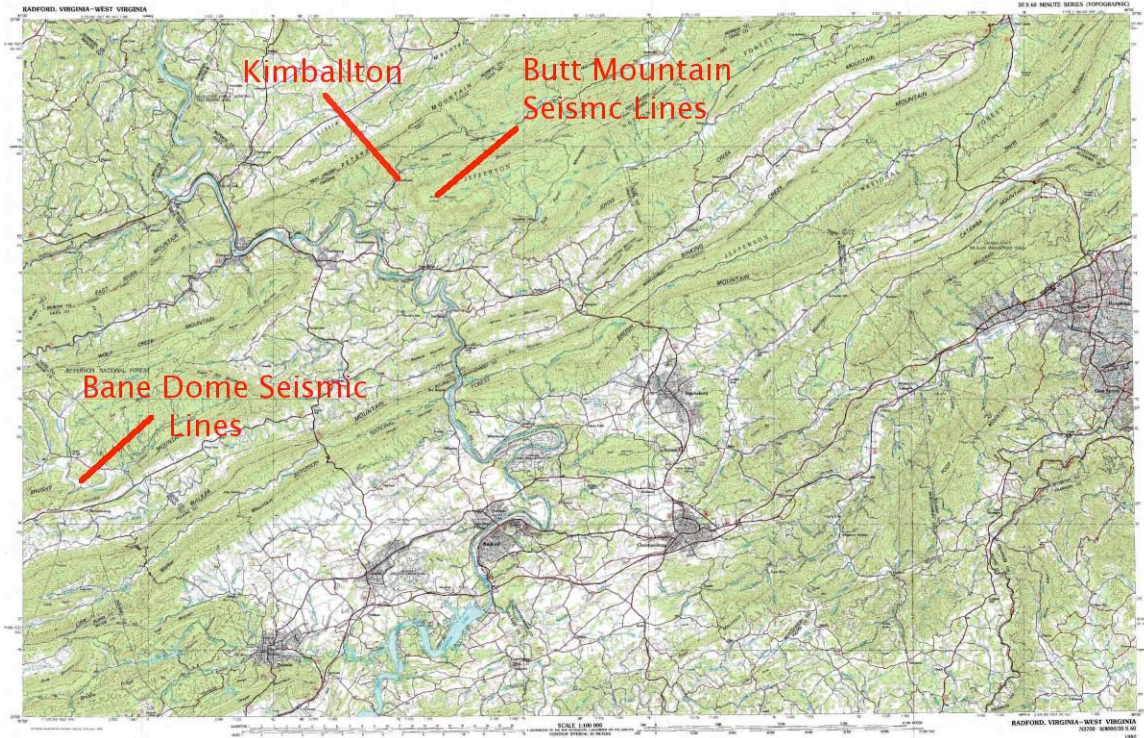
Figure 2: Regional map with location of Bane Dome and Butt Mountain seismic lines.
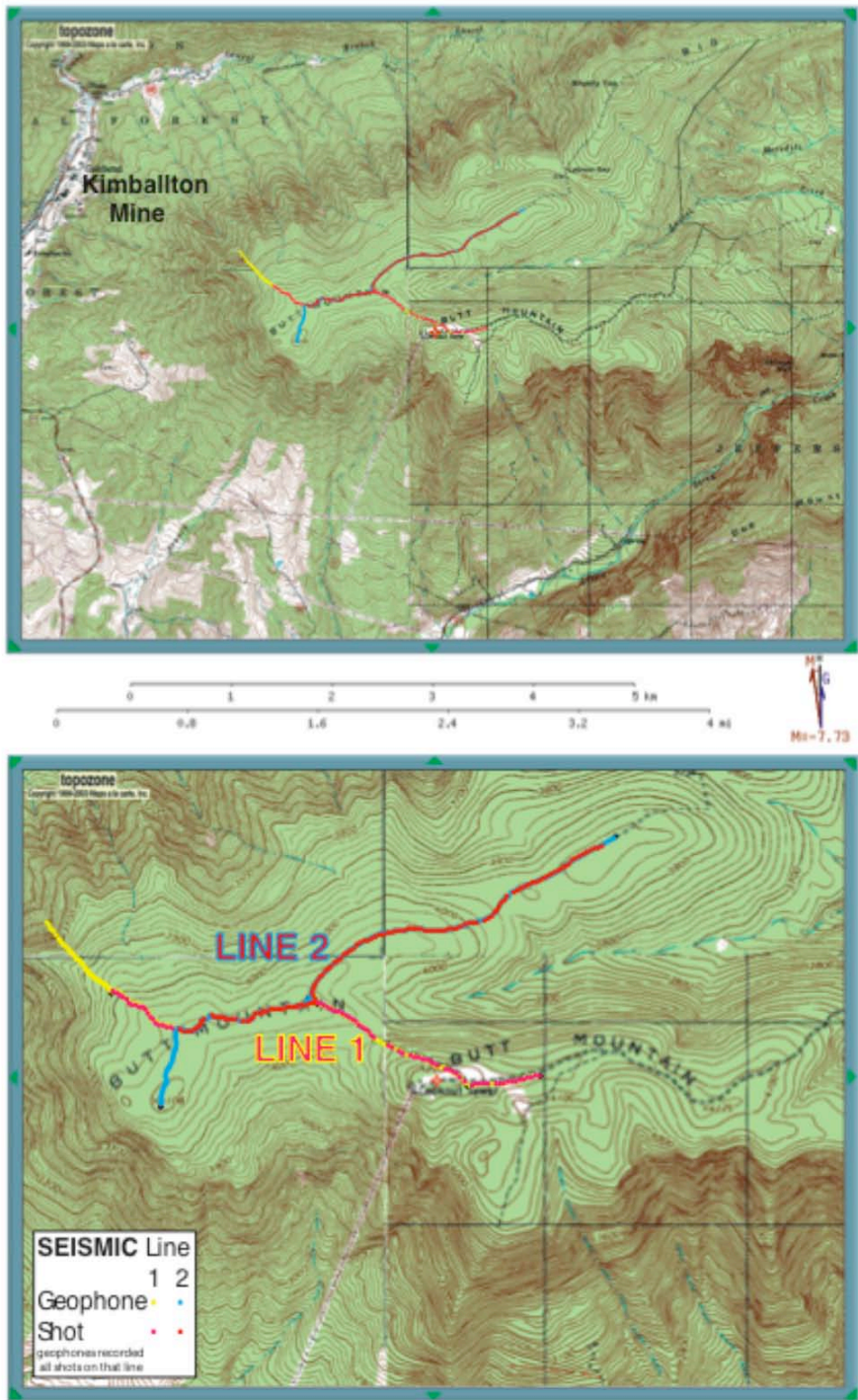
Figure 3. Index maps for Lines 1 and 2. Lines not recorded concurrently.
Line 1: receivers = yellow, shots = red. Line 2: receivers = blue, shots = red.
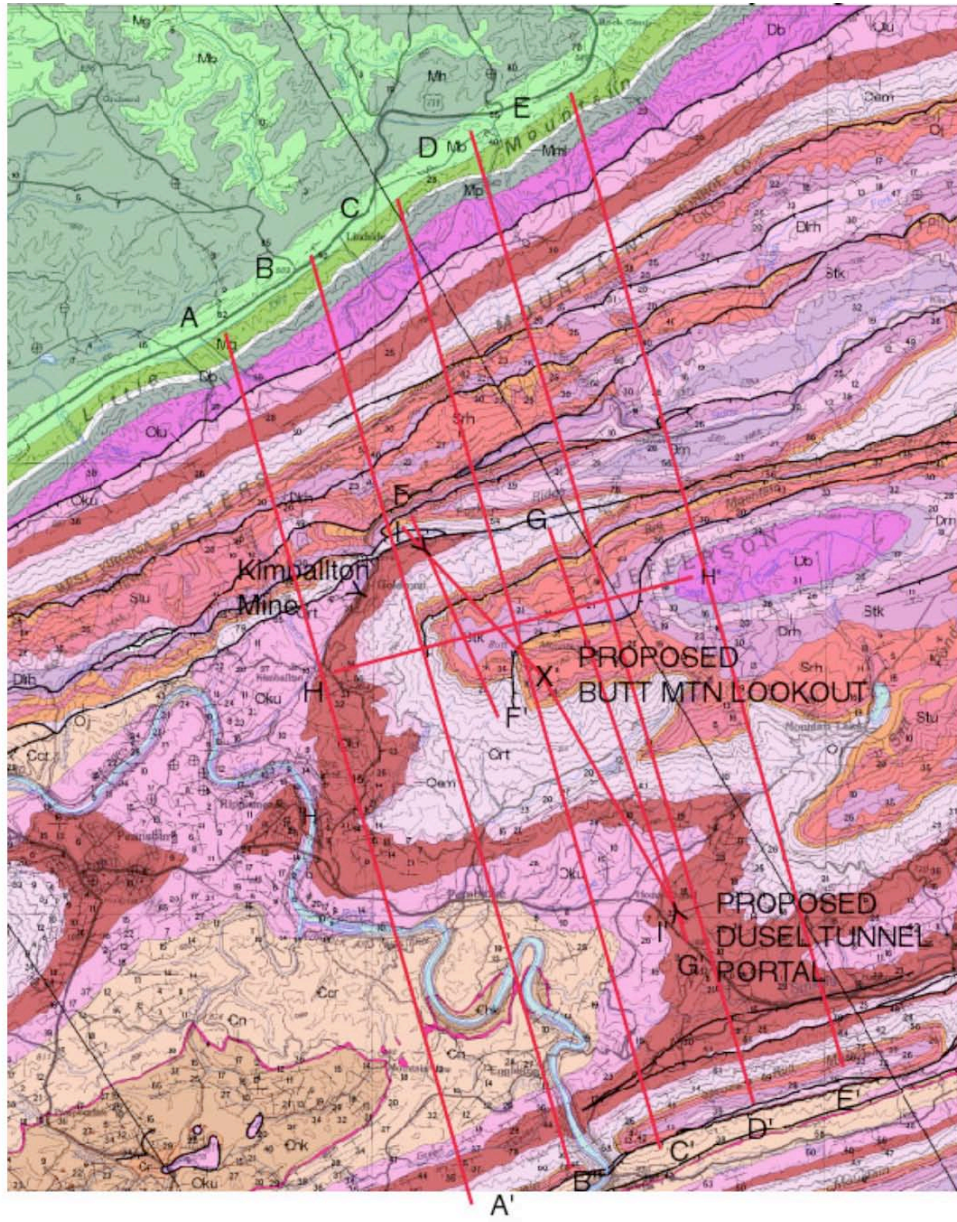
DIGITAL GEOLOGIC MAP OF THE RADFORD 30X60 MINUTE QUADRANGLE, VIRGINIA AND WEST VIRGINIA

Geology by Mervin J. Bartholomew, Arthur P. Schultz,
Sharon E. Lewis, Robert C. McDowell, and William S. Henika
2000
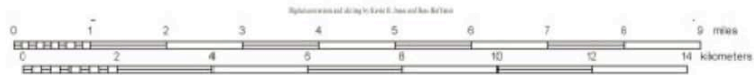
Figure 4: Cross section index map. Cross sections A-A' through I-I' from Henika
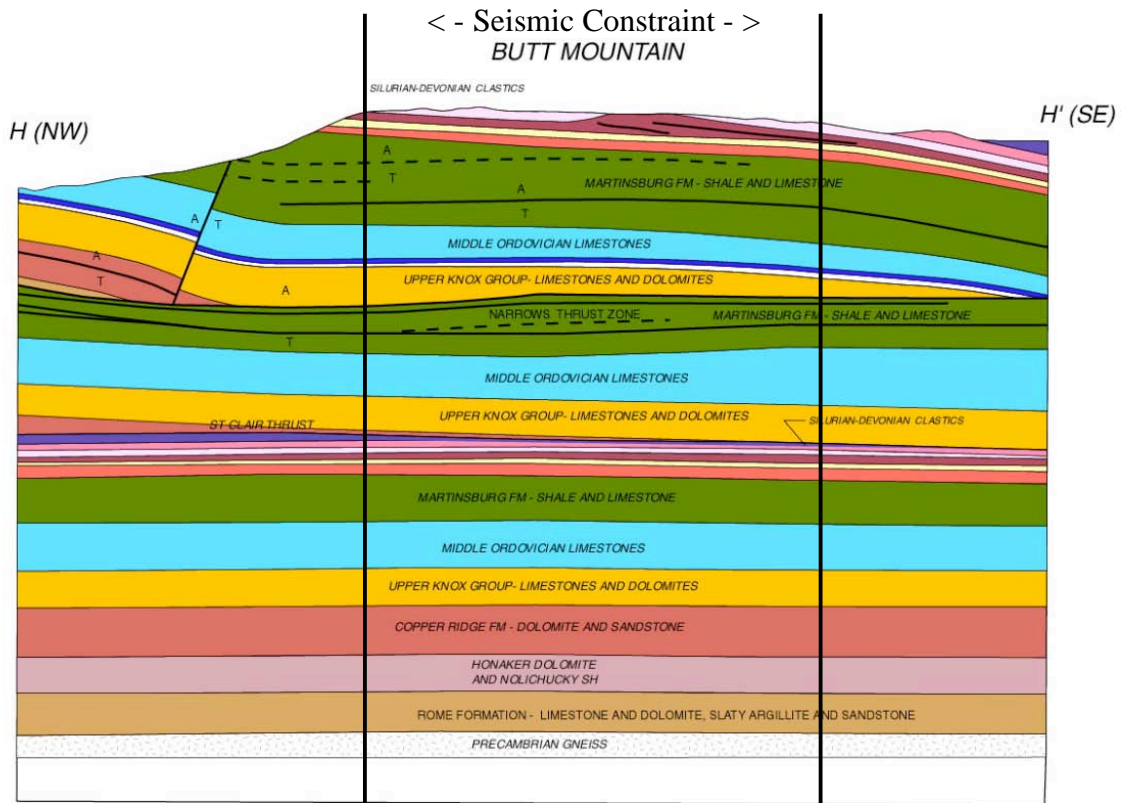
Figure 5: Cross section H-H' (Henika 2005).
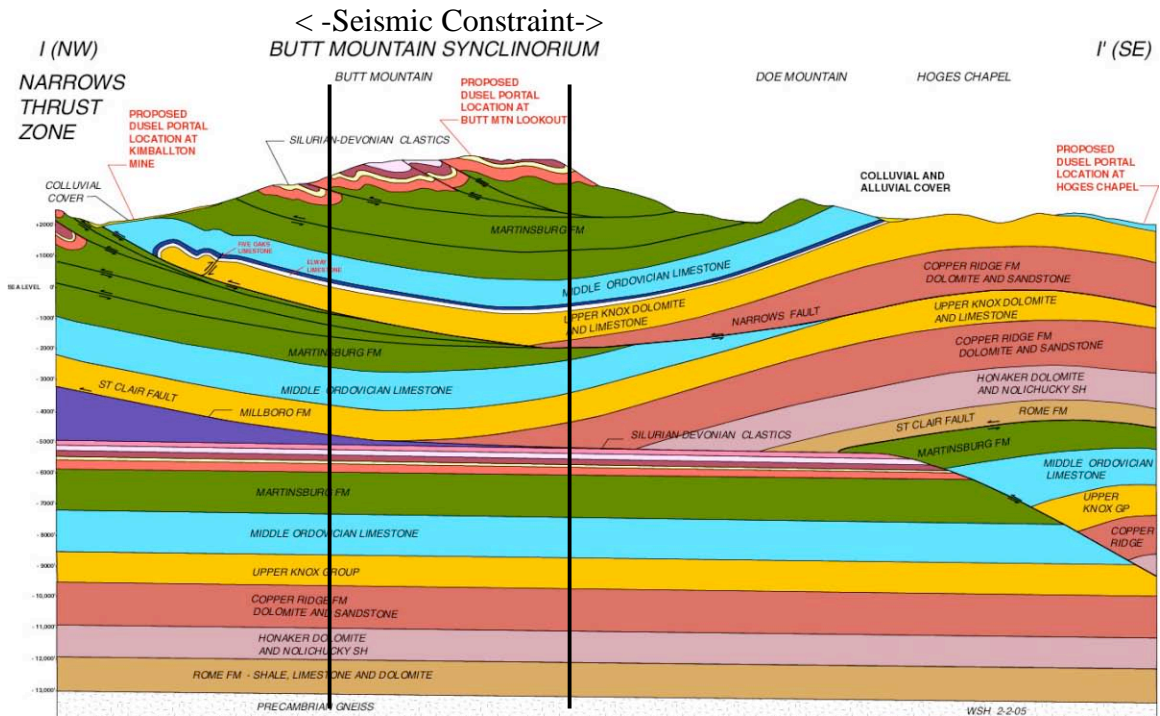
Figure 6: Cross section I-I' (Henika 2005).
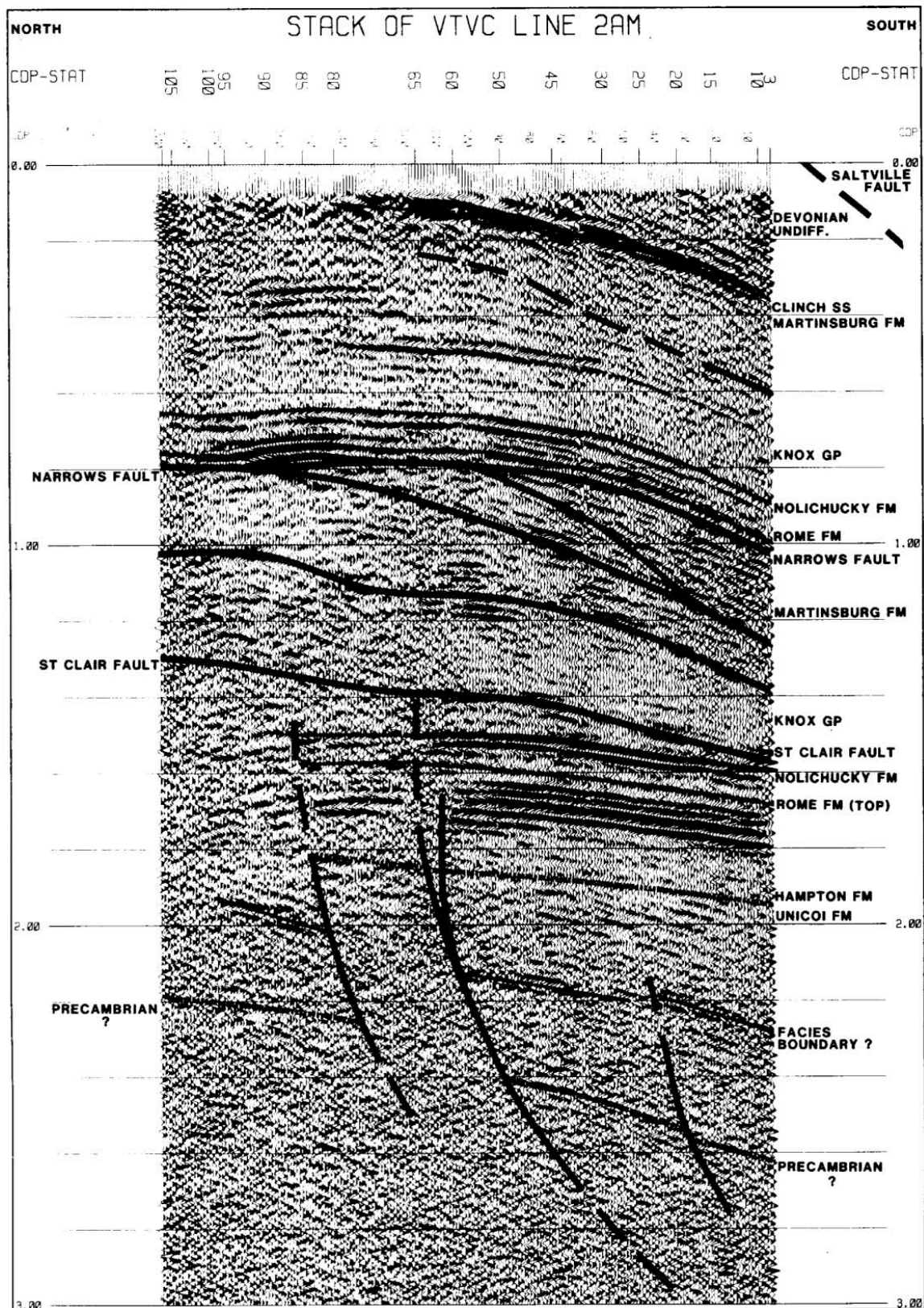
Figure 7. Interpreted stack of Line VTVC2A near the Bane Dome from Domoracki (1988).
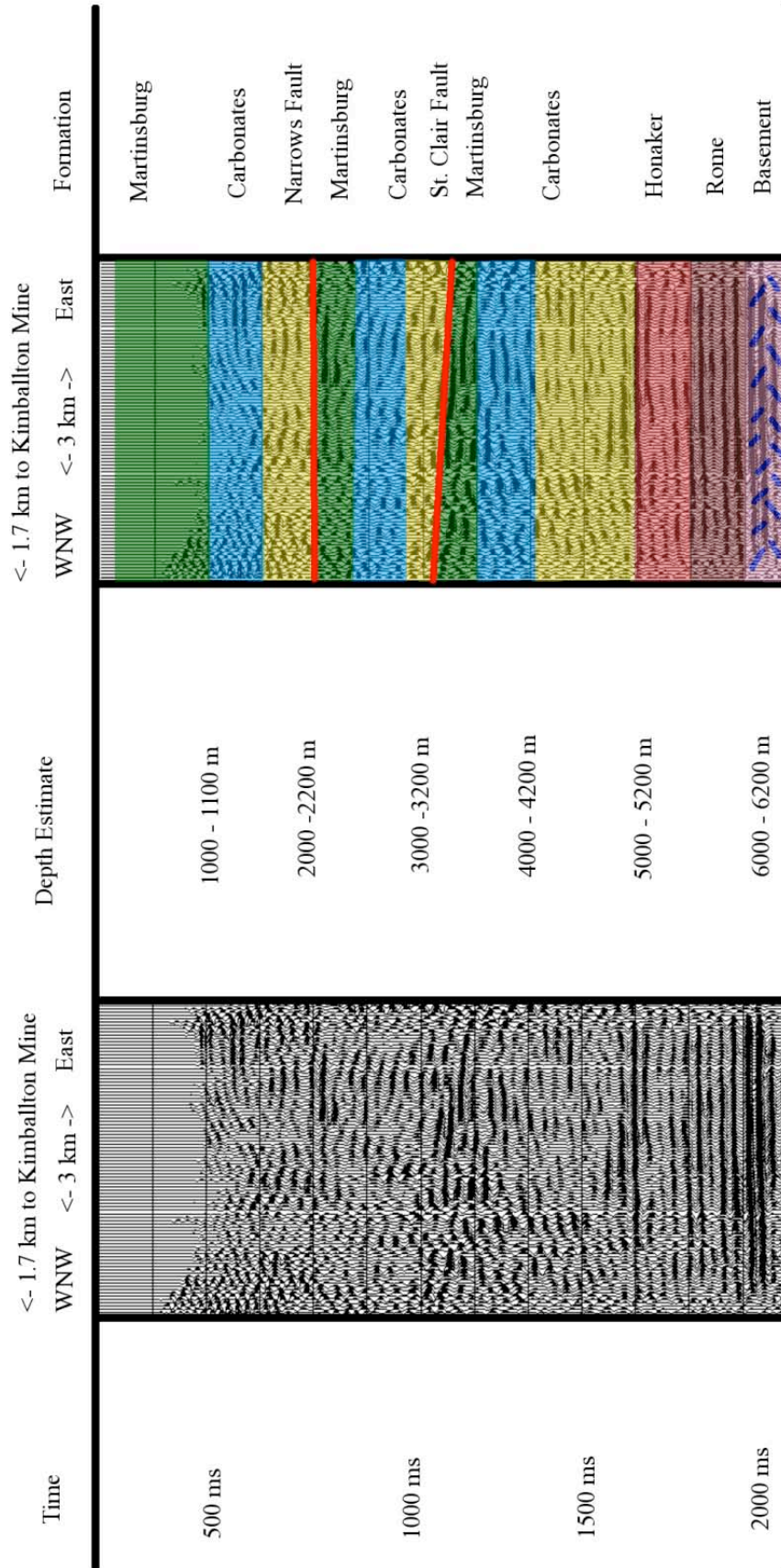
Figure 8. Line 1 with and without interpretation
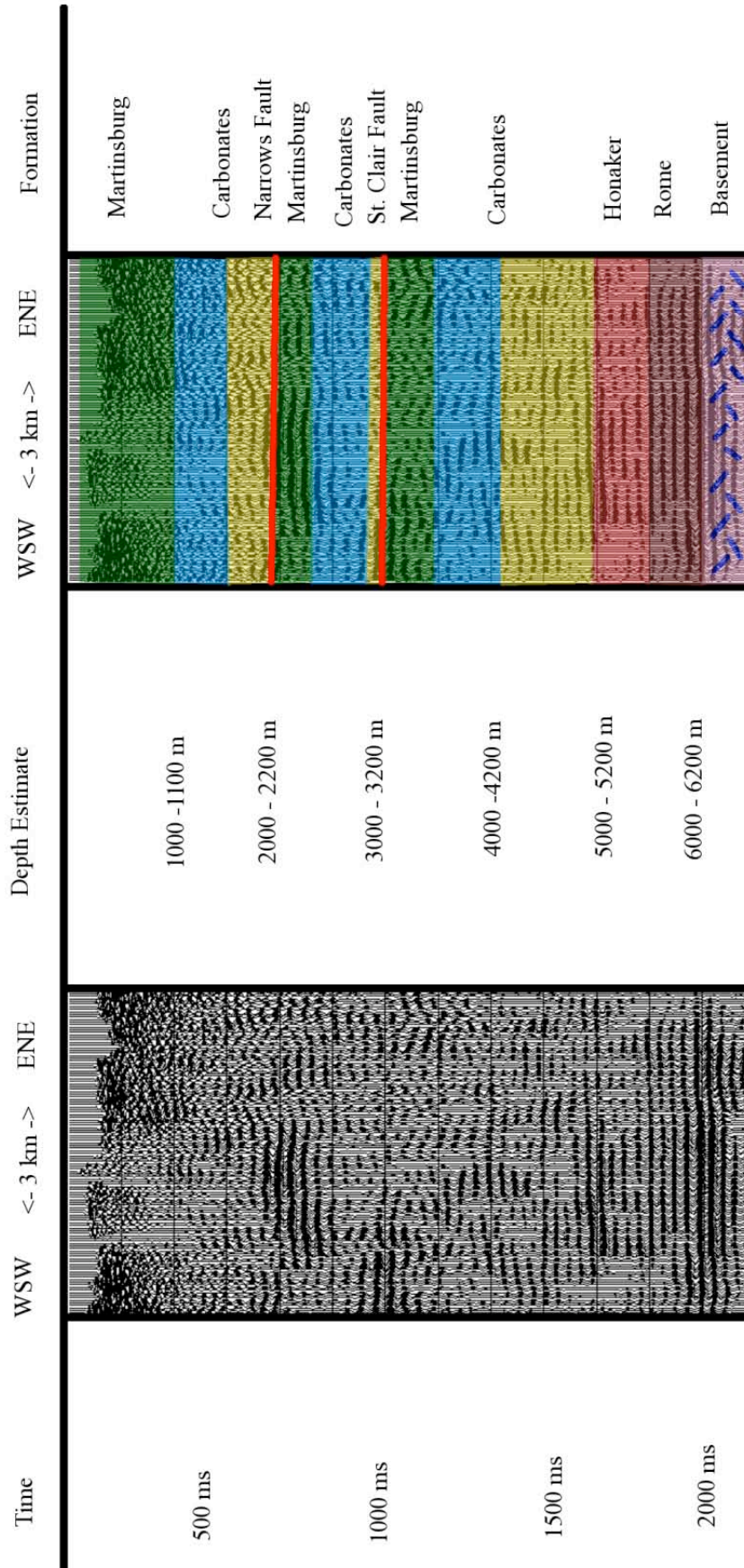
Figure 9. Line 2 with and without interpretation.
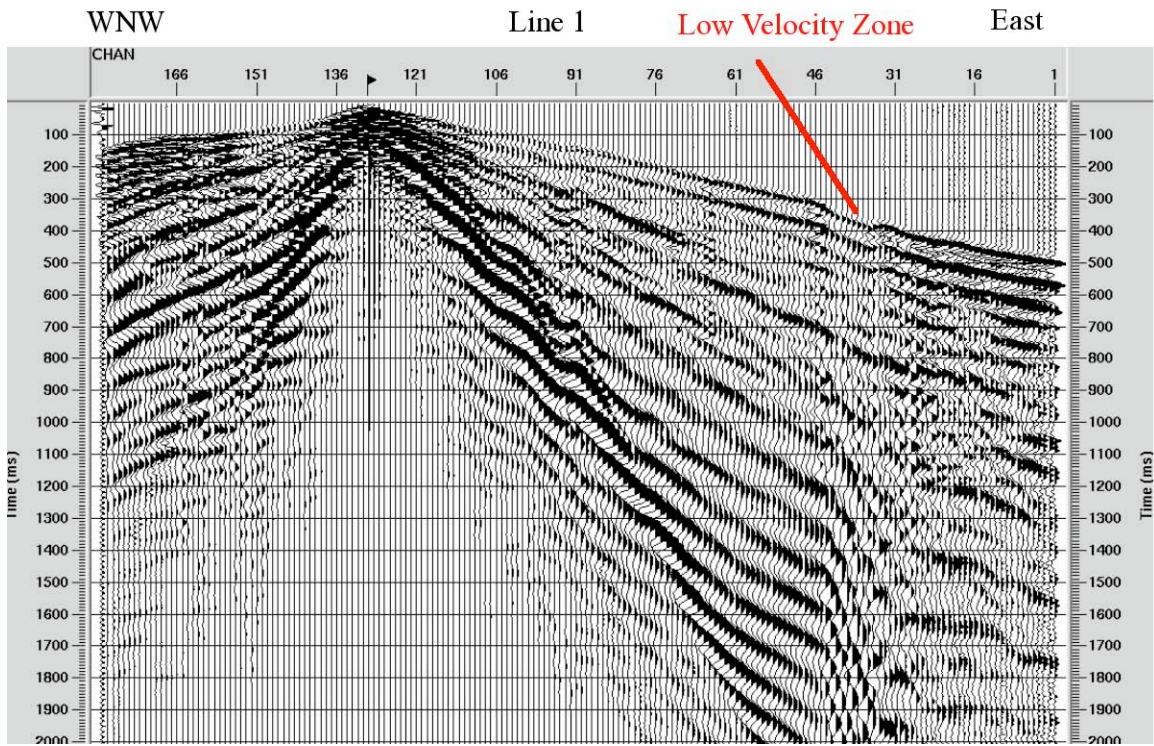
Figure 10. Shot gather with low velocity zone.
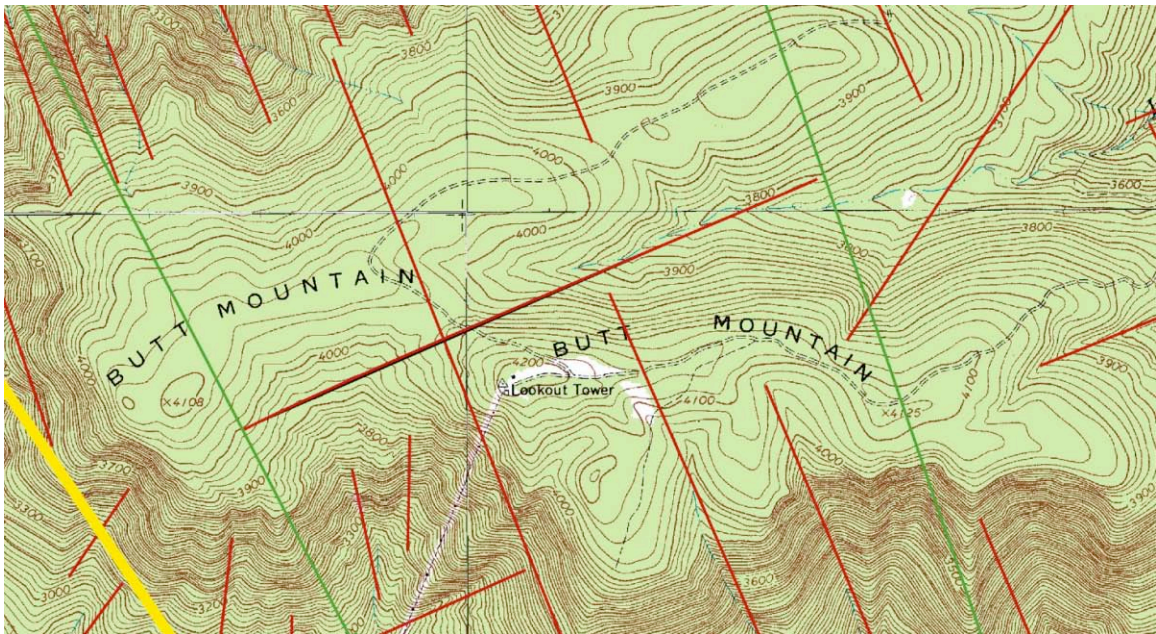
Figure 11. Lineament map from Henika (2004).

DUSEL at Kimballton

Appendix C: Geotechnical Evaluation

Table of Contents

1 Executive Summary

The proposed DUSEL at Kimballton will pierce 2300 m of folded sedimentary rocks adjacent to an existing limestone mine. The preferred mode of access to both an intermediate (~1560 m) and deep campus (~2300 m) is via a straight decline with a secondary access/egress via shaft (Appendix I). The underground laboratories and access tunnels will be developed in massive, high strength, Paleozoic limestones and dolostones (Appendix B). Abundant exposures show these rock units to be highly competent (UCS ~100-150 MPa), with major fractures occurring in well-defined sets with spacings on the order of several hundred meters. Prominent blocks of massive carbonate rock characterize the landscape - for example the "Palisades" along the New River at Pembroke.

The shallowly-dipping stratigraphy and gently-incised topography allows a linear decline to remain primarily within anticipated competent high strength limestones. Possible short excursions into adjacent competent mudstones and slates within the Martinsburg Formation are unlikely to be squeezing (above ~1400-2700 m) and such deviations are expected to be short if they occur at all.

Fracture data from surface and underground (mine) locations confirm the anticipated competence of the limestone formations that will potentially host large caverns. Rock mass classification by Q and RMR methods uniformly identify the rock mass as "good" - the second most favorable of five categories. This classification suggests that access tunnels (assumed ~4.5 m diameter) will require either no support or only spot bolting. This is consistent with existing tunnels of similar span mined to a depth of 750 m. Similarly, these "good quality" massive limestones will successfully accommodate large-span (40-60 m) UNO-type caverns. Projected support requirements for a 50 m span cavern in "good" rock (Q~20) are systematic bolting and shotcrete. Such rocks are documented to routinely host large cavities underground, and this is confirmed by large cavities (10×30×500 m) present to 750 m depth.

The feasibility of constructing large underground openings at Kimballton is demonstrated by large chambers in the Kimballton mine that have stood completely unsupported for 40 years or more. The mine at Kimballton is developed in the Five Oaks limestone, a subunit of the Middle Ordovician limestone that will host access tunnels and underground laboratories at depth.

Rather than having a separate section presenting geomechanical data and experience from the mine, this information is included wherever the particular topic is discussed (e.g., fracturing, water, stability). The management of uncertainty and risk, and the mechanisms by which information from the S-2 phase will be used to reduce risk are detailed in Appendix B - Geologic Setting, and in Appendix H – Risk and Uncertainty.

Major characteristics that indicate favorable conditions for constructing DUSEL, including large caverns at a depth of 2300 m, at Kimballton include the following.

1. Very large underground openings in the Kimballton mine, with heights up to 34 m, lengths up to 500 m and width of 14 m, have been stable for decades without support, or with occasional rockbolts in areas of heavy usage (e.g., lunch areas). These caverns are at depths up to 750 m, indicating competent rock and no major stress problems.
2. The formations to be encountered at depth are generally massive rocks, with widely spaced parallel fractures. Tunnels and underground chambers can be aligned between major fractures (if they persist at depth) to minimize stability problems.
3. The proposed host rocks for the Kimballton-DUSEL - the Knox and Middle Ordovician carbonates – are high strength rocks (UCS~100-150MPa).
4. Q values from area quarries and outcrops indicate "Fair" to "Very Good" rock quality. Most of the data indicate "Good" quality. Rock Mass Rating (RMR) values from area quarries and outcrops consistently indicate "Good" rock quality. These rock mass classification values are likely to be inferior to values at depth, due to near-surface stress relief and weathering.
5. Seismic data also indicate no degradation in rock quality with depth. Q-values from seismic velocity indicate "Good" to "Very Good" rock quality. No major differences in field and laboratory measured seismic velocities confirm the massive character of the rocks, and the absence of open fractures at depth.
6. The sedimentary rocks at Kimballton are particularly well suited to TBM (tunnel boring machine) tunneling – as they are high strength, but not abrasive. Potential difficult areas can be excavated using drill and blast methods.
7. Good stability numbers indicate no potential problems from squeezing and rock bursting.
8. No major water inflows occur in the existing Kimballton mine (which has close to 100 km of drifts), except at one location. Localized areas of water inflow can be pre-grouted before excavation. Fracture frequency typically decreases with depth, and due to insitu stresses fractures that do occur are unlikely to be open (e.g., Cosgrove and Engelder, 2004)
9. The geometry of existing caverns (tall and narrow) indicates an absence of high horizontal stress (in comparison to vertical stress).

1.1 Authorship

This Appendix was prepared by the Kimballton Team at Virginia Tech. Contributions and reviews were received from H. H. Einstein, D. Elsworth, A. Bobet and L. Gertsch.

2 Introduction

This preliminary report describes geotechnical conditions for the proposed national Deep Underground Science & Engineering Laboratory (DUSEL) under Butt Mountain at Kimballton VA. (referred to as Kimballton-DUSEL in this report). Kimballton-DUSEL is adjacent to an existing limestone mine, the Kimballton mine, which is owned and operated by Chemical Lime Company. Kimballton-DUSEL will be developed at depth primarily in massive limestones and dolostones. These same formations outcrop in quarries and road cuts in the vicinity of Butt Mountain (Fig. 2-1). As part of the preliminary assessment of geotechnical conditions for the underground lab, fracture data and rock samples were collected at these quarries and road cuts, with limited geomechanical data collected from within the Kimballton mine. In addition we report strength data on core samples collected in 1990 by Chemical Lime.

Presented in this appendix are (1) an overview of the geologic setting; (2) geomechanical data for the rock units and fracture sets that will be encountered at depth beneath Butt Mountain; (3) results from the application of rock mass classification schemes to these data, and (4) preliminary excavation stability and support estimates. Together with the stratigraphic, structural geologic and geophysical studies described in Appendix B. the information presented herein shows that the geologic and geotechnical conditions at Kimballton are well-suited to the construction of DUSEL, including large caverns at 2300 m depth. Procedures for handling geologic uncertainties during the design and construction phases are outlined in Appendix H and will be developed during S-2. Further geologic and rock mechanics studies to be undertaken as part of the S-2 process are described in Appendix B. Geologic and geotechnical characteristics that make DUSEL at Kimballton well-suited to research in several fields are discussed in Appendix E.
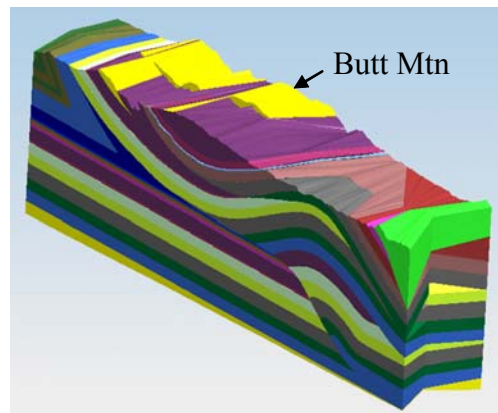
Figure 2-1. Geologic structure of Butt Mtn

3 Proposed Laboratory Layout

The proposed DUSEL at Kimballton comprises twin experimental campuses – the first at an intermediate depth of 4000 mwe (1520m) and second at the termination depth of 6000 mwe (2300 m). These campuses accommodate caverns for the conduct of experiments in physics, bioscience, geoscience, and engineering. Potential constructed layouts, together with the preferred design, are presented and discussed in Appendix I. A schematic of one possible layout is shown as Fig. 3-1.

The proposed caverns will be constructed at a maximum depth of 2300 m. Access to, and egress from, these habitable areas is via both decline and shaft. In the preferred design the decline is linear, but potential designs include a helical decline, combined in all cases with a single vertical access shaft. Correspondingly, all cavern spaces are accessible to standard 40ft shipping containers. The proposed DUSEL complex will be adjacent to an existing mine, currently reaching a depth of 700 m in proven highly competent massive limestones. This depth is comparable to the proposed completion depth of the intermediate campus, provides data on construction conditions (which are favorable), and affords important flexibility in both providing alternate egress points for emergency evacuation, and in reaching intermediate completion depth with minimum construction and investigation. Additionally, unused drifts and chambers in the existing mine provide potential research space for early science.

Further details regarding a full range of potential layout options are included in Appendix I. Issues related to permitting of the proposed facility are reported in Appendix G, and those regarding health and safety of laboratory occupants are included in Appendix F.
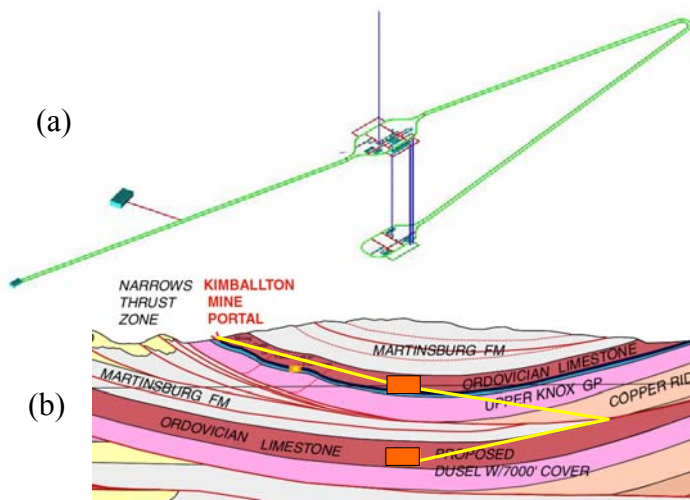
Figure 3-1. Schematic of possible layout for Kimballton-DUSEL: (a) perspective view; (b) access tunnels and lab locations projected onto a geologic cross section.

4 Geologic Setting

The location for Kimballton-DUSEL is beneath Butt Mountain in the Allegheny Mountains of southwestern Virginia (Fig. 4-1). Butt Mountain is a large synclinal mountain near the western edge of the Valley and Ridge Physiographic Province (Appendix B). The region is characterized by linear ridges of erosion-resistant sandstones separating eroded limestones and shales that comprise ancient valleys. Folding and thrusting reflect intense compression along the proto-Atlantic continental margin during the Alleghenian collision event between North America and Africa some 300 million years ago. Butt Mountain is located on the Narrows thrust sheet, a tectonic sliver that was rotated westward during the collision with the leading edge of the proto African continental margin. The present-day mountainous relief formed by erosion in response to broad uplift of the Appalachian spinal region during the post Cretaceous era.
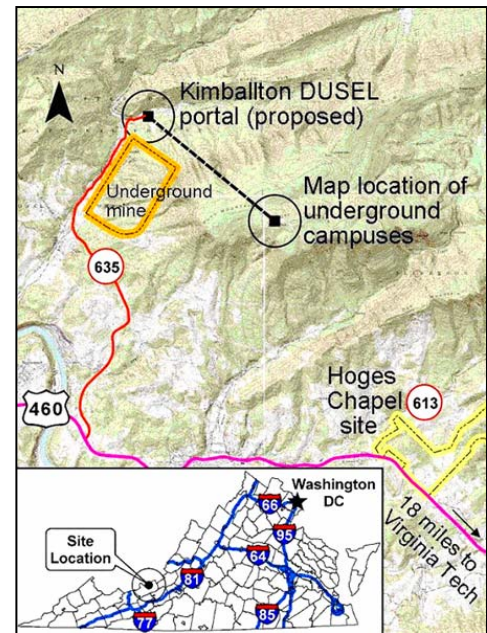
Figure 4-1. Location map

The geology in the vicinity of Kimballton-DUSEL is well-known (Appendix B), and is based on many regional geological and geophysical studies. These studies identify the stratigraphy (Appendix B - Stratigraphy), the complex structural setting (Appendix B - Structure), and the correspondence of stratigraphy and structure with a consistent seismic model (Appendix B - Seismic Model).

The geologic structure is that of a major anticline-syncline pair: the Bane Dome-Butt Mountain Syclinorium. These regional structures were produced by subsurface imbrication beneath the Saint Clair and Narrows overthrust faults that outcrop along Allegheny ridges to the west. The combination of detailed surficial geology, stratigraphy, subsurface and seismic data with fracture characterization studies and structural geologic interpretation has been used to develop a realistic three dimensional model. Fold axes determined from bedding attitudes provide geometrical constraints on the geological model of both the Bane and the Butt Mountain fold structures, and indicate a gently plunging syncline beneath Butt Mountain (Fig 4-2).

The stratigraphic units that will be encountered in the Kimballton-DUSEL excavations are described in Fig. 4-3. The boxes to the left indicate which units contain underground labs, and which host access tunnels. The stratigraphy is discussed in more detail in Appendix B – Stratigraphy .

Figure 4-2. Geologic section of Butt Mountain and approximate location of deep campus.

------------------------- DISCONFORMITY -----------------------

Silurian-Devonian Clastics

Undivided Devonian Limestones, Rocky Gap Sandstone & Huntersville Chert
Dlrh (Undivided Devonian Limestones) - bluish-gray, thick-bedded, coarse-grained, crystalline limestone and fine-grained, argillaceous limestone.
Dlrh (Rocky Gap Sandstone) - Medium-gray to locally dark-green (glauconitic), med. to coarse-grained, iron-oxide cemented, graywacke and medium-gray, crossbedded, quartz arenite, which weather to brownish-gray to yellowish- or reddish-gray
Dlrh (Huntersville Chert) - Light- to dark-gray, fine-grained chert in irregular, 2-10 cm-thick beds separated by 0.5-1 cm lenses of dark-gray to black mudstone with chert beds in tabular lenses 1-4 cm thick with shaly partings.

Tonoloway Limestone and Keefer Formation (Silurian)
Stk (Tonoloway Limestone)
Upper sequence (clastic) – med.-gray, calcareous, thinly laminated siltstones, light-gray, fine-grained, sandstones and dark-gray calcareous, finely laminated shales with minor fossiliferous, conglomeratic limestone and dark-gray, calcareous silty shale;
Lower sequence - dark-gray, thin-bedded, limestone, micrites and calcareous siltstones, dark-gray, fissile, calcareous shales and bluish-gray, massive, fine-grained limestones.
Stk (Keefer Formation) - light- to dark-gray, fine- to medium-grained sandstone and quartzite; crossbedded and crosslaminated, rippled, mudcracked, and burrowed. Includes some very light-gray, grayish-red and minor medium-red siltstone and shale

Rose Hill Formation (Silurian)
Srh - Dark-reddish-gray (hematitic), fine- to medium-grained, quartz sandstone irregularly interbedded with lesser amounts of dark-reddish-gray to occasionally bright-grayish-green shale; sandstone has prominent low-angle crossbedding and laminations. Grayish-red, massive-bedded, fine-grained sandstone and light-olive-gray, fissile shale is interbedded with the sandstone.

Tuscarora Formation (Silurian)
Stu – Tuscarora Formation
Lower transitional zone (with underlying Juniata Fm) -greenish-gray medium- to coarse-grained sandstones with interbedded medium-light-gray orthoquartzite and quartzarenite; crossbedding and crosslaminations common; local conglomeratic beds.
Middle quartzite zone - very light-gray, resistant, ledge-forming , exceptionally well sorted and well indurated, thick-bedded, fine- to coarse-grained orthoquartzite.
Upper transitional zone - alternating medium-light- to dark-gray, fine- to medium-grained sandstones with medium-gray quartzites.

ORDOVICIAN

Juniata Formation (Ordovician)
Oj - Juniata Formation. Lower part dominantly grayish-red and pale reddish-brown, fine-grained sandstone interbedded with minor grayish-red shale, crossbedding and brachiopod fragments common in the fine-grained sandstones. Grades upward into interbedded light-gray quartzites and grayish-red finely cross-laminated, fine- to medium-grained sandstones with minor grayish-red, fissile siltstone.

Cap rock (top of Buttn Mtn) – hosts ventilation shaft only

Fig. 4-3. Stratigraphy of major units at Kimballton

-------------------- MIDDLE LEVEL DETACHMENT ZONE ---------------------

Not a host rock for access tunnels or labs

Martinsburg Formation (Ordovician)
Omb – Martinsburg Formation
Upper portion dominantly interbedded dark-gray to black mudstone and medium- gray, massive-bedded to well laminated, fine-grained sandstone.
Lower portion: interbedded medium- to dark-gray, coarse-grained, 2-15 cm-thick beds of limestone with abundant bioclastic debris, and light- to medium-gray, calcareous mudstone. Locally intensely deformed with well developed solution-cleavage.

Eggleston Formation and Moccasin Formation
Oem (Eggleston) - Interbedded light-gray, fine- to medium-grained sandstone and siltstone and medium- to dark-gray, silty limestone with yellowish-green, waxy, translucent bentonite beds (St Clair, Narrows, and Saltville thrust sheets)
Oem (Moccasin) - Interbedded maroon mudstone and gray limestone, gradational contact with Middle Ordovician limestone. (St Clair, Narrows, and Saltville thrust sheets)

Main host rocks for underground laboratories

Middle Ordovician Limestone
Olu – Lower dolomite and dolomitic limestone sequence: medium- to light-gray, dolomitic limestone sequence with a basal, medium- to light-gray fine grained dolomitic limestone with angular chert and dolomite clasts both rounded and angular;
Middle cherty, fossiliferous limestone sequence: medium-light-gray to medium-dark-gray fine to medium grained limestone with coarse-grained calcarenite are dominant lithologies. Dark-gray and black nodular and bedded chert is abundant
Upper argillaceous limestone sequence: medium- to dark-gray, bedded, argillaceous micrites with interlaminated and interbedded, thin, olive-gray shales.

Knox Group
(Undivided Kingsport, Mascot, Longview, and Chepultepec Formations)
Oku - Medium-dark-gray to light-gray, massive-bedded to styolitic, thick-bedded fine- to medium-grained, crystalline dolomite with lenses and nodules of light-gray to black chert; dark-reddish-brown argillaceous dolomite and lenses of laminated to cross bedded, fine-grained, siliceous clastics are present in the basal part; algal laminations and domal structures are common; abundant cherty residuum obscures this unit; laterally equivalent to Beekmantown Group.

CAMBRIAN

Copper Ridge Formation (lower Knox)
(St Clair, Narrows, Saltville and Catawba thrust sheets; Ccr - in St Clair, Narrows, and Saltville thrust sheets, consists of dolomite, sandy dolomite, minor sandstone, and thinly laminated, argillaceous dolomite (near the base). Dolomite is light- to medium-gray, thin- to medium-bedded, crystalline to microcrystalline.
Sandy units include light-brown to grayish-orange, thinly-laminated to massive-bedded, carbonate-cemented, fine- to coarse-grained sandstone and light-gray, thin-bedded, sandy crystalline dolomites. Cross laminations, crossbedding and small-scale channels are prevalent in sandstones and sandy dolomites. Minor, dark-gray, siliceous, oolitic microcrystalline dolomites, dark-gray to black chert and very light-gray "cauliflower" chert scattered throughout the section.
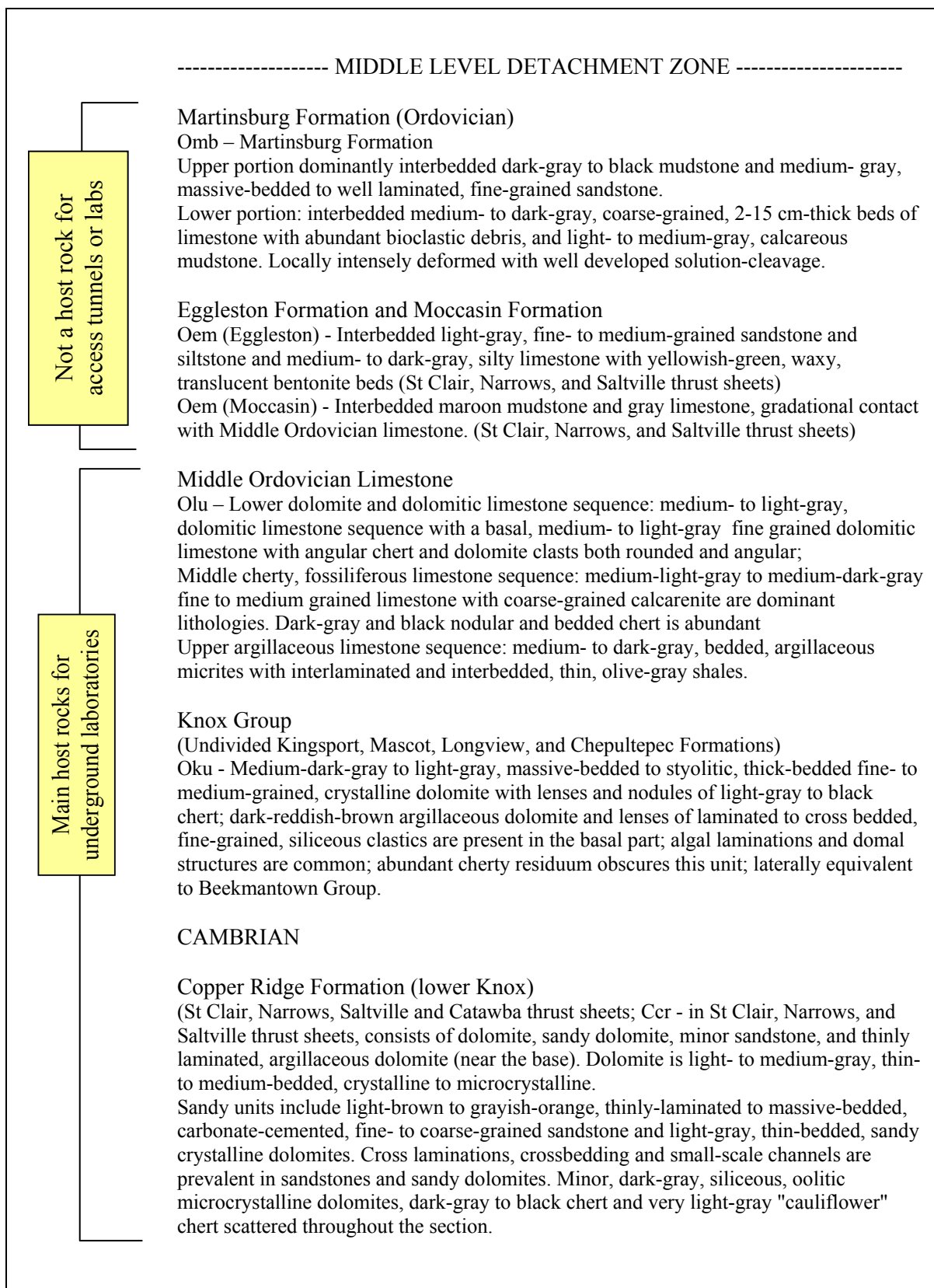
Fig. 4-3. Stratigraphy of major units at Kimballton (continued)

5 Geotechnical Characteristics

5.1 Geotechnical Sample/Data Collection Activities

The purpose of the geotechnical sample and data collection was to estimate rock and rock mass properties at depth for the purpose of evaluating feasibility, costs and uncertainties associated with Kimballton-DUSEL. At this stage of the investigation, extensive use was made of surface exposures, which, due to the overall synclinal structure of Butt Mtn (Figs. 2-1 & 4-2), expose the formations that will be encountered at depth. Geotechnical parameters obtained from surface exposures are generally conservative - and perhaps highly conservative - with respect to properties of unweathered rocks; i.e., data from the surface will tend to underestimate strengths (Goodman 1993; Rahn 1996).

Geomechanical data determined in the field or in the laboratory include the following:

Unit Weight – Unit weight was determined for the purpose of estimating vertical stresses at depth, for estimating meters water equivalent (mwe) and for calibrating strength estimates based on the Schmidt hammer tests.

Unconfined Compressive Strength – The unconfined compressive strength (UCS) is a basic strength parameter for rock, and an input parameter for both the Q and the RMR rock mass classification systems. The UCS is also used to quantify the potential for squeezing ground in tunneling. More generally, the UCS is used to determine the capacity for rocks to support applied stresses such as those that will occur at depth in Kimballton-DUSEL. Unconfined compressive strength was determined using three different testing techniques (the unconfined compressive strength test, the Schmidt hammer test, and the point load test). The results from these three independent techniques were in good agreement with each other.

Young's Modulus –A high modulus value indicates high stiffness, and implies limited elastic deformation under applied loads. The elastic modulus is a basic material property necessary for numerical modeling of the underground excavations, as will be undertaken as part of the S-2 process.

Fracture Characteristics – Fracture orientation and frequency data were collected along scanlines at area quarries and roadcuts in order to develop a model for fracturing in the Kimballton-DUSEL rocks. Information about fracture sets is essential for rock mass classification (Q and RMR) and is necessary for developing a geomechanical model of the rock mass. In addition, data on fracture roughness and infilling, and other parameters needed for input to the Q system, were collected along the scanlines.

Geotechnical Sample/Data Collection Sites: Fracture data and samples for geomechanical testing were collected from sites listed in Table 5-1 and shown in Fig. 5-1. These sites represent the rock formations that will be encountered at depth: in particular the Knox (including the Copper Ridge) and the Middle Ordovician limestone (including the Five Oaks), both of which are well exposed in abandoned quarries. With the exception of four locations in the Kimballton mine (Kim A-D) and a borehole dating

from 1990 (Kim-E), data were collected from surface locations – primarily quarries, and a few roadcuts. Because of decades or centuries of exposure at the ground surface, the geomechanical properties of rock specimens obtained from surface locations are expected to be inferior to properties of the same rock units at depth, as a result of near-surface weathering and development of microcracks due to stress relief. Geologic and rock mechanics studies to be carried out under S-2 (see Appendix B) will include geomechanical testing on core retrieved from boreholes at the locations of the mid-level and deep campuses

Table 5-1. Data collection sites and activities (see Fig. 5-1 for locations; roadcuts 460 C & D are east of map area)

	Location (1,2)	Formation	No. of Scanlines	Rock Samples	Digital Photos	Schmidt Hardness
Q-17	Quarry 17 – east of Klotz and northwest of Pembroke	Middle Ordovician limestone	2	Yes	Yes	Yes
Q-18	Quarry 18 – east of Klotz and northwest of Pembroke	Middle Ordovician limestone	2	No	Yes	No
Q-25	Quarry 25 – west of Pembroke	Copper Ridge (lower Knox)	6	Yes	Yes	Yes
RC-460A	Road Cut 460A – east of Pembroke on Hwy. 460	Middle Ordovician limestone	1	No	Yes	Yes
RC-460B	Road Cut 460B – east of Pembroke, east of Road Cut 460A on Hwy 460	Middle Ordovician limestone	1	Yes	Yes	Yes
RC-460C	Road Cut 460C – east of Pembroke	Martinsburg Fm	1	Yes	Yes	Yes
RC-460D	Road Cut 460D – east of Pembroke	Martinsburg Fm	1	Yes	Yes	Yes
FT-Butt Mtn.	Fire Tower- off route 613	Tuscarora sandstone, Rose Hill Fm	1	Yes	Yes	Yes
OC-613A	Route 613; Outcrop 613-A	Martinsburg Fm	1	Yes	Yes	Yes
OC-460A	Highway 460; Outcrop 460 A	Martinsburg Fm	0	Yes	Yes	Yes
Kim-A	Kimballton Mine 12E #5 & 6, #29W	Five Oaks (Middle Ordovician	0	Yes	Yes	No
Kim-B	Kimballton Mine 12E #5 & 6, #29W	Five Oaks (Middle Ordovician)	0	Yes	Yes	No
Kim-C	Kimballton Mine 13 West	Five Oaks (Middle Ordovician)	1	No	Yes	No
Kim-D	Kimballton Mine 13 West	Five Oaks (Middle Ordovician)	1	No	Yes	No
Kim-E	Borehole at Kimballton Mine	Martinsburg & Eggleston	0	Yes	Yes	No

Notes: (1) Prefixes indicate the following: Q = quarry, RC = road cut, OC= Outcrop, Kim = Kimballton Quarry; (2) Quarry numbers coincide with the Geologic Map of Giles County, VA, Publ. No. 69
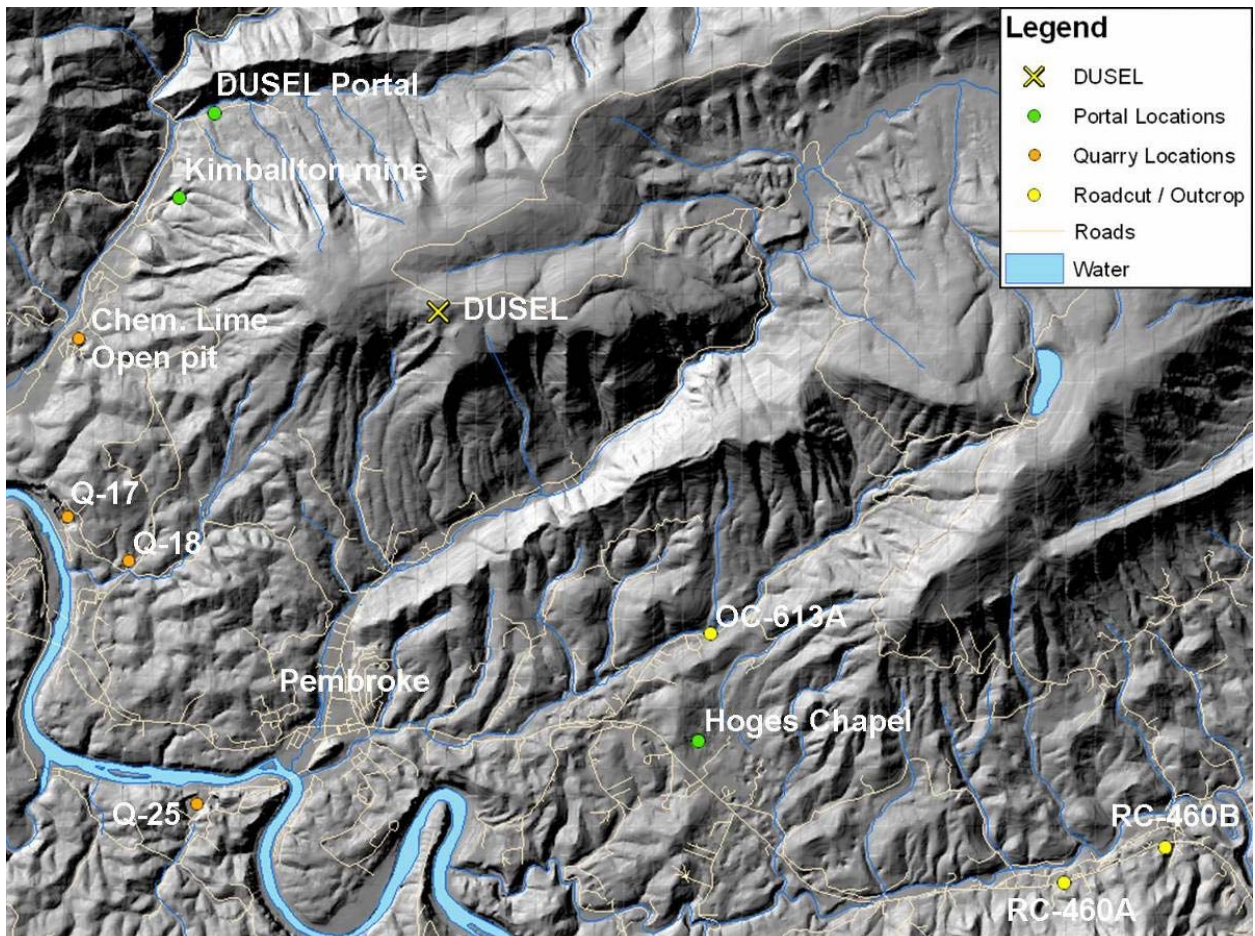
Figure 5-1. Locations of rock sample and fracture data collection sites

Samples for Geomechanical Testing: Samples of the primary rock formations for Kimballton-DUSEL - the Knox (which includes the Copper Ridge Formation), and the Middle Ordovician limestone (which includes the Five Oaks) - as well as samples of the Martinsburg shale and limestone, and the Tuscarora and Rosehill sandstones, were obtained from the sites listed in Table 5-1 for geomechanical testing. The purpose of the geomechanical testing was to estimate the properties of these same rock units at depth.

Fracture and Rock Mass Classification Data: In common with all rock masses, the rocks at Kimballton exhibit fractures. The fractures at Kimballton are systematic and can be organized into fracture sets. The geomechanical behavior of rocks in underground excavations is strongly impacted by the characteristics of the fracture sets. In order to estimate fracture characteristics at depth, fracture data were collected at several sites in the vicinity of Kimballton (Table 5-1). Scanlines were employed in order to collect data in a systematic way. As with the geomechanical properties obtained from testing of

outcrop samples, fracture data collected at or near the surface (Table 5-1) will tend to show inferior conditions than will be encountered at depth.

In addition to this, Chemical Lime Company has already cored to a depth of 2000 ft below the Kimballton Mine. Sections of core from beneath the Kimballton Mine have been shipped to Virginia Tech for testing, which thus far has consisted of petrographic analysis and point load tests. We have also conducted tests on unweathered shale of the Martinsburg Fm. retrieved (on an unrelated project) from a site in Martinsburg WVA.

Additional Geomechanical Data: Geologic and rock mechanics studies to be carried out under S-2 (see Appendix B) will include geomechanical testing on core retrieved from several shallow boreholes and at least one borehole drilled to the full depth under Butt Mtn. The boreholes will be imaged using a borehole televiewer.

5.2 Geomechanical Testing

As discussed previously, the preliminary geotechnical evaluation included the determination of unit weight, unconfined compressive strength (by three methods) and Young's modulus. Data on fracture characteristics were also collected and will be discussed in the next section. Geotechnical and geomechanical data were collected and analyzed in order to evaluate the feasibility of constructing DUSEL at Kimballton. The unit weight determination was needed to estimate stresses and for preliminary determination of support requirements for underground caverns at depth, and also to calibrate the Schmidt hammer test results. The unconfined compressive strength is a basic strength parameter for rock and an input parameter for rock mass classification, and is needed for evaluating the safety and stability of underground excavations. Young's modulus gives an indication of the response of the rock mass to loading and is also a needed parameter for the safe design of underground excavations. The following sections describe test methods and present results for each parameter in turn.

5.2.1 Unit Weight

Unit weight measurements were carried out using the test procedure described in USACE Rock Testing Handbook (USACE 1993). Representative samples were chosen to perform the unit weight test. The test consists of measuring the weight of the specimen (at least 50g) and its bulk volume ISRM (1981). Weights were determined with a scale, and bulk volume was found by the water displacement method - which involves putting a rock sample into a container of water, and measuring the volume of the displaced fluid. Paraffin wax was the coating material used to prevent the penetration of water into the rock. Because these rocks have low porosity, errors due to wax entering grain-scale pore space were minimal. The test results, with averages for each site, are given in Table 5-2.

Table 5-2. Rock unit weights

Site	Samples	Rock mass	Rock +wax mass	Volume Displaced (rock&wax)	Wax mass	Vol. wax (*)	Net rock volume	Density	Unit Weight	Avg. Unit Weight	Formation
		g	G	cm^3	g	cm^3	cm^3	g/cm3	KN/m^3	KN/m^3	
Quarry 17	17-A(1)	136.1	140.6	60	4.5	5.11	54.89	2.48	24.80	24.91	Middle Ordovician limestone
	17-A(2)	132	137.5	59	5.5	6.25	52.75	2.50	25.02		
Quarry 25	25-D(1)	212.4	216.9	83	4.5	5.11	77.89	2.73	27.27	26.52	Copper Ridge (lower Knox)
	25-D(2)	166.3	171.4	69	5.1	5.80	63.20	2.63	26.31		
	25-G(1)	220.9	225.4	90	4.5	5.11	84.89	2.60	26.02		
	25-G(2)	123.6	126.5	50	2.9	3.30	46.70	2.65	26.46		
460-A&B	460-A	138.3	141.7	60	3.4	3.86	56.14	2.46	24.64	25.22	Middle Ordovician limestone
	460-B	146.3	149.2	60	2.9	3.30	56.70	2.58	25.80		
460 C	460 C(1)	129.8	133.8	59	4	4.55	54.45	2.38	23.84	24.2	Martinsburg
	460 C(2)	90.8	93.1	39.5	2.3	2.61	36.89	2.46	24.62		
460 D	460-D(1)	252	257.4	101	5.4	6.14	94.86	2.66	26.56	26.3	
	460-D(2)	240.9	245.7	98	4.8	5.45	92.55	2.60	26.03		
Fire Tower	Fire Tower	106.9	109.6	45	2.7	3.07	41.93	2.55	25.49	24.3	Rosehill sandstone
OC 613	OC 613	161.6	164.8	65	3.2	3.64	61.36	2.63	26.33	26.33	Martinsburg

Notes: (*) Volume of wax = wax weight/wax mass. Wax density = 0.88g/cm^3

5.2.2 Compressive Strength

The compressive strengths of the Kimballton rocks were evaluated by three different test methods: (1) unconfined compressive strength tests, (2) by correlations with the Schmidt hammer rebound value, and (3) by point load tests. Of these methods, the unconfined compressive strength test is generally superior. However, sample preparation for the unconfined compressive strength test is time consuming and expensive. Use of the point load test and the Schmidt hammer allowed testing of a large number of samples and give a good indication of the range of results. The results of these tests are presented below.

Unconfined Compressive Strength Tests – Five Oaks Limestone: Stress-strain plots with brittle failure recorded from five unconfined compressive strength tests (Fig. 5-2) on samples of Five Oaks (Middle Ordovician) limestone from the Kimballton mine are shown in Fig. 5-3, and the strengths in Table 5-3. The sample locations for these tests are Kim-A and Kim-B.
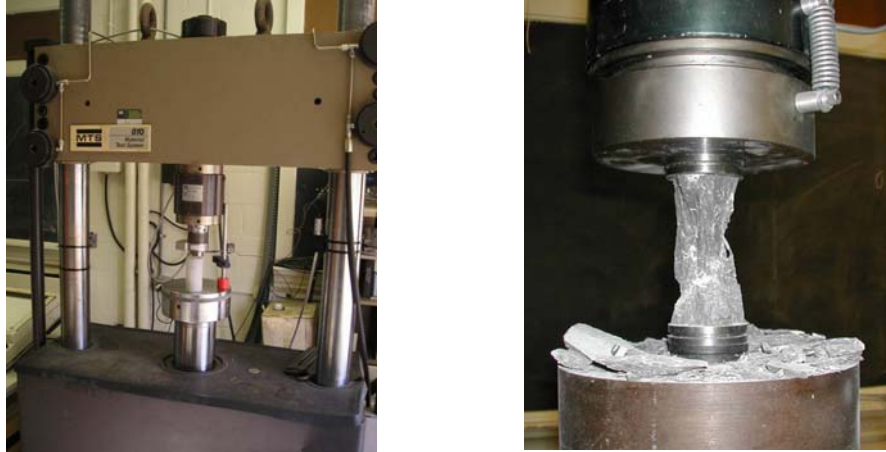
Figure 5-2. (a) Loading frame used for unconfined compression tests; (b) Specimen of Five-Oaks limestone at point of failure (failure pattern indicates high stiffness rock).
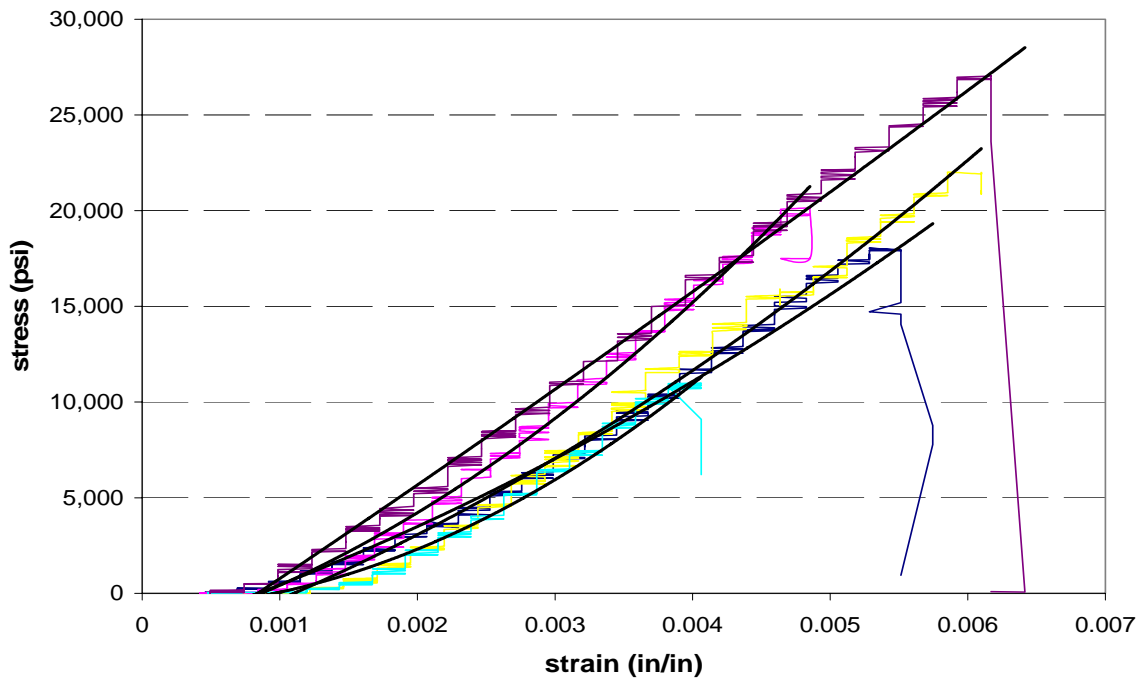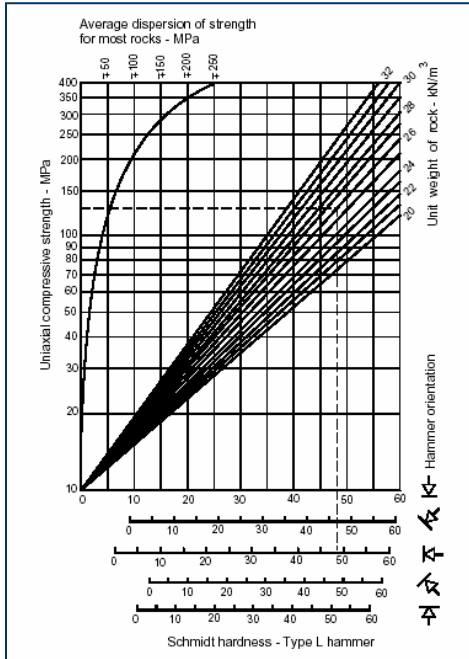

Figure 5-3. Stress-strain plots to failure for uniaxial compression of Five-Oaks limestone

Table 5-3. Unconfined compressive strength-Five Oaks limestone (Middle Ordovician)

Sample	Psi	MPa
1	18,050	124
2	22,012	152
3	20,156	139
4	10,987	76
5	27,058	187

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Compressive Strength Based on Schmidt Hammer Tests: A type-L Schmidt hammer was used to measure rebound hardness of rock faces. Measurements were taken on exposed rock fractures, and on exposed rock faces adjacent to the fractures. The Schmidt hammer was used in the horizontal position, (the rock face was vertical). The Schmidt rebound values for each scanline are presented in Table 5-4. Following standard procedure (Barton and Choubey, 1976), ten readings (in different locations) were taken at each face, with the highest five values averaged to obtain r* (or the highest 50% were averaged). A standard chart (Fig. 5-4) was used to estimate uniaxial compressive strength, with the results summarized in Table 5-5 and Fig. 5-5.

Figure 5-4. Unconfined compressive strength based on Schmidt Hammer (type-L) rebound values (after Deere and Miller, 1966)

Table 5-4. Schmidt Hammer Rebound Values

Site		Schmidt Hammer Rebound Values (r)
Quarry 17	Q-17A	40 46 47 45 50 50
	Q-17B	55 48 46 52 54 50 44 56 44 56 44 46 48
	Q-25A	52 48 48 39 45 45 45 45 50 48 49
	Q-25B	55 45 50 55 55 55
uarry 25	Q-25D	40 35 50
	Q-25E	30 55 49 55 50 28 34 40 54 40 50 44 40
	Q-25F	49 44 50 49 39 45 52 40
	Q-25G	42 45 45 48 52 35
	460-A	50 46 52 50 54 30 48 46 50 54 48 44
RC-460	460-B	50 54 49 50 48 52 52
	460-C	27 35 30 24 22 20 40
	460-D	30 26 25 35 35 36 30 25
Kimballton Mine	Kim-C	54 55 56 56 58 58 58 58 60 62
	Kim-D	42 50 55 55 56 56 58 60 61 65
Fire Tower	Fire Tower	60 65 58 51 55 58 50 58 65 64 65 59 65
OC 613-A	Outcrop 613-A	50 22 45 22 34 30 45 52 52
	Perpendicular	24 27 27 28 28 30 30 30 31 31
	Parallel	13 14 15 15 16 18 18 18 19 21
Martinsburg W VA	Perpendicular	14 16 18 19 20 22 24 28 30 30
	Perpendicular	24 24 25 26 26 26 26 28 28 30

Table 5-5. Uniaxial compressive strength of rock specimens based on Schmidt Hammer

Location		Unit Weight (KN/m³)	Schmidt Hammer r*	Uniaxial Compressive Strength (MPa)	Rock Type	Formation
Quarry 17	Q-17A	24.9	49	120	Limestone	Middle Ordovician limestone
	Q-17B		55	155		
	Q-18B		-	-		
Quarry 25	Q-25A	26.5	49	145	Limestone and dolostone	Copper Ridge Fm (lower Knox)
	Q-25B		55	185		
	Q-25D		45	130		
	Q-25E		51	160		
	Q-25F		50	155		
	Q-25G		48	140		
Road Cut 460	460-A	25.2	52	130	Limestone	Middle Ordovician limestone
	460-B	25.2	52	130		
	460-C	24.2	35	70	Slate	Martinsburg Fm
	460-D	26.3	34	65		
Kimballton Mine	Kim-C	25.3	59	175	Limestone	Five Oaks (Middle Ordovician limestone)
	Kim-D	25.3	60	190		
Fire Tower	FT	24.3	65	200	Sandstone	Rosehill Fm
Outcrop 613-A	OC 613-A	26.3	50	130	Slate	Martinsburg Fm
Martinsburg WVA	perp	26.0	30	49	Slate	Martinsburg Fm
	parallel	26.0	19	28		
	perp	26.0	27	43		
	perp	26.0	28	45		

Figure 5-5. Unconfined compressive strengths based on Schmidt hammer rebound values. Values marked with asterisks were from tests on large block samples of the Middle Ordovician limestone, collected from a drift at a depth of 1300 ft in the Kimballton mine. The Martinsburg will be avoided by both access tunnels and underground caverns.

Point Load Test Results: The point load test is an index test for strength classification of rock (A description of the testing and calculation procedure can be found in ASTM D5731 (2001), ISRM (1985) and Broch and Franklin (1972). Figure 5-6 shows the point load apparatus (TS 706/D of Tecnotest) used to perform the tests. All samples tested met the requirements for test specimens (Fig. 5-7).
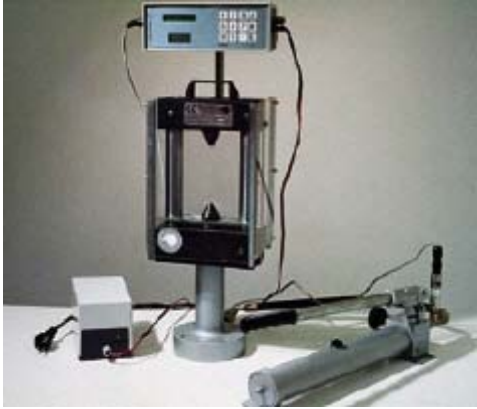
Figure 5-6. Point Load Test Apparatus
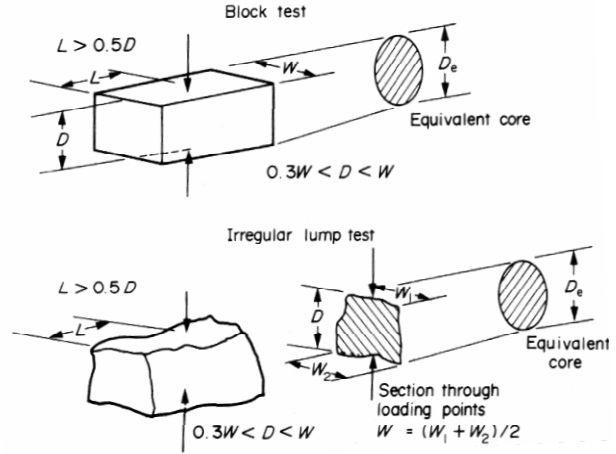
Figure 5-7. Test methods and critical dimensions for point load test (ISRM, 1985)

Results of the point load test determination of unconfined compressive strengths are given in Table 5-6 and Fig. 5-8. It is important to note that the Martinsburg shale samples were from a highly weathered outcrop along Highway 460, and are not representative of the Martinsburg at depth, which is expected to have significantly higher strength. It should also be noted that the underground layout and access tunnels for Kimballton-DUSEL will avoid the Martinsburg at depth.
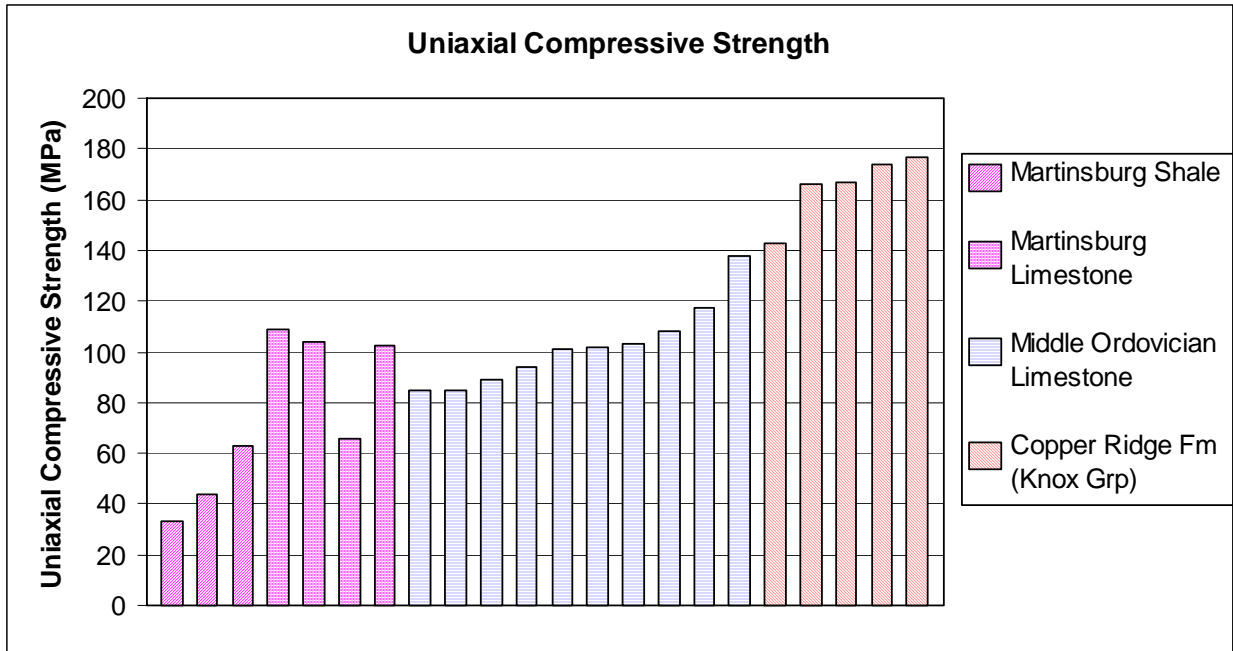
Figure 5-8. Point load test results. Note that the Martinsburg shale samples were from a highly weathered outcrop along Highway 460.

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Table 5-6. Data and results of the point load test

	Test Nr.	Water content	Direction	D (mm)	W (mm)	L (mm)	De (mm)	Valid Test?	P (kN)	I_S (kPa)	F (-)	I_S (50) (kPa)	qu (MPa)
Quarry 17	1	natural	normal	40	71	40.5	60	Y	13	3711	1.1	4033	89
	2	natural	normal	40	52	45	51	Y	14	5237	1.0	5306	117
	3	natural	normal	56.5	61.5	41	67	Y	18	4066	1.1	4624	102
	4	natural	parallel	35	52	41.5	48	Y	10	4367	1.0	4293	94
	5	natural	parallel	43	56	41	55	Y	14.4	4707	1.0	4928	108
Quarry 25	1	natural	normal	41	53	35.9	53	Y	20	7399	1.0	7569	167
	2	natural	normal	38	46	41	47	Y	18	8142	1.0	7931	174
	3	natural	normal	37	47	42	47	Y	18.3	8265	1.0	8042	177
	4	natural	normal	44	54.5	41	55	Y	22	7205	1.0	7537	166
	5	natural	parallel	39	47.5	43	49	Y	16	6593	1.0	6507	143
RC 460 A & B	1	natural	normal	42.5	53	35	54	Y	17	6060	1.0	6250	138
	2	natural	normal	35	47	40.5	46	Y	10	4798	1.0	4611	101
	3	natural	normal	46	55	40	57	Y	14	4414	1.1	4673	103
	4	natural	parallel	36	50	32	48	No	4	1724	1.0	1690	37
	5	natural	parallel	42	45	41	49	Y	9	3919	1.0	3885	85
	6	natural	parallel	37	56	31	51	Y	10	3802	1.0	3848	85
RC 460 C	1	natural	normal	43	52.5	32	54	No	2.47	859	1.0	887	20
	2	natural	parallel	41	46.5	36	49	No	0.58	239	1.0	237	5
	3	natural	normal	42	54	35	54	No	4.55	1576	1.0	1628	36
	4	natural	normal	30	65	41	50	Y	4	1490	1.0	1488	33
	5	natural	normal	32	54	36	47	Y	7	2954	1.0	2871	63
RC 460 D	1	natural	normal	39	50	43	50	No	4	1611	1.0	1609	35
	2	natural	normal	40	60	34	55	Y	14	4617	1.0	4831	106
	3	natural	parallel	40	50	40	50	Y	5	2011	1.0	2019	44
Kim-E	1	natural	normal	36	40	71	43	Y	9.68	5,333	0.9	4,962	109
	2	natural	normal	36	40	68	43	Y	9.19	5,063	0.9	4,711	104
	3	natural	normal	35	40	62	42	Y	5.68	3,219	0.9	2,976	65
	5	natural	normal	33	40	69	41	Y	8.5	5109	0.9	4,661	103
Firetower	1	natural	normal	44	64	32	60	Y	47.9	13360	1.1	14489	319

5.2.3 Geomechanical Properties of Intact Rock - Summary

Unit Weight: Unit weights are graphed in Fig. 5-9. These unit weights were measured on samples obtained from surface exposures. Because of prolonged exposure at the surface, they have been subjected to weathering and development of microcracks, both of which reduce unit weight. Unit weights at depth are expected to be slightly higher.
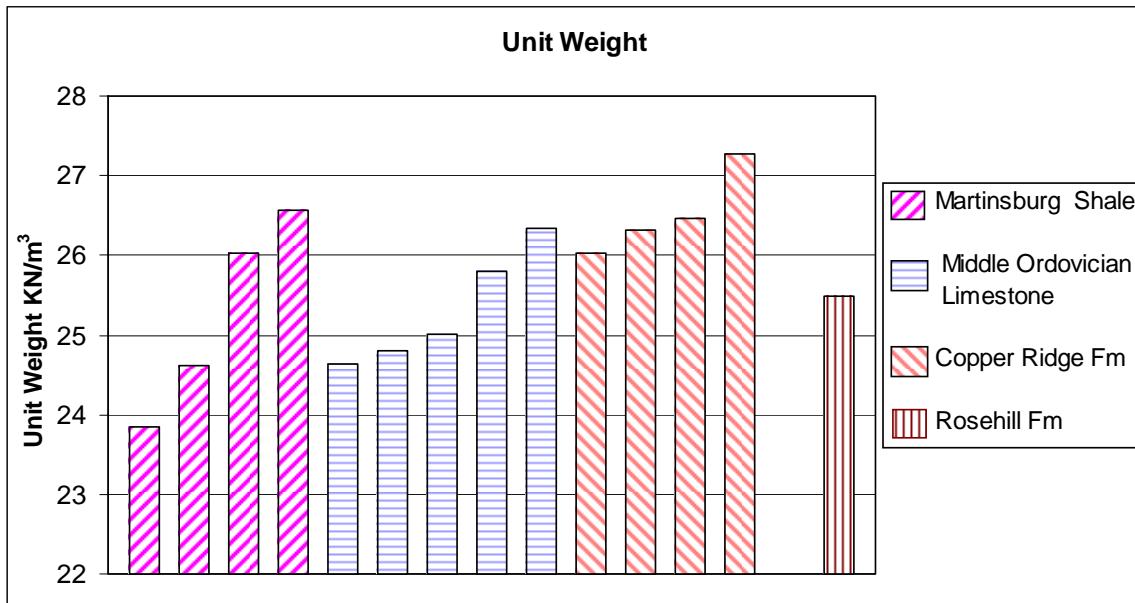

Figure 5-9. Unit weights (KN/m3) of rock formations exposed near Kimballton

Unconfined Compressive Strength: The data obtained on unconfined compressive strengths from all test methods are presented in Table 5-7 and Fig. 5-10. Note that two sets of strengths are reported for the Middle Ordovician limestone: one set based on measurements in quarries and roadcuts, and the other set based on measurements on samples collected from the Kimballton mine.

Table 5-7. Summary chart for unconfined compressive strength (MPa) by several test methods

Test Method:	UCS Test	Schmidt Hammer	Point Load	Average
Middle Ordovician – Quarry		134	96	115
Middle Ordovician – Mine	151	183		167
Knox – Quarry		153	166	159
Martinsburg Limestone			95	
Martinsburg Shale		54	38	46
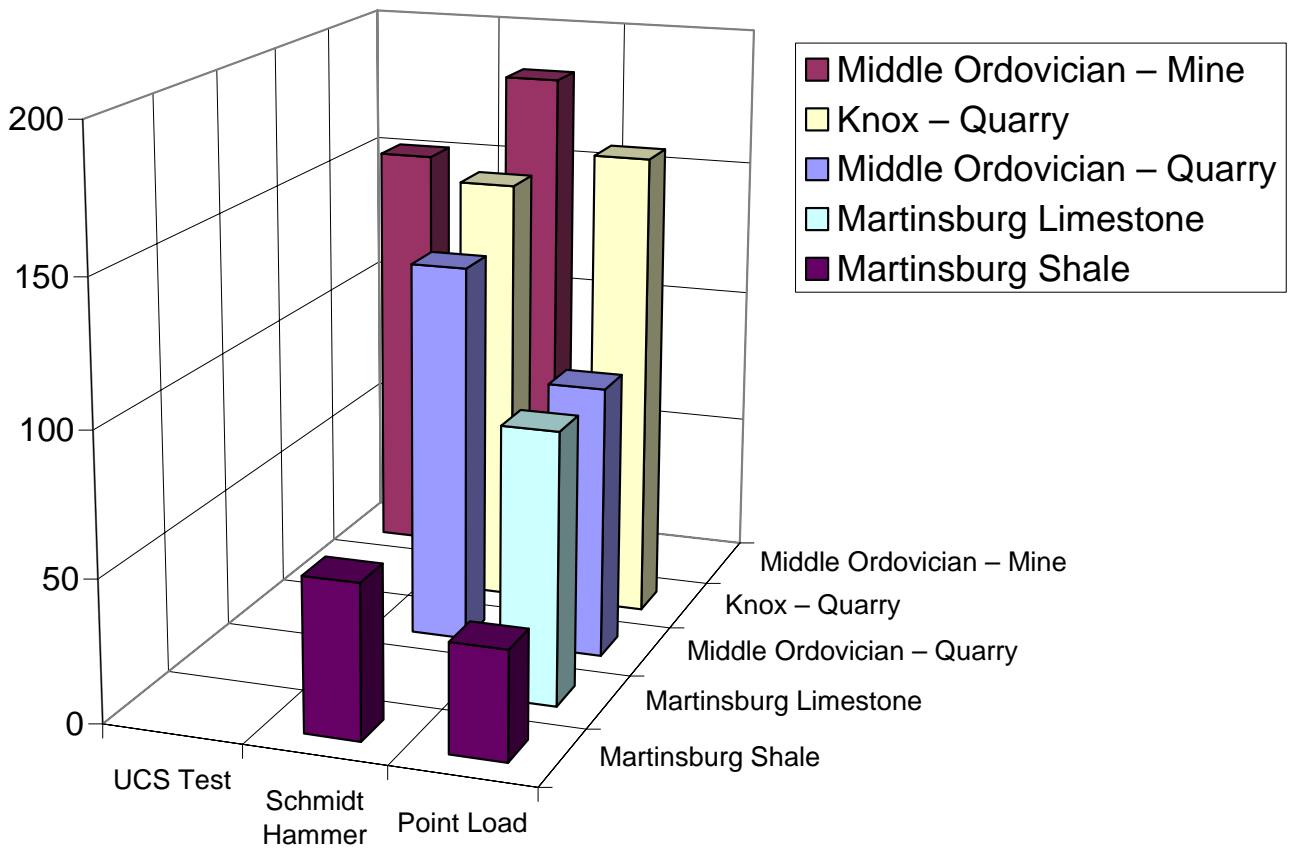
Figure 5-10. Unconfined compressive strength (MPa) by several test methods

5.3 Fracture Orientation Data

Fracture data were collected from several quarries and road cuts in the vicinity of the Kimballton mine, and limited data were gathered from the Kimballton mine itself. Scanline locations for quarries 17 and 25 are shown in Figures 5-11 and 5-12. The purpose of collecting and analyzing fracture data was to study regional fracture systems that are likely to be encountered in the DUSEL tunnels and excavations at depth.
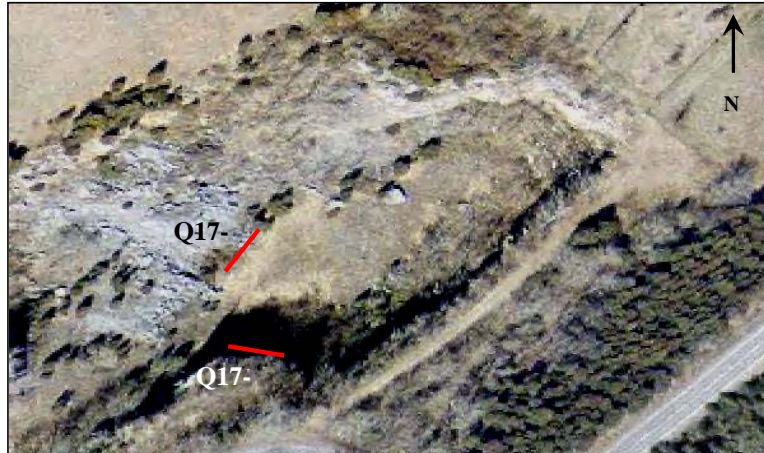
Figure 5-11. Aerial view of quarry 17, showing the locations of scanlines

Figure 5-12. Aerial view of quarry 25, showing the locations of scanlines

Lower hemisphere equal area pole plots for the various sites are shown in Figures 5-13 to 5-16. These plots, and the accompanying contour plots, generally show subhorizontal beds, with subvertical fractures in two distinct sets. In some cases, one of the fracture sets is poorly developed. Bedding orientation varies with respect to structural position on the syncline.

Q-25
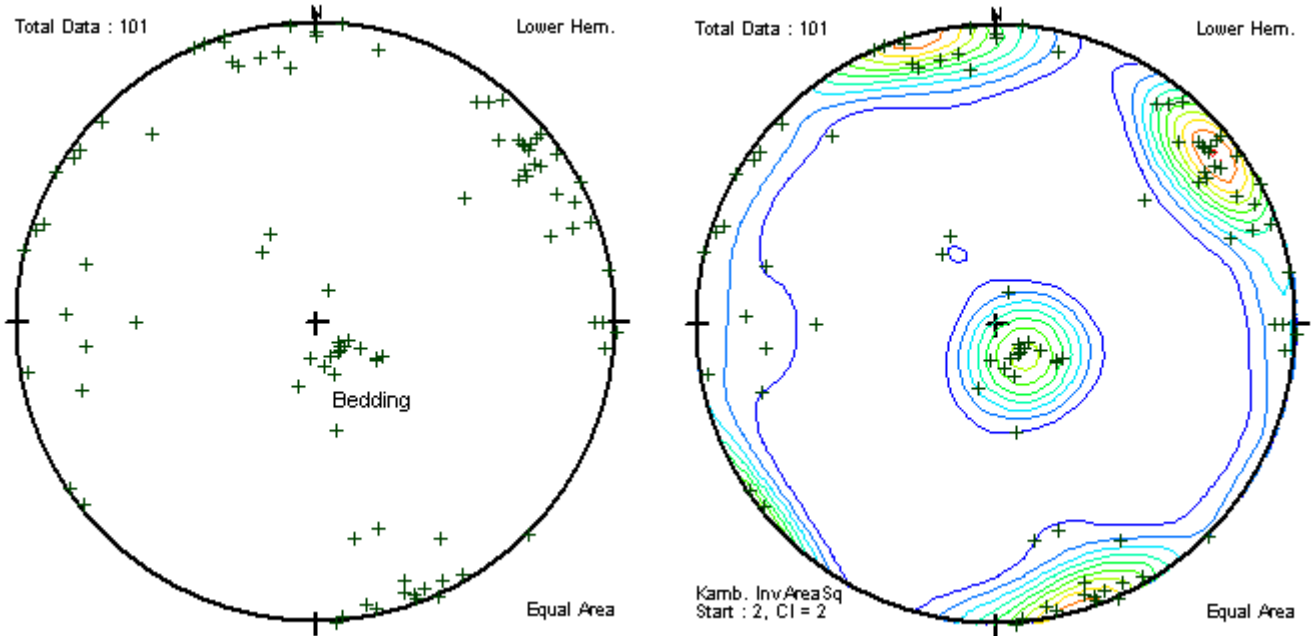
Q-17
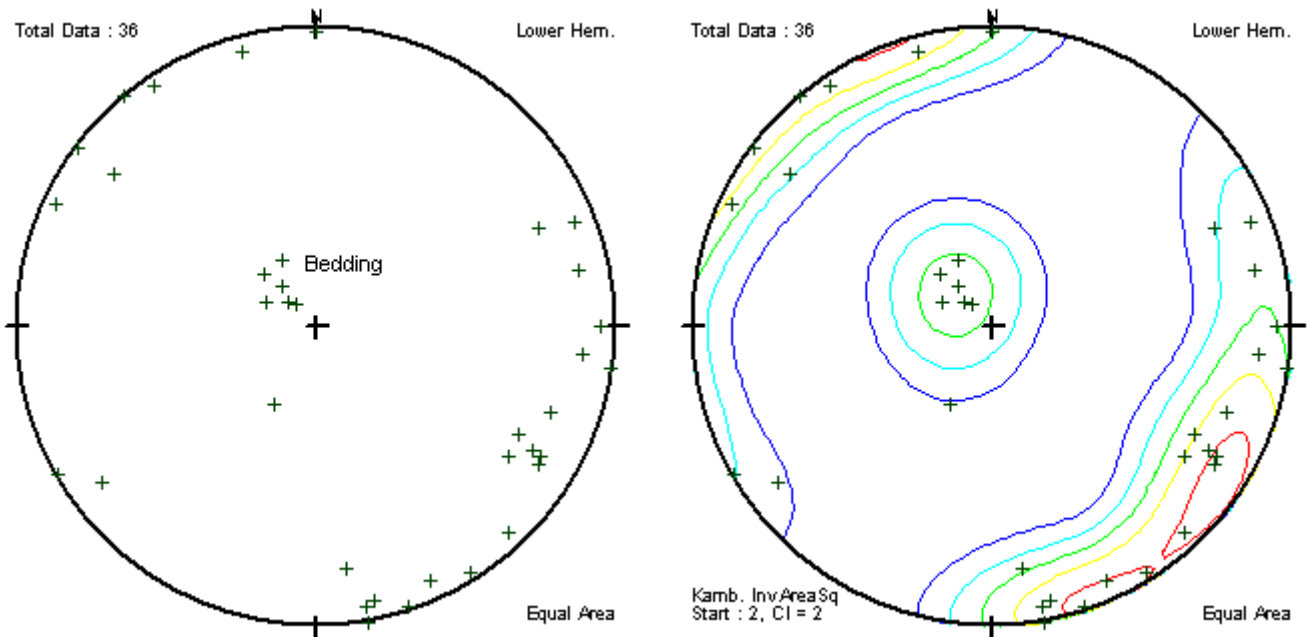
Figure 5-13. Lower hemisphere equal area fracture pole plots for quarries 25 and 17

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Q-18
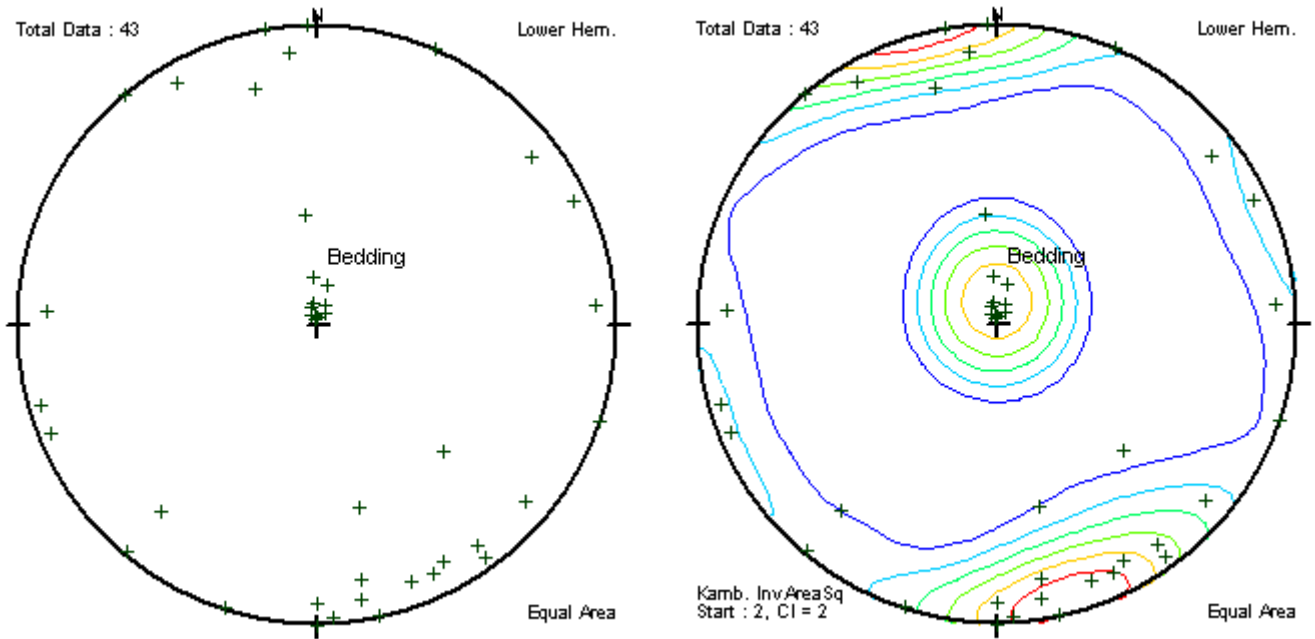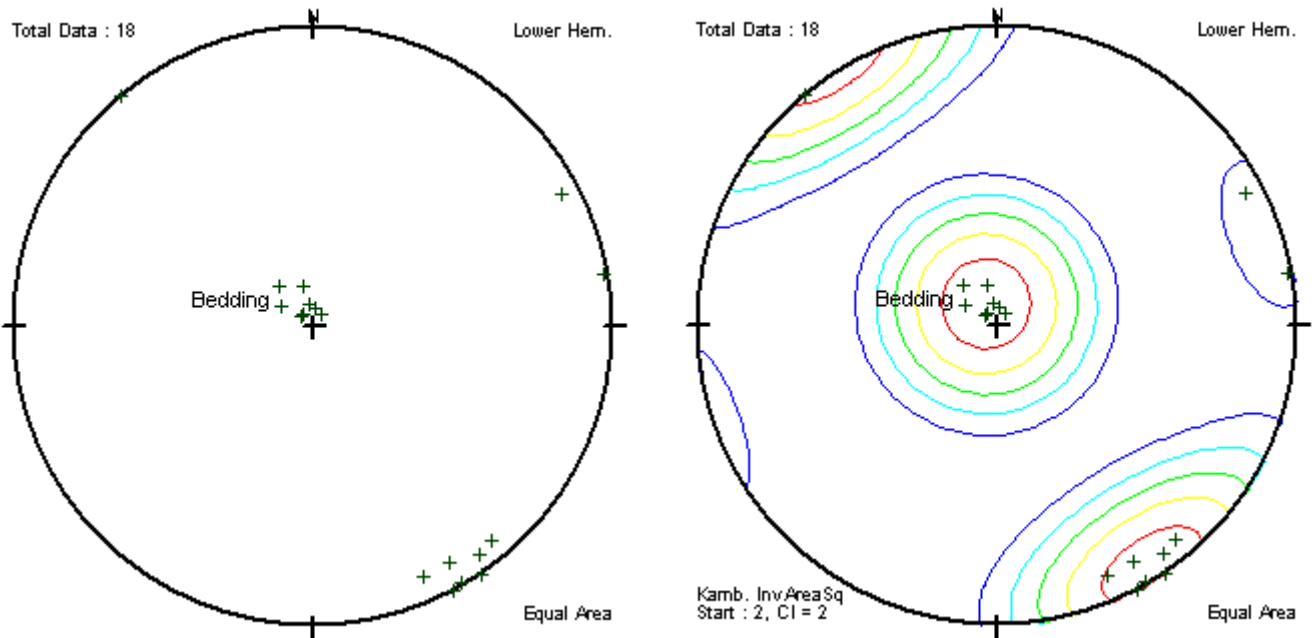
Firetower

Figure 5-14. Lower hemisphere equal area fracture pole plots for quarry 18 and the firetower.

24
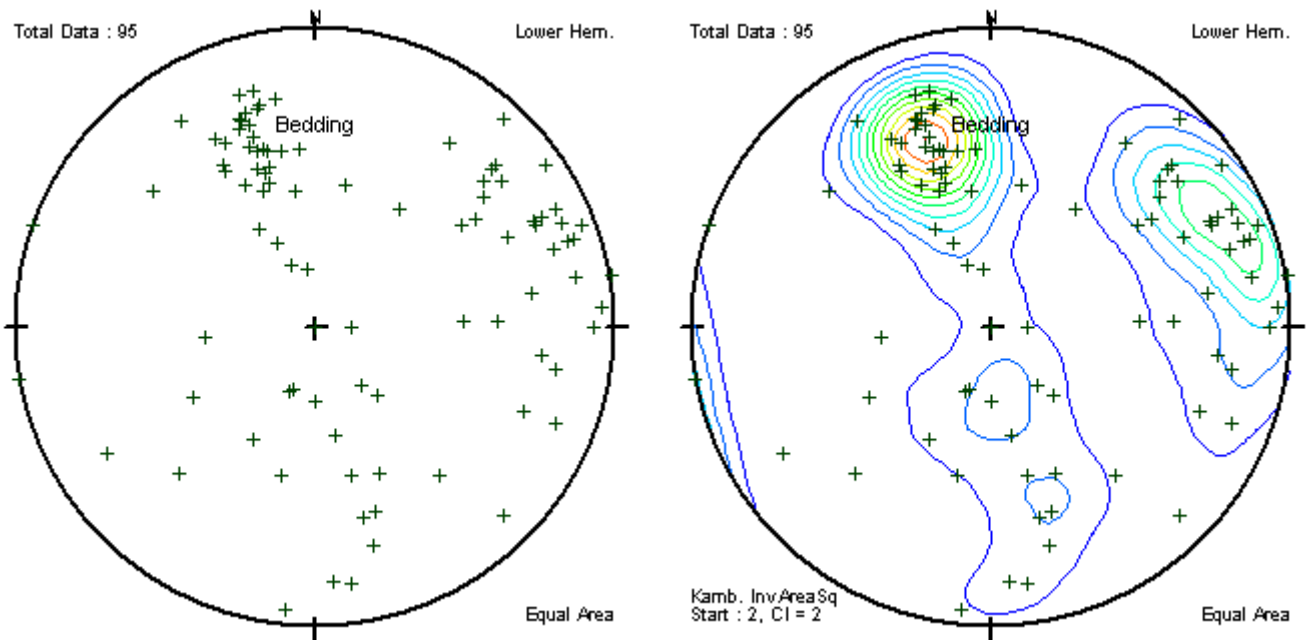
RC-460A
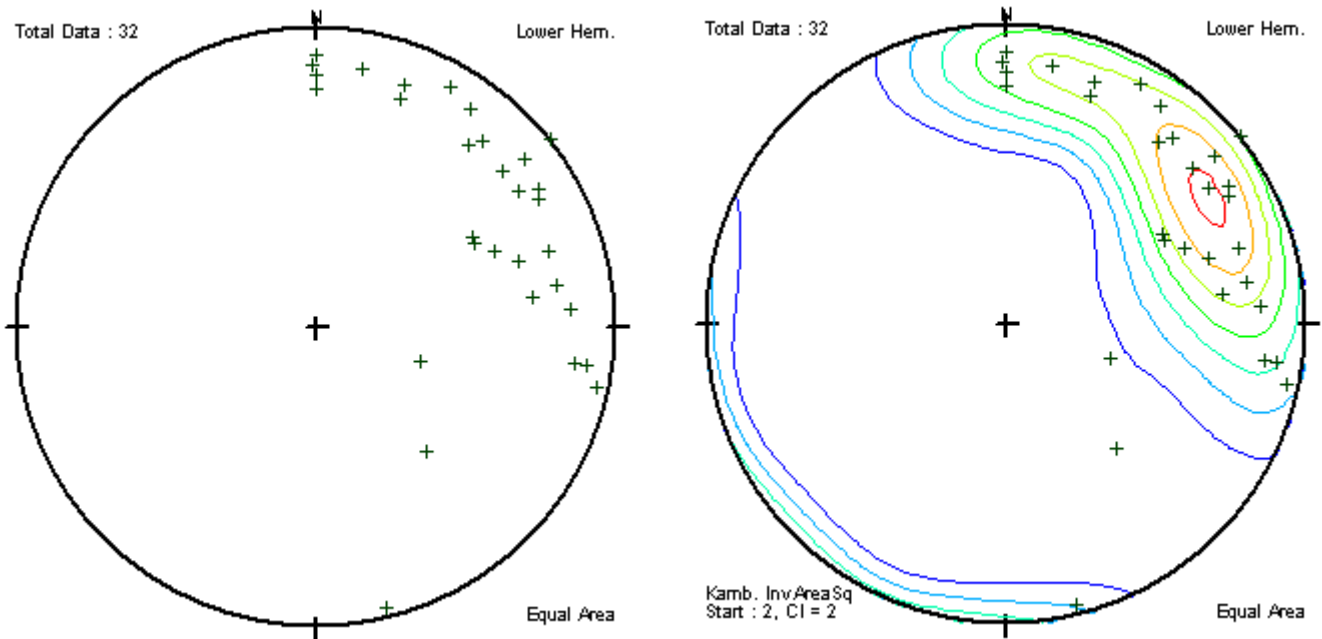

RC-460A rotated -53 deg
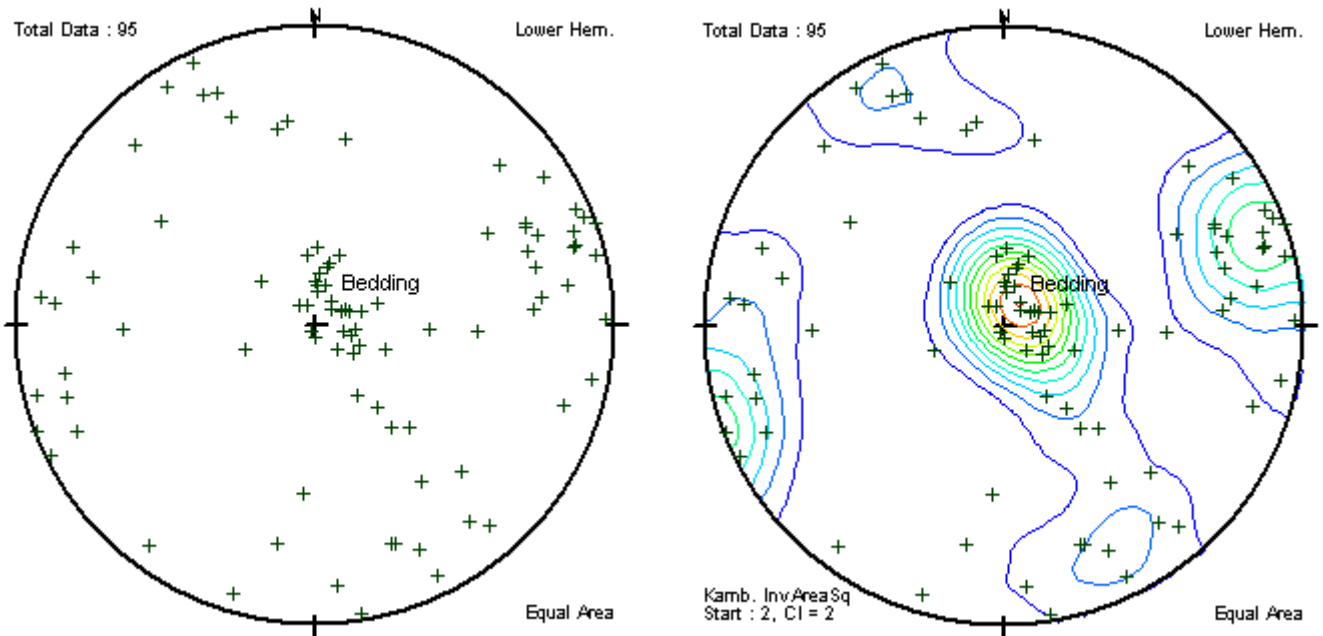
Figure 5-16. Lower hemisphere equal area fracture pole plots for Road Cut 460A. Data in the lower two plots have been back-rotated 53 degrees about the calculated (bedding-based) fold axis of the syncline. The back-rotated plots show a fracture geometry consistent with the other locations.

Kim Scanline 1

Kim Scanline 2
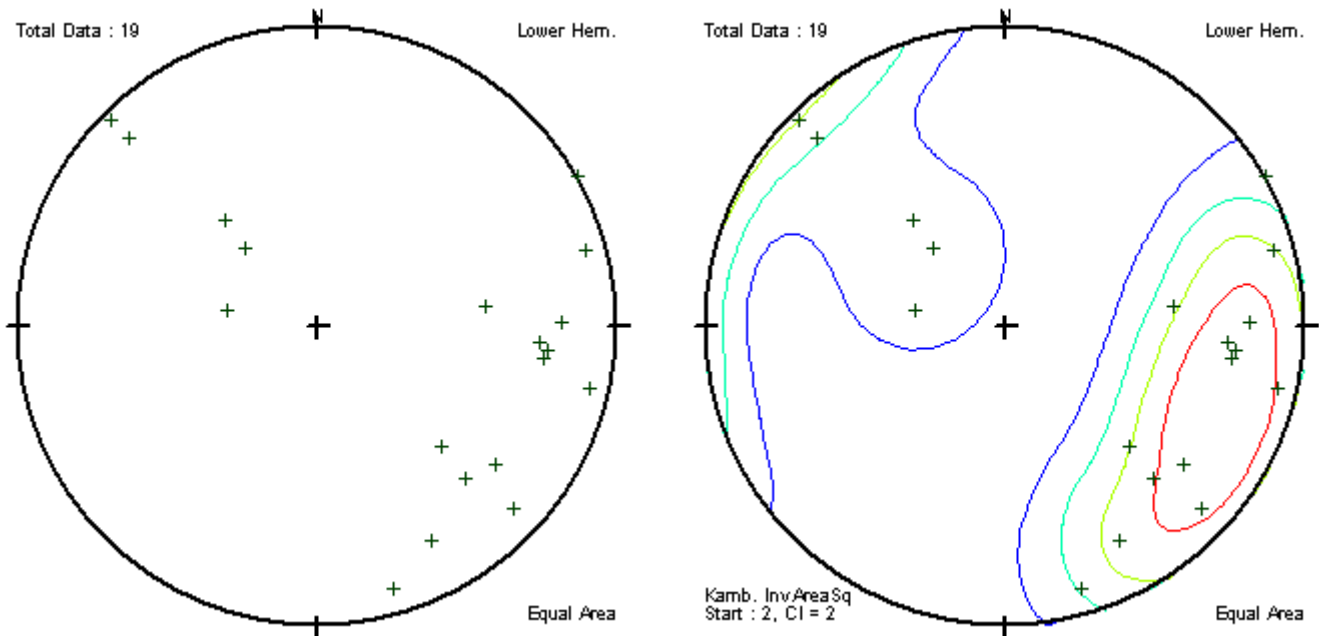
Figure 5-15. Lower hemisphere equal area fracture pole plots for two scanlines in Kimballton mine (locations Kim-C and Kim-D). Scanline 1 trended at azimuth 043 along the 80-ft side of a pillar. Scanline 2 trended at azimuth 322 along an adjacent side of the pillar.

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Other fracture data (in addition to orientation) such as fracture intensity as expressed by RQD and the fracture parameters needed for the Q-and RMR rock classifications have also been collected (see Table 5.1). This will be discussed in Section 5.4.

5.4 Rock Mass Classification

Rock mass classification is a means of assigning a numeric rating to the quality and likely performance of a rock mass, based on easily measurable parameters (Goodman, 1989). Rock mass classification is not usually considered a sufficient basis for the design of underground excavations, but it can be a starting point, and is a useful device for comparing rock masses. Two rock mass classification systems were used to estimate the rock quality of Kimballton-DUSEL. The systems used were the Q system (Barton, Lien, and Lunde, 1974), and the RMR (Rock Mass Rating) (Bieniawski 1974), which are the most widely used rock mass classification systems in the US. The Q and RMR systems are briefly described, and then Q and RMR estimates for the Kimballton site are reported, along with pertinent data. In all cases it is assumed that major water inflows are not encountered.

5.4.1   Q-System

The Q system was developed by Barton, Lien, and Lunde (1974), at the Norwegian Geotechnical Institute (NGI) and was recently updated by Barton and Grimstad (1994). The Q-value gives a description of the stability of a rock mass such that high values indicate good stability and low values indicate poor stability. Based on six parameters the Q-value is calculated using the following formula:

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

The six parameters are:

RQD   Degree of jointing (Rock Quality Designation)

J_n Related to number of joint sets

J_r Related to joint roughness

J_a Related to joint alteration

J_w Joint water reduction factor

SRF   Stress Reduction Factor

The individual parameters are determined during geological mapping using Tables that give numerical values to be assigned to a described situation. Paired, the six parameters express the three main factors which decide stability in underground openings:

RQD/J_n =   Degree of jointing (or block size)

J_r/J_n =   Joint friction (inter-block shear strength)

J_w/SRF =   Active stress

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Numerical values are assigned to each parameter of the Q system according to detailed descriptions to be found in Barton et al (1974). Table 5-8 assigns qualitative classes to the rock mass according to the overall value of Q.

Table 5-8. Q System Rock Classes (after Barton, Lien, and Lunde, 1974)

Q	Rock Mass Quality for Tunneling
<0.01	Exceptionally poor
0.01 – 0.1	Extremely poor
0.1 – 1.0	Very poor
1.0 – 4.0	Poor
4.0 – 10.0	Fair
10.0 – 40.0	Good
40.0 – 100.0	Very good
100.0 – 400.0	Extremely good
>400.0	Exceptionally good

Q-Ratings from Field Mapping: Values used as input for the Q Ratings are presented in Table 5-9. Figure 5-17 gives a summary of the Q-values obtained for all mapping done from outcrops and inside the mine, based on assumed values for J_w and SRF. As summarized in Figure 5-17, RQD values obtained from scanlines, which range from 70 to 100%, show very infrequent fracturing. Values of the parameters averaged for all scanlines at each location are given in Table 5-10. In all cases, average RQD is greater than 90%. The typical value of J_n of 9 corresponds to three joint sets (bedding planes plus two sub-vertical joint sets). Rock joints are typically unfilled, persistent and undulating. A few fractures are mineralized. Inside the mine, mainly dry conditions are observed, with a few minor areas of "wet" condition (characterized by dripping water), and one location with a major water inflow close to a hydraulically conductive fracture. Very favorable SRF values are indicated by existing excavations showing no major stress problems such as spalling, squeezing and breakouts. SRF values are therefore based mainly on stress/strength data as discussed below. An exception is for fracture zones (if encountered) where SRF = 7.5 is given. Note that areas of high SRF correspond to low J_w values.

As can be seen from Figure 5-17, Q values range from a minimum of 0.1 to a maximum of 63 with a most common value of 21. The most common value of 21 indicates a "Good" rock rating. The minimum of 0.1 corresponds to localized high fracture intensity measured in surface exposures, in proximity to a major fracture. Fracture intensity is usually enhanced by exposure at the surface. Therefore, such zones are not expected to be encountered at depth. It is reasonable to assume that most rocks away from fracture zones will have "Good" or better ratings.

Table 5-9. Field input parameters for determination of Q at Kimballton-DUSEL

Site	Scanline	RQD	Sets (Jn)	Roughness (Jr)	Alteration (Ja)	Formation
Quarry 17	17 A	99	6	2	2	Middle Ordovician limestone
	17 B	97	6	2	1.5	Middle Ordovician limestone
Quarry 18	18 A	92	6	2	1	Middle Ordovician limestone
	18 B	98	6	3	1	Middle Ordovician limestone
Quarry 25	25 A	92	9	2	2	Copper Ridge (Knox)
	25 B	100	9	2	2	Copper Ridge (Knox)
	25 D	97	9	1.5	1	Copper Ridge (Knox)
	25 E	94	9	2	3	Copper Ridge (Knox)
	25 F	100	9	2	1	Copper Ridge (Knox)
	25 G	98	9	2	1	Copper Ridge (Knox)
Road Cut 460	460 A	99	9	1.5	1	Middle Ordovician limestone
	460 B	100	9	2	1	Middle Ordovician limestone
	460 C	100	9	2	2	Martinsburg Shale
	460 D	100	9	3	2	Martinsburg Shale
Fire Tower	Fire Tower	97	9	2	1	Rosehill sandstone
Outcrop 613	OC-613A	100	9	1.5	3	Martinsburg Shale
Kimballton Mine	Kim C	100	6	2	1	Middle Ordovician limestone
Kimballton Mine	Kim D	100	6			Middle Ordovician limestone

Table 5-10 summarizes the specific Q values obtained from field measurements. Generally, the better rocks are the Middle Ordovician Limestone and the Copper Ridge Formation, and the Martinsburg Shale is of slightly lower quality. However, significant differences are observed in the strength of the three rock formations, and these differences will influence the SRF and the final Q values. The influence of intact rock strength on rock mass rating of each rock formation is discussed in Section 5.2.4.

Table 5-10. Q values for major rock types in Kimballton (primarily from surface exposures).

Rock Unit	Q (typical min)	Q (typical max)	Q (mean value)	Q (most frequent)
Middle Ordovician Limestone	7.9	50.0	23.8	31.7
Copper Ridge (Knox)	5.3	22.2	12.4	21.1
Martinsburg Shale	5.6	16.7	10.3	18.0

Q - VALUES:	(RQD	/	Jn)	*	(Jr	/	Ja)	*	(Jw	/	SRF)	=	Q
Q (typical min)=	75	/	12.0	*	1.5	/	4.0	*	0.33	/	7.5	=	0.103
Q (typical max)=	95	/	9.0	*	3.0	/	1.0	*	1.00	/	0.5	=	63.3
Q (mean value)=	91	/	10.1	*	1.9	/	1.9	*	0.83	/	1.6	=	4.93
Q (most frequent)=	95	/	9.0	*	2.0	/	1.0	*	1.00	/	1.0	=	21.11

BLOCK SIZES

V. POOR | POOR | FAIR | GOOD | EXC

RQD %
Core pieces >= 10 cm

10 20 30 40 50 60 70 80 90 100

EARTH | FOUR | THREE | TWO | ONE | NONE

J_n
Number of joint sets

20 15 12 9 6 4 3 2 1 0,5

TAN (ϕ_r) and TAN (ϕ_p)

FILLS | PLANAR | UNDULATING | DISC.

J_r
Joint roughness - least favourable

1 0,5 1 1,5 1,5 2 3 4

THICK FILLS | THIN FILLS | COATED | UNFILLED | HEAL

J_a
Joint alteration - least favourable

20 13 12 10 8 6 5 12 8 6 4 4 3 2 1 0,75

ACTIVE STRESS

EXC. INFLOWS | HIGH PRESSURE | WET | DRY

J_w
Joint water pressure

0.05 0.1 0.2 0.33 0.5 0.66 1

SQUEEZE | SWELL | FAULTS | STRESS / STRENGTH

SRF
Stress reduction factor

20 15 10 5 20 15 10 5 10 7.5 5 2.5 400 200 100 50 20 10 5 2 0.5 1 2.5

Figure 5-17. Summary of Q data for the Knox carbonates and the Middle Ordovician limestone

Q-Values from Seismic Data: To provide a check on the Q-values determined from field mapping and to check how Q-value and rock mass quality vary with depth at Kimballton, correlations between Q and seismic velocity are used. Barton et al. (1992) developed the following correlation between Q-value and P-wave seismic velocity,

$$V_p = 50Q + 3600$$,

where V_p is in m/s. P-wave velocities from the field seismic survey are in the range of 5.5 to 6 km/s for Butt Mtn (Appendix B), giving Q values in the range of 38 to 48. The lower Q-values from field mapping compared to Q-values calculated from the seismic velocity is attributed to reduction in rock quality due to rock weathering and stress relief in exposed rocks. The Q-values from V_p are higher than those obtained from field mapping and confirm the "Good" rock mass rating obtained from field mapping. Table 5-11 shows the laboratory and field measured seismic velocities, and back-calculated Q-values for the three main rock types in Kimballton. Except for the Martinsburg shale, there is a good agreement between laboratory and field measured seismic velocities. Since laboratory values of seismic velocities are for intact rock, the good agreement between field and laboratory data confirm the generally massive nature of the rock units in the field.

Table 5-11. Laboratory and field seismic velocities with back-calculated Q-values.

Rock Unit	Lab Velocity (km/sec)	Field Velocity (km/sec)	Q from field seismic velocity
Middle Ordovician Limestone	6.20	5.5 to 6.0	38 to 48
Copper Ridge Knox	6.40	5.5 to 6.0	38 to 48
Martinsburg Shale	4.70	5.5 to 6.0	38 to 48

5.4.2 RMR (Rock Mass Rating)

Rock Mass Rating (RMR) (Bieniawski 1974), increases with rock quality from 0 to 100. The RMR is based upon five parameters: unconfined compressive strength of the rock, rock quality designation (RQD), groundwater conditions, joint and fracture spacing, and joint characteristics. A sixth parameter, orientation of joints, is used for specific applications in tunneling, mining, and foundations. Subvalues for each parameter are summed to determine RMR.

1. Unconfined compressive strength of the intact rock can be evaluated by means of the point load test, by correlations with the Schmidt hammer rebound value, or by unconfined compressive strength tests (we report values from all three methods).
2. RQD is evaluated as described by Deere (1963); RQD is essentially the percent of core run or scanline length in segments longer than 100 mm (4 inches).
3. Joint spacing is evaluated from drill core or scanline data. The rock mass rating for joint spacing increases as the spacing of joints increases.

4. Joint and fracture condition is examined with respect to the fracture sets most likely to influence the work. In general, the descriptions of joint surface roughness and coating materials are weighted toward the smoothest and weakest joint set.
5. Groundwater can strongly influence rock mass behavior. The groundwater rating varies according to the conditions encountered (dry, damp, wet, dripping or flowing), with a higher rating for a drier rock mass.

The orientation of joints relative to an excavated face can have an influence on the behavior of the rock. For this reason, Bieniawski recommends adjusting the sum of the first five rating numbers to account for favorable or unfavorable orientations. The Final RMR value is determined as the sum of the ratings from the six categories, and places the rock mass in one of the categories defined in Table 5-12.

Table 5-12. Classification of Rock Masses based on RMR (Goodman, 1989)

Class	Description of Rock Mass	RMR
I	very good rock	81-100
II	good rock	61-80
III	fair rock	41-60
IV	poor rock	21-40
V	very poor rock	0-20

RMR Values from Field Mapping: Values of RMR obtained at several sites in the vicinity of Kimballton are shown in Table 5-13 and Figure 5-18. Note that the RMR subscores that are summed to obtain the overall RMR are obtained from the parameter values by means of charts (Bieniawski 1974). For example, RQD in the range 90-100 has a score of 20 (Table 5-13). A rating adjustment of -3 (favorable/fair) for discontinuity orientation is assumed. Scanline data from all scanlines at each site were combined for determining the RMR values for that site. The results based on fractures measured along scanlines at quarries and roadcuts give an average RMR of around 70, right in the middle of the "Good Rock" range (Class II). Data from the Kimballton Mine give an average RMR of around 78, at the upper end of the "Good Rock" range (Class II). The RMR logging does not show consistent differences between the different rock units.

Correlation with Q: Barton (1995) developed the following correlation between Q and RMR:

$$RMR = 15 \log Q + 50$$

Using this correlation gives a range of Q-values of 20 to100 for RMR values of 70-80 for Kimballton. The back-calculated upper range of Q = 100 from the RMR-Q correlation is higher than that obtained from field mapping, but otherwise the range of back-calculated Q values indicate a rating of "Good" rock. Overall, the mean values and ranges of Q and RMR are mutually consistent, both indicating "Good" rock quality.

Table 5-13. Values of RMR for sites in the vicinity of Kimballton-DUSEL

Site	Strength	RQD	Spacing	Fracture Condition	Ground water	Adjust-ment	RMR	Formation
Quarry 17	12	20	12	20	10	-3	71	Middle Ordovician limestone
Quarry 18	12	20	10	20	10	-3	69	Middle Ordovician limestone
Quarry 25	12	20	10	20	10	-3	69	Copper Ridge (Knox)
RC 460 A-B	10	20	15	20	10	-3	72	Middle Ordovician limestone
Fire Tower	15	20	10	20	10	-3	72	Rosehill sandstone
Outcrop 613	12	20	12	20	10	-3	71	Martinsburg Shale
Kim-C	12	20	15	25	10	-3	79	Middle Ordovician limestone
Kim-D	12	20	15	22	10	-3	76	Middle Ordovician limestone
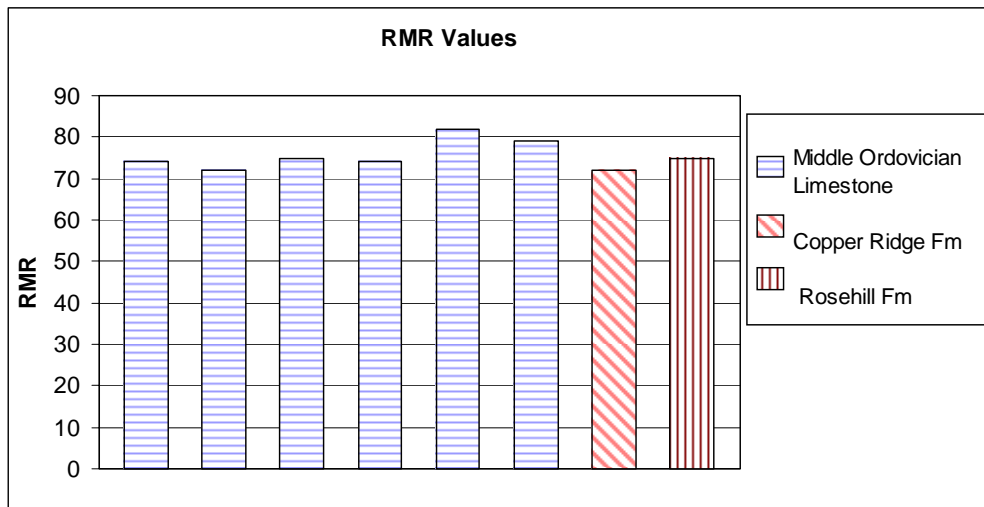
Figure 5-18. Values of RMR for Kimballton-DUSEL rocks

5.4.3   Rock Mass Classification - Summary

Both the Q and RMR rock mass classification systems assign the description "Good" to the rock mass quality. For the RMR system, it should be noted that "Good" is the second highest (second most favorable) of five categories. Numerous tunnels and underground caverns have been successfully built in rock masses classified as "Good." Hoek (2000) gives several examples. In fact, Hoek (2000) describes case histories of large underground caverns successfully constructed in rock masses classified as "Fair to Poor", such as the Mingtan pumped storage project in Taiwan.

6 Preliminary Performance Evaluation

6.1 Stability and Support Estimates

This section gives very preliminary assessments of the stability and support requirements for Kimballton-DUSEL. More detailed studies are required and will be performed as part of the S-2 process. The main intent here is to provide an indication of the feasibility of constructing DUSEL at Kimballton. The assessments given here are based primarily on the Q system. The actual design will utilize additional empirical approaches such as RMR and GSI (Hoek, 2000), as well as analytical techniques and numerical analysis. In addition, methods will be developed during S-2 to manage geological (and other) uncertainties during the design and construction phases. As discussed in Appendix H – Uncertainty and Risk, the basic techniques for managing uncertainties have been demonstrated on other large and complex projects.

The overall large-scale geomechanical model for Kimballton-DUSEL is one of strong sedimentary rocks in relatively unfractured blocks. Subvertical fractures occur in parallel sets at spacings of several hundred meters. The more significant fractures are manifested as lineaments, and the underground laboratories will be placed so as to avoid any major features. The western end of Butt Mountain was selected as the site for the underground laboratories partly because of the relative absence of major lineaments at this location. As discussed in Appendix B –Geologic Setting, the evidence suggests that large surface fractures do not persist to great depth at Kimballton as open fractures, in the majority of cases. Small scale fractures, in well-defined sets, are expected to occur in the Kimballton rocks, consistent with the plots shown in Section 5.3. None of the underground laboratories will be close to the Narrows fault, with the exception of geoscience laboratories that might intentionally target the thrust fault as an extraordinary research opportunity. More specific information on fracturing at depth will be obtained during the S-2 process. The assessments below refer to fairly massive blocks, as it is expected will be encountered at depth.

6.1.1 Preliminary Stability Estimates

Preliminary estimates of stability and support requirements were performed on the basis of the results of the field mapping, laboratory testing and seismic surveys. These preliminary data are provided to show the viability of constructing a DUSEL at Kimballton. Preliminary estimates will be revised when new data become available. Continuous design modifications will also be made during tunnel/cavern construction to account for local conditions.

Possible concerns for instability in constructing large tunnels and caverns at great depth include rock bursting and rock squeezing. Peck (1969) developed a quick method for estimating stability of excavations in clays in terms of a stability number relating the total vertical pressure at depth and the undrained shear strength of the clay. This method was later adapted for hard rocks by Bhasin (1994). The degree of potential squeezing is given by the stability number N_t

$$N_t = \frac{2\sigma_v}{UCS}$$

where σ_v is the total vertical stress at depth obtained by summing the overburden weights above the point, and UCS is the unconfined compressive strength. Table 6-1 gives criteria for the degree of squeezing on the basis of N_t. The two in the above equation corresponds to an assumption that the horizontal stress is equal to the vertical stress. The stability number is reduced if the horizontal stresses are lower than the vertical stress (as is expected for the Kimballton – thus the estimated stability numbers are conservative). Squeezing is possible for $N_t > 1$ and the severity of squeezing increases with increasing value of N_t.

Table 6-1. Criteria for degree of squeezing based on stability number N_t (Bhasin 1994).

N_t	Degree of squeezing
<1	Non-squeezing
1-5	Mid to moderate squeezing
>5	Highly squeezing

Table 6-2 gives estimated stability numbers for the main rock types at Kimballton. The unconfined compressive strengths are based on the results of the Schmidt hammer, point load and unconfined compression tests. The vertical stress corresponds to the maximum depth of the rock unit and assumes dry conditions. Stability numbers increase with depth, and higher stability numbers are detrimental to stability. The presence of water in the rock will increase the total overburden weight and the stability factor. Field investigations indicate major water flows only close to faults, thus the data given below are only for non-faulted regions. However, there are significant uncertainties and large variations on locations of water table in the field. As shown in Table 6-2, the stability numbers are generally less than 1.0, indicating no potential squeezing problems. An exception is the weaker Martinsburg formation where the potential for squeezing is expected at depth on the order of 1 km. The strategy that will be adopted to avoid squeezing in this formation is to align access tunnels to avoid the Martinsburg shale at significant depth.

Table 6-2. Estimated stability numbers for the main rock units at Kimballton.

Rock Unit	UCS (MPa)	Depth (m)	Vert. Stress σ_v (MPa)	Stability number N_t
Middle Ordovician Limestone	80 to 190	1000 to 1500	40	0.5 to 1.0
Copper Ridge (Knox)	140 to 180	1500 to 2000	55	0.6 to 0.8
Martinsburg Limestone	65 to 110	1300 to 2000	50	0.9 to 1.5
Martinsburg Shale	35 to 60	0 to 1000	25	0.8 to 1.4

Singh et al. (1993) have identified a fairly clear demarcation or boundary, based on the Q-value, between tunnels that suffer squeezing in poor conditions or at great depth. Their criterion is given in terms of depth H where squeezing conditions are expected:

$$H \geq 350Q^{1/3},$$

where H is the critical tunnel depth in m. Depths larger than the value given above will lead to potential squeezing. Table 7-3 lists the estimated Q-values for the different rock units at Kimballton. The Q-values are based on the likely Q values from Table 6-3, an assumed Stress Reduction Factor (SRF) based on stress/strength data (i.e., SRF ≈ Stability Number N_t) and estimates of J_w assuming dry conditions. The Q-values are then converted to the critical depth for squeezing to occur using the above equation. These Q-values are for non-faulted regions, and regions devoid of major fractures. If major fractures are encountered, special design provisions will be formulated.

Table 6-3. Estimated Q-values and depth to squeezing for rock units at Kimballton

Rock Unit	Most likely Q-value	SRF	Q	Critical depth for squeezing (km)
Middle Ordovician Limestone	32	0.5 to 1.0	32 to 64	3.7 to 7.5
Copper Ridge Knox	21	0.6 to 0.8	21 to 26	2.4 to 3.0
Martinsburg Shale	18	0.8 to 1.4	12 to 23	1.4 to 2.7

As can be seen in Table 6-3, no potential squeezing problems are expected, assuming the largest depth for a DUSEL facility is 2.3 km (except for the Martinsburg Shale which can squeeze even at depths shallower than 2.3 km). Faults or major fractures, if encountered, will increase the squeezing potential. It is expected that most such features can be avoided during construction. Strategies for avoiding detrimental geologic features will be developed during S-2 as part of the uncertainty management plan (Appendix H).

6.1.2   Preliminary Support Estimates

The Q system tunnel support chart (Fig. 6-1) is used to arrive at preliminary estimates of the support requirements for tunnels and caverns at Kimballton. This chart was originally developed by Barton et al. (1974), and was later updated using an expanded list of case histories by Grimstad et al. (1986), and Grimstad and Barton (1993). Using this system, there are nine classes of tunnel support ranging from no support required for rocks with high Q-ratings, to cast concrete lining for exceptionally poor rock. The most typical support is fiber reinforced shotcrete and bolting. In addition to specifying the type of support, the chart provides specifications on dimensions of support elements (e.g., shotcrete thickness, rock bolt spacing, etc.) The support requirements shown depend on the Q-value and effective span or height (whichever is the larger), and is equal to the span or height divided by the effective span ratio (ESR). For the Kimballton DUSEL, ESR =1.0 is recommended for access tunnels, and ESR=0.8 is recommended for large caverns. The use of ESR is equivalent to applying a factor safety in the design by increasing the span or height for ESR<1.0.

Figure 6-2 gives the preliminary estimates of the range of support requirements for access tunnels for a DUSEL at Kimballton (a tunnel diameter of 4.5 m is assumed). For tunnel segments with Q rating of "Good" (most frequent Q-value), the access tunnels will require no support or only spot bolting. The adequacy of using no support required for rocks with "Good" rating is consistent with experience in the current mine, where no support has been required for large excavations at depths up to 750 m. Since most tunnel segments may require no support, the access tunnel can be constructed at relatively low

cost. For sections with low Q-values (e.g., close to fault zones), fiber-reinforced shotcrete with systematic bolting may be required.
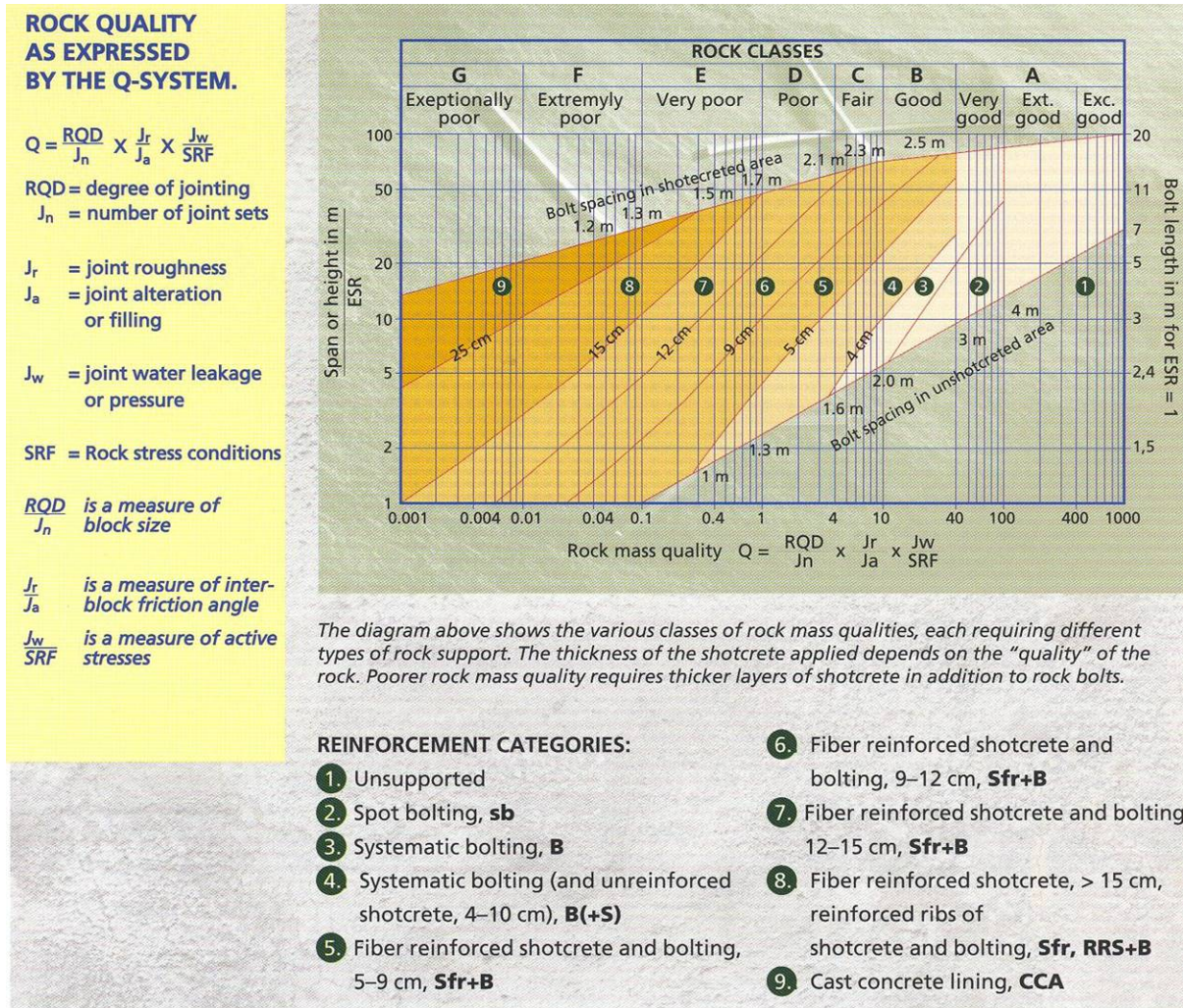
ROCK QUALITY AS EXPRESSED BY THE Q-SYSTEM.

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

RQD = degree of jointing
J_n = number of joint sets

J_r = joint roughness
J_a = joint alteration or filling

J_w = joint water leakage or pressure

SRF = Rock stress conditions

$\dfrac{RQD}{J_n}$ is a measure of block size

$\dfrac{J_r}{J_a}$ is a measure of inter-block friction angle

$\dfrac{J_w}{SRF}$ is a measure of active stresses

The diagram above shows the various classes of rock mass qualities, each requiring different types of rock support. The thickness of the shotcrete applied depends on the "quality" of the rock. Poorer rock mass quality requires thicker layers of shotcrete in addition to rock bolts.

REINFORCEMENT CATEGORIES:
1. Unsupported
2. Spot bolting, **sb**
3. Systematic bolting, **B**
4. Systematic bolting (and unreinforced shotcrete, 4–10 cm), **B(+S)**
5. Fiber reinforced shotcrete and bolting, 5–9 cm, **Sfr+B**
6. Fiber reinforced shotcrete and bolting, 9–12 cm, **Sfr+B**
7. Fiber reinforced shotcrete and bolting 12–15 cm, **Sfr+B**
8. Fiber reinforced shotcrete, > 15 cm, reinforced ribs of shotcrete and bolting, **Sfr, RRS+B**
9. Cast concrete lining, **CCA**

Figure 6-1. Tunnel support requirements as function of rock mass quality Q, span or height, and ESR, the effective span ratio (Grimstad and Barton, 1993).

Support requirements change dramatically with the size of excavation. For UNO-type facilities, cavern widths on the order of 40 to 60 m are expected. Due to the critical nature of the caverns, including safety of personnel working inside the cavern, a low ESR value of 0.8 is used. As an example, Figure 6-3 shows the support requirements for large cavern of 50 m width for the range of Q-values at Kimballton. As can be seen, for the most frequent Q-value of 20, the required support is shotcreting with systematic bolting. For the occasional low Q value, the support calls for cast concrete lining (steel sets might also be required). Figure 6-3 indicates that excavation of large caverns which do not require extensive and expensive reinforcement is possible if the caverns are located in rocks with "Good" rating. Future geotechnical investigations will, therefore, endeavor to carefully map geologic details at Kimballton for suitable placements of the caverns.

Q ROCK MASS CLASSIFICATION CHART
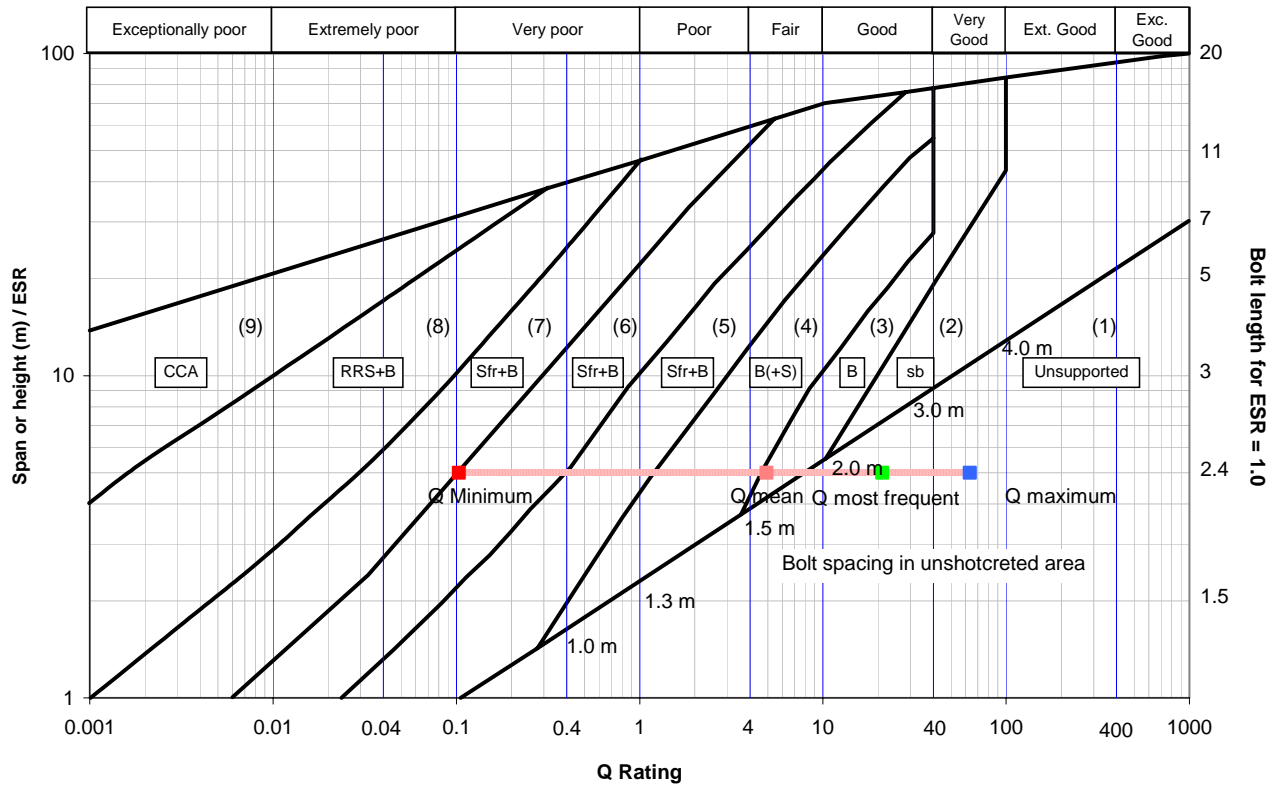
Figure 6-2. Preliminary estimates of support requirements for access tunnels at Kimballton-DUSEL (based on field estimates of Q). Abbreviations are defined in Fig. 6-1. Note markers indicating Q minimum, mean, most frequent and maximum.

6.1.3   Comparison with Case Histories of Large Caverns

DUSEL will require the construction of large caverns at depths on the order of 2300 m. To obtain an indication of the feasibility of building the large caverns for Kimballton-DUSEL, a brief survey of existing large natural and engineered excavations was performed (Table 6-4). The largest natural cavern is the Lubang Nasib Bagus in Sarawak, Malaysia, with an average width of 300 m (maximum width 400 m), height 70 m and depth 420 m. There are numerous examples (Table 6-4) of large engineered caverns for different applications, and several in sedimentary rock, showing that large caverns in rocks similar to those at Kimballton are feasible. The largest engineered cavern for public use is the Olympic Cavern in Gjøevik, Norway with a span of 62 m, height of 24 m and length of 90 m. This structure is of particular interest as it was successfully designed using the Q-system. For comparison purposes, the Q-values in Gjøevik Olympic Cavern range from 1.1 to 30, with the most frequent value of 12.2 (Barton et al. 1994).

Q ROCK MASS CLASSIFICATION CHART
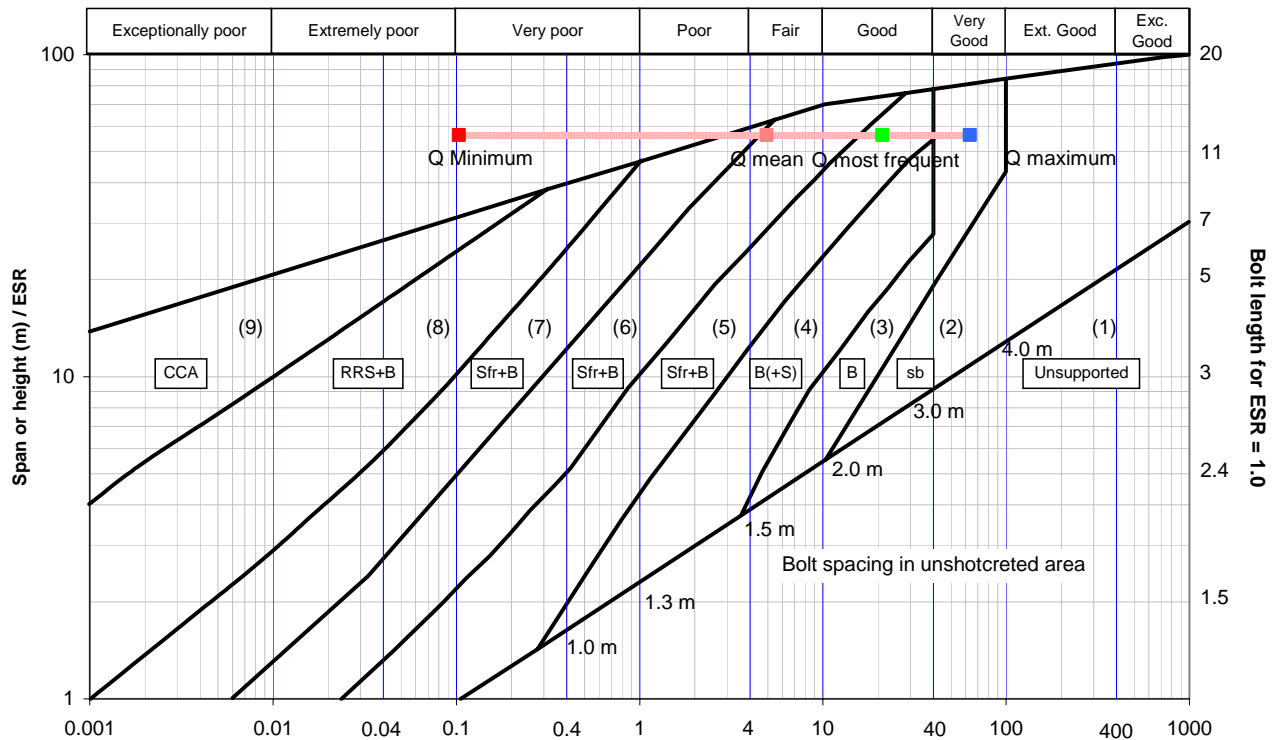
Figure 6-3. Preliminary estimates of support requirements for large caverns with width 50 m, for the range of Q-values in Kimballton.

Table 6-4. Examples of natural and engineered large caverns in rock.

Name and Country	Use	Dimensions WxHxL (m)	Depth (m)	Rock Type
Lubang Nasib Bagus, Malaysia	Natural Cavern	300x70x700	400	Limestone
Vihanti Mine, Finland	Mine	40x160x150	200	Dolomite
Imaichi, Japan	Power Station	33x51x160	400	Sandstone
Etrez Facility, Tersanne, France	Oil Storage	262x492x?	4600	Rock Salt
Dinorwic, Great Britain	Power Station	24x52x180	300	Slate
Olympic Cavern, Gjøevik, Norway	Public Use	62x24x90	34	Gneiss
Gran Sasso	Public Use	20 x 20 x 100	1300	Dolostone

6.2 In Situ Stresses and Rockburst Hazard

The long-term stability of high aspect ratio caverns (30 m tall by 10 m wide) suggest horizontal stresses are not elevated. Adequate stability numbers for the Martinsburg shale indicate low likelihood of swelling at least below threshold depths of 1400 to 2700 m. The rockburst hazard is undefined, but no problems are apparent in current high-extraction mining to 750 m.

For tunnel design and construction both the absolute stress-levels and the relation of the principal stresses to each other as well as their directions play a role. Part of the S-2 process will be to conduct studies on insitu stress magnitudes and direction.

6.3 *Hydrogeology and Drainage*

Water transport within the low matrix permeability shales and limestones is primarily fracture dominated. At mine depth (~750 m), the Five Oaks limestone that the Kimballton mine accesses, has tight fractures with no apparent discharge. No major water inflows occur in the existing Kimballton mine (which has close to 100 km of drifts), except at one location. Localized areas of water inflow can be pre-grouted before excavation. Because stresses are increasingly compressive with depth, large fractures are unlikely to be open at deeper levels. It is also known generally that fracture intensity decreases with depth (Cosgrove and Engelder, 2004)

6.4 *Anticipated In Situ Temperatures*

No anomalous geothermal gradients are anticipated. Normal gradients of 15° to 30°C per kilometer are anticipated to yield average tock temperatures at completion depth at the lower end of the range 50° to 85°C.

7 Conclusions

This preliminary evaluation shows that the construction of DUSEL at the Kimballton site is feasible. Kimballton is characterized by high strength rocks and an overall rock mass quality assessment of "Good." Assessment of stability and support requirements based on these data show that construction of Kimballton-DUSEL is quite feasible. Activities to be undertaken during S-2 will minimize both the likelihood of encountering unfavorable conditions, and the effect of unfavorable conditions, should they be encountered.

On the whole, the geomechanical properties of fresh rocks encountered during construction of DUSEL are expected to be superior to those of rocks tested for this preliminary investigation. Similarly, rock mass quality assessments for rocks at depth are likely to be better than assessments based on surface exposures, due to enhanced fracture intensity near the ground surface, and especially in quarries that have been undergoing stress relief for more than half a century.

Figure 7-1. Large unsupported cavern in the Kimballton mine

Key characteristics that indicate favorable conditions for constructing the proposed DUSEL at Kimballton are outlined in the Overview and include large existing chambers in the Kimballton mine, high strength rocks, "Good" rock mass quality and localized water inflows. Further detailed site investigations and rock mechanics studies will be carried out as part of the S-2 process. A plan for uncertainty management will also be developed during S-2. Proposed further geological and geotechnical/rock mechanics investigations and the uncertainty management plan are outlined in Appendix B - Geologic Setting, and in Appendix H – Risk and Uncertainty.

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Appendix D: Environmental Assesment
(preliminary)

NEPA CHECKLIST

DEEP UNDERGROUND SCIENCE AND ENGINEERING LABORATORY
(DUSEL)
KIMBALLTON/BUTT MOUNTAIN
GILES COUNTY, VIRGINIA

Prepared for:

Virginia Polytechnic Institute and State University
Blacksburg, Virginia

Prepared by:

Schnabel Engineering, South LLC
Richmond, Virginia

February 21, 2005

TABLE OF CONTENTS

INTRODUCTION

This environmental analysis is intended to provide an evaluation of the likely impacts to the human environment from proposed actions of the project cited below. This analysis will help to fulfill the project sponsor's oversight obligations and satisfy rules and regulations of the National Environmental Policy Act (NEPA). The project sponsor has a responsibility to ensure that all impacts have been identified and addressed. Some effects may be negative; others may be positive. Please provide a discussion for each section. If no impacts are likely, be sure to discuss the reasoning that led to that determination.

PART - I   PROPOSED ACTION DESCRIPTION

1. Type of proposed action:

	Check One
Development	√
Renovation	
Maintenance	
Land Acquisition	
Equipment Acquisition	
Other (Describe)	

2. Federal involvement (provide agency or federal entity responsible for proposed action):

   __National Science Foundation_____

3. Name, address phone number and E-mail address of project sponsor.

   Virginia Polytechnic Institute and State University

   _Blacksburg, VA 24061__ _____

   _(540) 231-7455_____   _____

   _rjb@vt.edu_____ _____

4. Name of project:

   Deep Underground Science and Engineering Laboratory - Kimballton

5. If applicable:

   Estimated construction/commencement date: _____

   Estimated completion date: _____

   Current status of project design (% complete): _Preliminary Design and Assessment_

6. Location affected by proposed action (city, county):

   Preferred Alternative: __(SG-2) Olean, Giles County_____

   Second Alternative: ___(SG-1) Hoges Chapel, Giles County___

7. Project size: estimate the numbers of acres that would be directly affected that are currently:

   a) Developed:

- Residential	_____	acres
- Industrial	_____	acres

b) Open Space/Woodlands/Recreation	___50___	acres

c) Wetlands/Riparian Areas	_____	acres

d) Floodplain	_____	acres

   e) Productive:

- Irrigated cropland	_____	acres
- Dry cropland	_____	acres
- Forestry	_____	acres
- Pasture	___30___	acres
- Other	_____	acres

8. Map/site plan: attach an original 8 1/2" x 11" or larger section of the most recent USGS 7.5' series topographic map showing the location and boundaries of the area that would be affected by the proposed action. A different map scale may be substituted if more appropriate or if required by agency rule. If available, a site plan should also be attached.

9. Narrative summary of the proposed action or project including purpose and need for the proposed action:

   This proposed action is in response to a solicitation issued by the National Science Foundation (NSF) for an integrated study of a Deep Underground Science and Engineering Laboratory (DUSEL) at one or more sites. This is a community-wide and cross-disciplinary effort to develop deep underground science and engineering program planning and technical requirements, as requested by NSF. The research work proposed for the DUSEL involves physics (nuclear physics, particle physics and astrophysics), earth sciences, biology, and engineering communities including resource development and environmental management.

10. Description and analysis of reasonable alternatives to the proposed action:

    a) Preferred Alternative: Construct a portal (SG-1) entrance to the DUSEL Kimballton Laboratory near to the currently operating Kimballton Mine in Olean on property belonging to Kimballton Mine. This location is less accessible to the outside world but has the advantage of being near to an ongoing mining operation and a railroad siding for transport of mined materials.

b) <u>Second Alternative</u>: Construct a portal (SG-1) entrance to the DUSEL Kimballton Laboratory near to Hoges Chapel on Giles County municipal property. This site provides convenient, unrestricted access for the staff, community (visitors), Virginia Tech, and scientific community at large. The development of the property has the support of the County.

c) No-action Alternative: This alternative would result in no National laboratory being constructed in the area and the loss of revenue for the community and opportunity for advanced scientific and engineering research for VATech and its affiliates.

11. Listing of each local, state or federal agency that has overlapping or additional jurisdiction.

(a)	Permits - See permit section below.	
Agency Name: USEPA/VADEQ USACE/VADEQ	Permit: SEE APPENDIX G	Date Filed: PENDING

(b)	Funding
Agency Name: National Science Foundation	Funding Amount:

(c)	Other Overlapping or Additional Jurisdictional Responsibilities or Interest
Agency Name:	Type of Responsibility:

12. List of agencies consulted during preparation of this Environmental Checklist:

_Virginia Departments of Mines, Minerals, and Energy, Environmental Quality, _

_and Historic Preservation; Virginia Heritage Society_____

U.S. Mine Safety and Health Administration, U.S. Army Corps of Engineers,

_U.S. Environmental Protection Agency (Region III)_____

13. Name of Preparer(s) of this Environmental Checklist:

Christopher McQuale, P.E., Steve Pond, CPG, King Troensegaard, CPG,

_Craig Vanderhoef, Esq., Garrie Rouse, Botanist_____

14. Date prepared: _February 21, 2005_ Information valid as of: _February 21, 2005_

PART - II   ENVIRONMENTAL CHECKLIST

A.   PHYSICAL ENVIRONMENT

1.   Land Resources

At the bottom of this "Land Resources" checklist, provide a narrative description and evaluation of the cumulative and secondary effects on land resources. Even if you checked "none" in the above table, explain how you came to that conclusion. Consider the immediate, short-term effects of the action as well as the long-term effects. Attach additional pages of narrative if needed.

LAND RESOURCES	IMPACT				Can Impact Be Mitigated	Comment Index
Will the proposed action result in:	Unknown	None	Minor	Potentially Significant		
a. Soil instability or changes in geologic substructure?				√	√	
b. Disruption, displacement, erosion, compaction, moisture loss, or over-covering of soil which would reduce productivity or fertility?			√		√	
c. Destruction, covering or modification of any unique geologic or physical features?			√		√	
d, Changes in siltation, deposition or erosion patterns that may modify the channel of a river or stream or the bed or shore of a lake?				√	√	
e. Exposure of people or property to earthquakes, landslides, ground failure, or other natural hazard?				√	√	
f. Other:						

The highest potential for impacts to land resources will occur during the construction phase of the project. Once constructed, the DUSEL will function as a research facility with most of its operations, experiments, and activities occurring within the existing belowground facilities. Modifications to accommodate future studies will typically be located within the physical confines of the space created during the construction of the DUSEL. As an underground research facility, most of the structural infrastructure will be located significantly below the ground surface in stable geology, with provisions for offices, maintenance buildings, and a visitor's center for limited access to the public.

Initial estimates for the quantity of rock to be removed during construction range between 10 and 18 million tons.

2. Air

At the bottom of this "Air" checklist, provide a narrative description and evaluation of the cumulative and secondary effects on air resources. Even if you checked "none" in the above table, explain how you came to that conclusion. Consider the immediate, short-term effects of the action as well as the long-term effects. Attach additional pages of narrative if needed.

AIR	IMPACT					
Will the proposed action result in:	Unknown	None	Minor	Potentially Significant	Can Impact Be Mitigated	Comment Index
a. Emission of air pollutants or deterioration of ambient air quality? (also see 13(c))				√	√	
b. Creation of objectionable odors?			√		√	
c. Alteration of air movement, moisture, or temperature patterns or any change in climate, either locally or regionally?		√				
d. Adverse effects on vegetation, including crops, due to increased emissions of pollutants?		√				
e. Any discharge that will conflict with federal or state air quality regs?		√				
f. Other:						

There have been two air emissions related concerns identified with the potential of having a significant impacts. During the construction phase of the proposed action, the removal (mining) and transporting of the rock materials will potentially generate fugitive dust emissions. Given estimated quantity of rock that will need to be removed the amount of dust generated will need to be managed. It is not anticipated that the majority of the rock will be contaminated.

The second potential source of air emissions would result if a radon-bearing zone (black shale/Chattanooga formation) were intersected during the creation of the DUSEL. Indications are that this formation is found in the regional geology. However, based on routine monitoring done by the federal Mine Safety and Health Administration (MSHA) there is no record of Radon being present in the Kimballton mine. Additionally, the geologic profiles for the formations in the immediate area of both the preferred and alternative locations for the DUSEL at Kimballton do not indicate the presence of this black shale formation.

During the planning stage for the construction of the DUSEL, it will be necessary to obtain an air permit to provide for the control of fugitive emissions. This will require an assessment be made of the quantities of emissions that will potentially be generated as a result of the interior mining activities, exterior grading, and vehicular transport offsite of the mined/excavated stone or excess soil. The assessment will include plans for reducing dusk emissions. Additionally, an air monitoring plan will need to be developed to ensure that the dust emission controls are effective.

This information will be included in an air permit application for the construction phase of the project.

3.   Water

At the bottom of this, "Water" checklist, provide a narrative description and evaluation of the cumulative and secondary effects on water resources. Even if you checked "none" in the above table, explain how you came to that conclusion. Consider the immediate, short-term effects as well as the long-term effects. Attach additional pages of narrative if needed.

WATER	IMPACT					
Will the proposed action result in:	Unknown	None	Minor	Potentially Significant	Can Impact Be Mitigated	Comment Index
a. Discharge into surface water or any alteration of surface water quality including but not limited to temperature, dissolved oxygen or turbidity?				√	√	
b. Changes in drainage patterns or the rate and amount of surface runoff?				√	√	
c. Alteration of the course or magnitude of floodwater or other flows?				√	√	
d. Changes in the amount of surface water in any water body or creation of a new water body?				√	√	
e. Exposure of people or property to water related hazards such as flooding?		√				
f. Changes in the quality of groundwater?				√	√	
g. Changes in the quantity of groundwater?			√		√	
h. Increase in risk of contamination of surface or groundwater?			√		√	
i. Effects on any existing water right or reservation?		√				
j. Effects on other water users as a result of any alteration in surface or groundwater quality?		√				
k. Effects on other users as a result of any alteration in surface or groundwater quantity?		√				
l. Effects to a designated floodplain?			√		√	
m. Any discharge that will affect federal or state water quality regulations?			√		√	
n. Work in, under, over, or having an effect on navigable waters of the United States?			√		√	
o. Discharge of dredged or fill material into waters of the United States?		√				
p. Other:						

Water (continued)

Information obtained from the Chemical Lime's Kimballton Mine *existing* operations indicates that there is one isolated area in mine where groundwater has been encountered in a fault zone other than general seeps. The average yield from this groundwater source in the mine is approximately 5.5 million gallons per day. This water is allowed to pool in rock basins in the mine from which it is pumped to the surface and discharged to the adjacent Stony Creek under a VPDES permit and requires no treatment. During the dry season, this flow makes up a considerable portion of the flow in the creek. The VPDES permit requires the discharge be monitored for suspended solids, pH, and temperature. There have been no notice of violation for the discharge although there have been occasional elevated levels of particulates visually identified in the discharge following major rain events.

It is not certain what the exact source of the groundwater is, i.e., whether it is fed by stormwater infiltration or hydrologic connection with the New River, which is located within a couple of miles of Butt Mountain. The consensus of the local geologists is that it is more likely to be stormwater infiltrating through the soil into the fracture zones.

For the purposes of the proposed action, the likelihood of encountering significant quantities of groundwater in this fractured terrain of the DUSEL is unknown. The presence/absence of significant groundwater will be further evaluated during the Phase II analysis.

Given the size of the Kimballton Mine operation there is the potential that significant quantities of groundwater could be encountered. If the flows are significant enough to require pumping and ultimate discharge the permitting process is straightforward and there is no indication that there would be resistance to this activity from a regulatory perspective.

During construction a VPDES stormwater permit for construction-related activities will be required.

4. Vegetation

At the bottom of this "Vegetation" checklist, provide a narrative description and evaluation of the cumulative and secondary effects on vegetative resources. Even if you checked "none" in the above table, explain how you came to that conclusion. Consider the immediate, short-term effects as well as the long-term effects. Attach additional pages of narrative if needed.

VEGETATION	IMPACT					
Will the proposed action result in:	Unknown	None	Minor	Potentially Significant	Can Impact Be Mitigated	Comment Index
a. Changes in the diversity, productivity or abundance of plant species (including trees, shrubs, grass, crops, and aquatic plants)?		√				
b. Alteration of a plant community?		√				
c. Adverse effects on any unique, rare, threatened, or endangered species?	√					
d. Reduction in acreage or productivity of any agricultural land?			√		√	
e. Establishment or spread of noxious weeds?		√				
f. Effects to wetlands or prime and unique farmland?		√				
g. Other:						

During construction, it is anticipated that there will be disturbance of vegetation typically associated with a relatively small development projects, since the majority of the constructed facilities will be below ground. Construction activities will involve the creation of access roads, staging areas for equipment, stockpiling of materials, followed the creation of the planned facilities including parking areas and offices/support buildings.

The portal location at SG-1 will involve the conversion of land currently used for cattle grazing. However, this is open rural land and the majority of the grazing land will remain intact and not significantly impacted.

A preliminary screening of rare and endangered plant species potentially located in the region has been performed using the Virginia Heritage Online Database and a site walk through by a qualified botanist. Appendix B contains a list of Rare and Endangered Plant Species list as having been identified in Giles County, Virginia. This list has been reduced to the following Federally and State listed Rare and Endangered Plant Species that have the potential of growing in the area: Bentley's Coral Foot (Corallorhiza bentleyi), Long-Stalked Holly (Hex collina), and Peter's Mountain Mallow (Iliamna corei).

During the environmental impact assessment, an in-depth assessment and field verification of the rare and endangered plant species will be conducted.

5. Fish/Wildlife

At the bottom of this "Fish/Wildlife" checklist, provide a narrative description and evaluation of the cumulative and secondary effects on fish and wildlife resources. Even if you checked "none" in the above table, explain how you came to that conclusion. Consider the immediate, short-term effects as well as the long-term effects. Attach additional pages of narrative if needed.

15. FISH/WILDLIFE	IMPACT					
Will the proposed action result in:	Unknown	None	Minor	Potentially Significant	Can Impact Be Mitigated	Comment Index
a. Deterioration of critical fish or wildlife habitat?		√				
b. Changes in the diversity or abundance of game animals or bird species?		√				
c. Changes in the diversity or abundance of non-game species?		√				
d. Introduction of new species into an area?		√				
e. Creation of a barrier to the migration or movement of animals?		√				
f. Adverse effects on any unique, rare, threatened, or endangered species?		√				
g. Increase in conditions that stress wildlife populations or limit abundance (including harassment, legal or illegal harvest or other human activity)?		√				
h. Adverse effects to threatened/endangered species or their habitat?		√				
i. Introduction or exportation of any species not presently or historically occurring in the affected location?		√				
j. Other:						

The sites for the proposed action are located in areas that are out of the flood plains for surface water features in their vicinity. The areas are rural in nature but located where there are already human activities occurring in the form of mining operations (SG-2) and farms with open grazing land and residences near a major highway (RT 460). Additionally, the amount of surface area to be impacted as a result of this action is confined to approximately 50 acres, with the majority of the construction occurring below the ground surface.

During construction projects, there is always the potential for fish habitat to be impacted because

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of excess sediment erosion by stormwater runoff to streams. However, the combination of the interests of the project, VPDES Stormwater permit and Sediment and Erosion control permit requirements, use of best management practices (BMPs), and monitoring of all sediment control structures and discharges, will mitigate against those potential impacts.

A preliminary screening of rare and endangered animal species potentially located in the region has been performed using the Virginia Heritage Online Database and a site walk through by a qualified environmental scientist. Appendix B contains a list of Rare and Endangered Animal Species list as having been identified in Giles County, Virginia. This list has been reduced to the following Federally and State listed Rare and Endangered Animal Species that have the potential of growing in the area: Loggerhead Shrike (Lanius ludovicanus), Appalachian Bewick's Wren (Thryomanes bewickii altus), James Spinymussel (Pleurobema collina), and Indiana Social Bat (Mycotis sodalis).

During the environmental impact assessment, an in-depth assessment and field verification of the rare and endangered animal species will be conducted.

B.   HUMAN ENVIRONMENT

1.   Noise/Electrical Effects

At the bottom of this "Noise/Electrical Effects" checklist, provide a narrative description and evaluation of the cumulative and secondary effects of noise and electrical activities. Even if you checked "none" in the above table, explain how you came to that conclusion. Consider the immediate, short-term effects as well as the long-term effects. Attach additional pages of narrative if needed.

NOISE/ELECTRICAL EFFECTS	16. IMPACT					
Will the proposed action result in:	Unknown	None	Minor	Potentially Significant	Can Impact Be Mitigated	Comment Index
a. Increases in existing noise levels.				√	√	During Construction
b. Exposure of people to severe or nuisance noise levels?			√		√	
c. Creation of electrostatic or electromagnetic effects that could be detrimental to human health or property?		√				
d. Interference with radio or television reception and operation?		√				
e. Other:						

During the construction phase of the proposed action the operation of heavy equipment in grading the site and movement in and out of the portal will generate potentially significant amounts of noise. Additionally, rock-blasting techniques may be used to create the portal, access shaft, and laboratory. The blasting noise exposure level to potential receptors will be highest during the period when blasting is occurring at the portal. Subsequent noise from subsurface blasting will diminish as the rock mining activities move deep in the interior of the mountain.

The two locations (preferred and alternate) proposed for the construction of the DUSEL are both located in rural areas with low population densities. SG-2 is located on property currently owned by an operating mine where similar levels of noise are routinely generated by heavy equipment, processing plant operation, and blasting. SG-1 is located in open pasture surrounded by woods at least a quarter of a mile from the nearest dwelling or business.

No high level electrostatic or magnetic generating or radio/television inference activities are anticipated in conjunction with the scientific/engineering research planned for DUSEL.

2.   Land Use

At the bottom of this "Land Use" checklist, provide a narrative description and evaluation of the cumulative and secondary effects on land use. Even if you checked "none" in the above table, explain how you came to that conclusion. Attach additional pages of narrative if needed. Consider the immediate, short-term effects as well as the long-term effects.

LAND USE	IMPACT					
Will the proposed action result in:	Unknown	None	Minor	Potentially Significant	Can Impact Be Mitigated	Comment Index
a. Alteration of or interference with the productivity or profitability of the existing land use of an area?			√		√	
b. A conflict with a designated natural area or area of unusual scientific or educational importance?		√				
c. A conflict with any existing land use whose presence would constrain or potentially prohibit the proposed action?		√				
d. Adverse effects on, or relocation of, residences?			√		√	
e. Conflicts with existing land policies for land use, transportation, and open space?		√				
f. Increased traffic hazards, traffic volume, or speed limits or effects on existing transportation facilities or patterns of movement of people and goods?				√	√	
g. Other:						

The alterations to land use that will result from the proposed action will have a significant positive impact on scientific research with associated educational importance. This benefit is the primary purpose of the project and the basis for it being funded by the National Science Foundation in association with Virginia Tech.

Both of the two locations selected for the portal entrances to the DUSEL are situated so that they will not conflict with either current land policies or uses. SG-2 is located on property currently owned by an operating mine, with the equipment and infrastructure necessary to support the construction activities, including roads, rail sidings, good hydrologic drainage (active well formed and stable stream bed, and a supportive community eager for investment of resources and employment opportunities.

SG-1 is located on property owned by Giles County and designated for commercial development in a rural area where growth opportunities are slow to achieve. The land use change from

grazing pastureland (approximately 50 acres) to an entrance and support buildings for the underground laboratory is welcomed by the County as an first large step towards achieving their goals for the growth and strengthening of their community.

During construction there will be a significant impact on transportation largely because of the massive volume of rock to be excavated to access and make room for the laboratory. The railroad lines will used to as high a degree as possible to transport excavated materials. Road improvements will be funded to provide for entrance to and exiting from the site and minimize any potential hazards resulting from the increased volume of traffic, although traffic volumes are relatively small because population density is low.

Once the DUSEL is operational, the impacts on local traffic will be minimal. However, because access by the public to the facility in a limited form (visitor center) will be encouraged as an important aspect of the proposed action, traffic volume will experience an increase. Traffic controls will be included as part of the project.

3. Risk/Health Hazards

At the bottom of this "Risk/Health Hazards" checklist, provide a narrative description and evaluation of the cumulative and secondary effects of risks and health hazards. Even if you checked "none" in the above table, explain how you came to that conclusion. Consider the immediate, short-term effects of the action as well as the long-term effects. Attach additional pages of narrative if needed.

17.RISK/HEALTH HAZARDS	IMPACT					
Will the proposed action result in:	Unknown	None	Minor	Potentially Significant	Can Impact Be Mitigated	Comment Index
a. Risk of an explosion or release of hazardous substances (including, but not limited to oil, pesticides, chemicals, or radiation) in the event of an accident or other forms of disruption?			√		√	
b. Effects on existing emergency response or emergency evacuation plan or create need for a new plan?			√		√	
c. Creation of any human health hazard or potential hazard?			√		√	
d. Disturbance to any sites with known or potential deposits of hazardous materials?			√		√	
e. The use of any chemical toxicants?			√		√	
f. Other:						

Based on a preliminary review of the ongoing mining operations at CLC Kimballton Mine and MSHA records, there have no incidents of either mine explosion or release of radiation (radon) at this location. The geologic formations are not known to contain toxic hazardous constituents, with the following exceptions of a

- Black shale (i.e., lower member of the McCrady formation) known to contain radon gas. It is not known if this formation will be intersected during the construction of the laboratory but preliminary evaluation of geologic profiles suggest that it will not. This situation would be monitored and adequate ventilation of said gases provided in the design (during both construction and operational activities) in the event that radon is encountered.

- Shale containing pyrite has the potential of oxidizing *and producing acidity* when exposed to *oxygen and water*. This *shale* is not abundant in this region. *The* presence *of pyrite* will be monitored during excavation and material containing *pyrite* will be segregated and *disposed of using developed best management practices*.

An Environmental Risk Management Report was prepared by EDR for each proposed DUSEL portal location after completing a search of government environmental databases. The relevant aspects of these reports is as follows:

SG-2: (Olean)

No environmental problems identified or mapped by EDR. However, Chemical Lime Company Kimballton Plant and Chemical Lime Company Area 2 are listed as unmapped/orphan sites. Kimbalton Plant is listed on the following databases UST, AST, MLTS (Material Licensing Tracking System), SPILLS, TRIS (Toxic Chemical Release Inventory System), CEDS (Comprehensive Environmental Data System ((VPDES permit)), RCRA-SQG and FINDS (Facility Index System). Area 2 is listed as a RCRA-SQG and FINDS site. These folks are listed to be located on Route 635 and also at 2309 Big Stony Creek Road.

SG-1: (Hoges Chapel)

No environmental problems identified or mapped by EDR. Some unmapped/orphan sites are listed along Route 460 and involve USTs and leaking USTs at stores and gasoline stations. One tanker spill is listed to have occurred along Route 460 at the East River. Based on our observations during the site visit no such stores or gasoline stations were present in the near vicinity. Also, given the upgradient position of SG-1 in relation to Route 460, even if these unmapped/orphan sites were very near our site, it would be unlikely that they would have adversely affected SG-1.

It is not anticipated that toxic chemicals other than the fuels typically used during construction. During the operation of the laboratory certain toxic compounds or hazardous substances may be used but they chemical will be managed and disposed of in accordance federal permits guidelines. No large quantities of toxic/hazardous chemicals are planned for usage at the facility during operation at this time.

4.   Community Impact

At the bottom of this "Community Impact" checklist, provide a narrative description and evaluation of the cumulative and secondary effects on the community. Even if you checked "none" in the above table, explain how you came to that conclusion. Consider the immediate, short-term effects as well as the long-term effects. Attach additional pages of narrative if needed.

COMMUNITY IMPACT Will the proposed action result in:	IMPACT					
	Unknown	None	Minor	Potentially Significant	Can Impact Be Mitigated	Comment Index
a. Alteration of the location, distribution, density, or growth rate of the human population of an area?			√		√	
b. Alteration of the social structure of a community?			√		√	
c. Alteration of the level or distribution of employment or community or personal income?			√		√	
d. Changes in industrial or commercial activity?				√	√	
e. Increased traffic hazards or effects on existing transportation facilities or patterns of movement of people and goods?				√	√	
f. Affects on minority and/or low-income populations to the extent that such effects are disproportionately high and adverse?		√				
g. Other:						

During construction, there will be a demand for laborers and support services. During operation there will be predominantly scientists, engineers, and associated college students performing research projects. The will also be a need for support personnel, maintenance workers, and security officers. Researchers will bring their families and their children will attend schools in the County. The pay scale will be that predominantly of professionals and technicians. However this facility will typically require a total staff of approximately 120 people, which will significantly impact the population of the area, minority or otherwise. There will therefore be a modest increase in both the economic input and the demand for community resources.

The potential for traffic hazards will increase during the construction phase of the proposed action because of increased vehicle usage, especially large, slow moving trucks and other construction-related equipment. However, the need for increased safety planning will be incorporated into the design phase of the project.

5. Public Services/Taxes/Utilities

At the bottom of this "Public Services/Taxes/Utilities" checklist, provide a narrative description and evaluation of the cumulative and secondary effects on public services, taxes and utilities. Even if you checked "none" in the above table, explain how you came to that conclusion. Consider the immediate, short-term effects as well as the long-term effects. Attach additional pages of narrative if needed.

PUBLICE SERVICES/ TAXES/UTILITIES	IMPACT					
Will the proposed action result in:	Unknown	None	Minor	Potentially Significant	Can Impact Be Mitigated	Comment Index
a. An effect upon, or result in a need for new or altered, governmental services in any of the following areas: fire or police protection, schools, parks/recreational facilities, roads or other public maintenance, water supply, sewer or septic systems, solid waste disposal, health, or other governmental services? If so, specify:			√		√	
b. Effects on the local or state tax base and revenues?			√		√	
c. A need for new facilities or substantial alterations of any of the following utilities: electric power, natural gas, other fuel supply or distribution systems, or communications?			√		√	
d. Increased used of any energy source?			√		√	
e. Other.						
Additional information requested						
f. Define projected revenue sources:						
g. Define projected maintenance costs:						

No significant impacts are anticipated on Public Services/Utilities as a result of the proposed action. Giles County is planning an expansion of the potable water system that would terminate near the proposed portal. This expansion is independent of the proposed DUSEL project. The current level of capacity for these services is adequate to provide for the needs of the project. The presence of the facility and its staff will increase the tax base for the County modestly. Indirectly, the presence the facility could encourage the expansion of existing or movement of other businesses to the area, further increasing the tax base.

6. Aesthetics/Recreation

At the bottom of this "Aesthetics/Recreation" checklist, provide a narrative description and evaluation of the cumulative and secondary effects on aesthetics & recreation. Even if you checked "none" in the above table, explain how you came to that conclusion. Consider the immediate, short-term effects as well as the long-term effects. Attach additional pages of narrative if needed.

AESTHETICS/ RECREATION	IMPACT					
Will the proposed action result in:	Unknown	None	Minor	Potentially Significant	Can Impact Be Mitigated	Comment Index
a. Alteration of any scenic vista or creation of an aesthetically offensive site or effect that is open to public view?		√				
b. Alteration of the aesthetic character of a community or neighborhood?		√				
c. Alteration of the quality or quantity of recreational/tourism opportunities and settings? (Attach Tourism Report)		√				
d. Adverse effects to any designated nr proposed wild or scenic rivers, trails or wilderness areas?		√				
e. Other:						

Modest changes to the landscape and aesthetic character of the area are anticipated, since most of the facility will be underground.

Because of the interest to provide and encourage limited access to the facility through a visitors' center, there will be a significant positive impact on the tourism in the area.

The nearest wild or scenic river is the New River, which is approximately a mile from the project. No impacts are anticipated to that area.

7.   Cultural/Historical Resources

At the bottom of this "Cultural/Historical Resources" checklist, provide a narrative description and evaluation of the cumulative and secondary effects on cultural/historical resources. Even if you checked "none" in the above table, explain how you came to that conclusion. Consider the immediate, short-term effects as well as the long-term effects. Attach additional pages of narrative if needed.

CULTURAL/ HISTORICAL RESOURCES	IMPACT					
Will the proposed action result in:	Unknown	None	Minor	Potentially Significant	Can Impact Be Mitigated	Comment Index
a. Destruction or alteration of any site, structure or object of prehistoric, historic, or paleontological importance?	√					None identified
b. Physical changes that would affect unique cultural values?		√				
c. Effects on existing religious or sacred uses of a site or area?		√				
d. Adverse effects to historic or cultural resources, including any properties eligible for listing on the National Register of Historic Places or the National Registry of Natural Landmarks?	√					None identified
e. Other:						

A file review was conducted and the Virginia Department of Historic Preservation to identify previously documented sites where either historic landmarks or cultural resources are located.

There were no specific sites identified within a quarter of a mile of the immediate area of the proposed action, (either SG-1 or SG-2). Those sites that were identified are shown on Figures 1 and 2. They consist of historic landmarks such as farmhouses, barns, outbuildings, and the observation towers on Butt Mountain.

A more in-depth archaeological evaluation will be made of the specific locations around the portals including field investigations as part of the environmental impact assessment.

8.   Summary Evaluation of Significance

At the bottom of this "Summary Evaluation of Significance" checklist, provide a narrative description and evaluation of the cumulative and secondary effects. Even if you have checked "none" in the above table, explain how you came to that conclusion. Consider the immediate, short-term effects as well as the long-term effects. Attach additional pages of narrative if needed.

SUMMARY EVALUATION OF SIGNIFICANCE	IMPACT					
Will the proposed action result in:	Unknown	None	Minor	Potentially Significant	Can Impact Be Mitigated	Comment Index
a. Impacts that are individually limited, but cumulatively considerable? (A project or program may result in impacts on two or more separate resources which create a significant effect when considered together or in total.)			√		√	
b. Potential risks or adverse effects which are uncertain but extremely hazardous if they were to occur?			√		√	
c. Potential conflict with the substantive requirements of any local, stale, or federal law, regulation, standard or formal plan?		√				
d. Establishment of a precedent or likelihood that future actions with significant environmental impacts will be proposed?		√				
e. Substantial debate or controversy about the nature of the impacts that would be created?		√				
f. Organized opposition or generate substantial public controversy?		√				
g. Effects upon Native American Communities?	√					None identified
Additional information requested						
h. List any federal or state permits required:	VPDES/NPDES permit(s) Mining permits, Section 404/401 permits/certifications					

GLOSSARY OF TERMS

Affected Environment - The aspects of the human environment that may change as a result of an agency action.

Alternative - A different approach to achieve the same objective or result as the proposed action.

Categorical Exclusion - A level of environmental review for agency action that do not individually, collectively, or cumulatively cause significant impacts to the human environment, as determined by rulemaking or programmatic review, and for which an EA or EIS is not required.

Cumulative Impacts - Impacts to the human environment that, individually, may be minor for a specific project, but, when considered in relation to other actions, may result in significant impacts.

Direct Impacts - Primary impacts that have a direct cause and effect relationship with a specific action, i.e. they occur at the same time and place as the action that causes the impact.

Environmental Assessment (EA) - The appropriate level of environmental review for actions that either do not significantly affect the human environment or for which the agency is uncertain whether an Environmental Impact Statement (EIS) is required.

Environmental Assessment Checklist - An EA checklist is a standard form of an EA, developed by an agency for actions that generally produce minimal impacts.

Environmental Impact Statement (ElS) - A comprehensive evaluation of the impacts to the human environment that likely would result from an agency action or reasonable alternatives to that action. An EIS also serves a public disclosure of agency decision-making. Typically, an EIS is prepared in two steps. The Draft ElS is a preliminary detailed written statement that facilitates public review and comment. The Final EIS is a completed, written statement that includes a summary of major conclusions and supporting information from the Draft EIS, responses to substantive comments received on the Draft EIS, a list of all comments on the Draft EIS and any revisions made to the Draft EIS and an explanation of the agency's reasons for its decision.

Human Environment - Those attributes, including but not limited to biological, physical, social, economic, cultural, and aesthetic factors that interrelate to form the environment.

Long-Term Impact - An impact, which lasts well beyond the period of the initial project.

ADDENDUM
CHECKLIST OF RARE, THREATENED AND ENDANGERED SPECIES
DOCUMENTED FROM GILES COUNTY, VIRGINIA

Scientific Name	Common Name	Global Rarity	State Rarity	Federal Status	State Status	Last Obs.
AMPHIBIANS						
Cryptobranchus alleganiensis	Hellbender	G3G4	S2S3		SC	ND
ARACHNIDA (SPIDERS & PSEUDOSCORPIONS)						
Nesticus tennesseensis	A Cave Spider	G2G4	S2			ND
BIRDS						
Lanius ludovicianus	Loggerhead Shrike	G4	S2B,S3N		LT	
Thryomanes bewickii altus	Appalachian Bewick's Wren	G5T2Q	S1B	SOC	LE	1993
BIVALVIA (MUSSELS)						
Lasmigona subviridis	Green Floater	G3	S2		SC	ND
Pleurobema collina	James Spinymussel	G1	S1	LE	LE	1984
COLEOPTERA (BEETLES)						
Atheta annexa	A Rove Beetle	G2G4	S2			ND
Pseudanophthalmus egberti	New River Valley Cave Beetle	G1	S1	SOC		1958
Pseudanophthalmus gracilis	A Cave Beetle	G1G2	S1S2	SOC		ND
Pseudanophthalmus punctatus	Spotted Cave Beetle	G1	S1	SOC		1994
Pseudanophthalmus quadratus	Straley's Cave Beetle	G1	S1	SOC		1958
COLLEMBOLA (SPRINGTAILS)						
Arrhopalites commorus	A Cave Springtail	G1G2	S1	SOC		1994
CRUSTACEA (AMPHIPODS, ISOPODS & DECAPODS)						
Caecidotea henroti	Henrot's Cave Isopod	G2G3	S1S2	SOC		ND
Caecidotea vandeli	Vandel's Cave Isopod	G2G3	S1S2	SOC		1994
Stygobromus abditus	James Cave Amphipod	G2	S2	SOC		1996
Stygobromus ephemerus	Ephemeral Cave Amphipod	G1	S1	SOC	SC	1994
Stygobromus estesi	Craig County Cave Amphipod	G1G2	S1S2	SOC		1999
DIPLOPODA (MILLIPEDES)						
Pseudotremia sublevis	A Millipede	G1	S1	SOC		ND
Rudiloria trimaculata tortua	A Millipede	G5T2	S2	SOC		1958
Trichopetalum packardi	Packard's Blind Cave Millipede	G4	S2			ND
DIPLURA (DIPLURANS)						
Litocampa sp. 1	A Cave Dipluran	G1	S1	SOC		1992
FISH						
Etheostoma osburni	Candy Darter	G3	S1		SC	1994

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CHECKLIST OF RARE, THREATENED AND ENDANGERED SPECIES DOCUMENTED FROM GILES COUNTY, VIRGINIA

Scientific Name	Common Name	Global Rarity	State Rarity	Federal Status	State Status	Last Obs.
LEPIDOPTERA (BUTTERFLIES & MOTHS)						
Boloria selene	Silver-bordered Fritillary	G5	S2			1938
Euchlaena milnei	Milne's Euchlaena Moth	G2G4	S2			1984
Euchloe olympia	Olympia Marble	G4G5	S2S3			1974
Euphyes conspicua	Black Dash	G4	S1S3			1953
Phyciodes batesii batesii	Tawny Crescent	G4T1	SH	SOC		1940
MAMMALS						
Myotis leibii	Eastern Small-footed Bat	G3	S1			1986
Myotis sodalis	Indiana Bat	G2	S1	LE	LE	1939
MECOPTERA (SCORPIONFLIES)						
Brachypanorpa jeffersoni	Jefferson's Short-nosed Scorpionfly	G2	S1S2	SOC		1993
NON-VASCULAR PLANTS						
Sphagnum flexuosum	Flexuose Peatmoss	G5	S1S2			1985
Sphagnum fuscum	Brown Peatmoss	G5	S1			1958
Sphagnum girgensohnii	Girgensohn's Peatmoss	G5	S1S2			1983
Sphagnum quinquefarium	Five-rowed Peatmoss	G5	S2S3			1992
Sphagnum rubellum	Red Peatmoss	G5	S2			1992
Sphagnum subtile	Delicate Peatmoss	G5?Q	S1S2			1978
ODONATA (DRAGONFLIES & DAMSELFLIES)						
Aeshna tuberculifera	Black-tipped Darner	G4	S2S3			1978
Enallagma hageni	Hagen's Bluet	G5	S2			1978
Neurocordulia yamaskanensis	Stygian Shadowdragon	G5	S2			1974
Ophiogomphus incurvatus alleghaniensis	Allegheny Snaketail	G3T3	S2			1974
Somatochlora elongata	Ski-tailed Emerald	G5	S1S2			1977
Sympetrum obtrusum	White-faced Meadowhawk	G5	S1			1978
VASCULAR PLANTS						
Bolboschoenus fluviatilis	River Bulrush	G5	S2			1985
Botrychium lanceolatum var. angustisegmentum	Lance-leaf Grape-fern	G5T4	S1			1970
Botrychium multifidum	Leathery Grape-fern	G5	S1			1962
Botrychium simplex	Least Grape-fern	G5	S1			2003
Camassia scilloides	Wild Hyacinth	G4G5	S2			1983
Campanula rotundifolia	American Harebell	G5	S1			2003
Cardamine flagellifera	A Bittercress	G3	S1			1985
Carex buxbaumii	Brown Bog Sedge	G5	S2			1998
Carex flava	Green Sedge	G5	S1			1998

ADDENDUM
CHECKLIST OF RARE, THREATENED AND ENDANGERED SPECIES
DOCUMENTED FROM GILES COUNTY, VIRGINIA

Scientific Name	Common Name	Global Rarity	State Rarity	Federal Status	State Status	Last Obs.
VASCULAR PLANTS						
Carex oklahomensis	Oklahoma sedge	G4	S1			1997
Cheilanthes alabamensis	Alabama Lipfern	G4G5	S1			1962
Clematis catesbyana	Satin-curls	G4G5	S1			1965
Corallorhiza bentleyi	An Orchid	G1?	S1	SOC	LE	2003
Cornus sericea ssp. sericea	Red-osier Dogwood	G5T5	S1			194?
Crataegus pruinosa	A Hawthorn	G5	S2			1956
Cuscuta indecora	Pretty Dodder	G5	S2?			1938
Cypripedium reginae	Showy Lady's-slipper	G4	S1			1998
Houstonia canadensis	Canada Bluets	G4G5	S2			1934
Ilex collina	Long-stalked Holly	G3	S2		LE	1986
Iliamna corei	Peter's Mountain Mallow	G1Q	S1	LE	LE	2002
Juncus brachycephalus	Small-head Rush	G5	S2			1998
Juncus brevicaudatus	Narrow-panicled Rush	G5	S2			1993
Lilium grayi	Gray's Lily	G3	S2			1884
Liparis loeselii	Loesel's Twayblade	G5	S2			2003
Lycopodiella inundata	Northern Bog Clubmoss	G5	S1			1993
Muhlenbergia cuspidata	Plains Muhly	G4	S2			1985
Parnassia grandifolia	Large-leaved Grass-of-parnassus	G3	S2			1982
Paxistima canbyi	Canby's Mountain-lover	G2	S2	SOC		2003
Platanthera grandiflora	Large Purple-fringe Orchis	G5	S1			1962
Poa paludigena	Bog Bluegrass	G3	S2			1997
Poa palustris	Fowl Bluegrass	G5	S1S2			1971
Potamogeton amplifolius	Large-leaf Pondweed	G5	S1S2			1986
Pyrola elliptica	Shinleaf	G5	S2			1973
Rhododendron arborescens	Smooth Azalea	G4G5	S2			1985
Rudbeckia triloba var. pinnatiloba	Pinnate-lobed Black-eyed Susan	G4/5T2	S1	SOC		1982
Sarracenia flava	Yellow Pitcher-plant	G5?	S1			1984
Sarracenia purpurea ssp. purpurea	Northern Purple Pitcher-plant	G5T5?	S2?			1986
Silene nivea	Snowy Campion	G4?	S1			1980
Sparganium chlorocarpum	Narrow-leaf Burreed	G5	S1			1966
Spartina pectinata	Freshwater Cordgrass	G5	S2			1997
Stylophorum diphyllum	Celandine Poppy	G5	S2			1981
Vaccinium macrocarpon	Large Cranberry	G4	S2			1981
Viburnum lentago	Nannyberry	G5	S1			1936
Viola walteri	Prostrate Blue Violet	G4G5	S2			1992

**Definitions of Abbreviations Used
Rare, Threatened and Endangered Species**

State Ranks

The following ranks are used by the Virginia Department of Conservation and Recreation to set protection priorities for natural heritage resources. Natural Heritage Resources, or "NHR's," are rare plant and animal species, rare and exemplary natural communities, and significant geologic features. The criterion for ranking NHR's is the number of populations or occurrences, i.e. the number of known distinct localities; the number of individuals in existence at each locality or, if a highly mobile organism (e.g., sea turtles, many birds, and butterflies), the total number of individuals; the quality of the occurrences, the number of protected occurrences; and threats.

S1 Critically imperiled in the state because of extreme rarity or because of some factor(s) making it especially vulnerable to extirpation from the state. Typically 5 or fewer populations or occurrences; or very few remaining individuals (<1000).

S2 Imperiled in the state because of rarity or because of some factor(s) making it very vulnerable to extirpation from the state. Typically 6 to 20 populations or occurrences or few remaining individuals (1,000 to 3,000).

S3 Vulnerable in the state either because rare and uncommon, or found only in a restricted range (even if abundant at some locations), or because of other factors making it vulnerable to extirpation. Typically 21 to 100 populations or occurrences (1,000 to 3,000).

S4 Apparently secure; Uncommon but not rare, and usually widespread in the state. Possible cause of long-term concern. Usually>100 populations or occurrences and more than 10,000 individuals.

S5 Secure; Common, widespread and abundant in the state. Essentially ineradicable under present conditions. Typically with considerably more than 100 populations or occurrences and more than 10,000 individuals.

S#B Breeding status of an animal within the state

S#N Non-breeding status of animal within the state. Usually applied to winter resident species.

S#? Inexact or uncertain numeric rank.

SH Possibly extirpated (Historical). Historically known from the state, but not verified for an extended period, usually > 15 years; this rank is used primarily when inventory has been attempted recently.

S#S# Range rank; A numeric range rank, (e.g. S2S3) is used to indicate the range of uncertainty about the exact status of the element. Ranges cannot skip more than one rank.

SU Unrankable; Currently unrankable due to lack of information or due to substantially conflicting information about status or trends.

SNR Unranked; state rank not yet assessed.

SX Presumed extirpated from the state. Not located despite intensive searches of historical sites and other appropriate habitat, and virtually no likelihood that it will be rediscovered.

SNA A conservation status rank is not applicable because the element is not a suitable target for conservation activities.

Global Ranks

Global ranks are similar, but refer to a species' rarity throughout its total range. Global ranks are denoted with a "G" followed by a character. Note GX means the element is presumed extinct throughout its range, not relocated despite intensive searches of historical sites/appropriate habitat, and virtually no likelihood that it will be rediscovered. A "Q" in a rank indicates that a taxonomic question concerning that species exists. Ranks for subspecies are denoted with a "T". The global and state ranks combined (e.g. G2/S1) give an instant grasp of a species' known rarity.

* Rankings should not be interpreted as legal designations.

Federal Status

The Division of Natural Heritage uses the standard abbreviations for Federal endangerment developed by the U.S. Fish and Wildlife Service, Division of Endangered Species and Habitat Conservation.

LE - Listed Endangered	**LT** - Listed Threatened	**PE** - Proposed Endangered	**PT** - Proposed Threatened
C - Candidate (formerly C1 - Candidate category 1)	**E(S/A)** - treat as endangered because of similarity of appearance	**T(S/A)** - treat as threatened because of similarity of appearance	**SOC** - Species of Concern species that merit special concern **(not a regulatory category)**

State Status

The Division of Natural Heritage uses similar abbreviations for State endangerment:

LE - Listed Endangered	**PE** - Proposed Endangered	**SC** - Special Concern - animals that merit special concern according to VDGIF (**not a regulatory category**)
LT - Listed Threatened	**PT** - Proposed Threatened	**C** - Candidate

Appendix E: Supplementary Science Book

Geoscience, Bioscience and Engineering

The ability to see clearly into the depths beneath our feet (the *transparent earth paradigm*), explore fluid flow in the deep subsurface, and accurately predict failure of a highly stressed rock mass are key to developing our understanding of the earth and expanding the safe and efficient use of earth resources. A world-class facility DUSEL facility should be able to host the broadest range of experiments identified by the research community. The Kimballton DUSEL site offers a unique opportunity to conduct integrated, collaborative experiments in sedimentary rocks, which are the primary source of groundwater, hydrocarbons, and mineral wealth, and are also the most common location for construction of underground space facilities.

Many, if not all of the experiments identified in the S1 matrices, the EarthLab report, and the preliminary DUSEL S1 Science Book can be conducted at the Kimballton site. This Appendix, however, describes research opportunities that are uniquely suited to the Kimballton DUSEL site, including:

- Tectonics and structural geology
- Hydrology
- Carbon management
- Ore formation
- Geophysical imaging
- Hydrocarbon resources
- Cavern stability
- Scaling laws in space and time
- Mining technologies
- Geomicrobiology

1.0 TECTONICS/STRUCTURAL GEOLOGY

The Kimballton DUSEL site can be considered a 5 x 1 x 2 km 3–D block of rock that allows access to a volume of the Earth's crust in the Appalachian foreland fold-thrust belt. As such, the block contains a number of existing geologic structures worthy of study that would provide new information and advance ideas how such structures originate not only on the east coast of the United States, but everywhere on Earth. Moreover, the accessed volume is large enough that it offers the unique opportunity to conduct dynamic experiments on the scale of the block that can never be conducted in a regular laboratory. Crustal experiments have been conducted before, but the opportunity offered by a such a facility for experimental design and direct observation in 3-D are unparalleled. The Kimballton block contains several – mostly very strong and competent – rock units that are repeated, folded and fractured, and are cut by several major and minor faults.   All these features present not only initial research challenges for

characterization for engineering design and opportunities for basic research in the near term, but also long-term opportunities to create new structures in a dynamic setting within a 3-D volume of the Earth's crust.

The proposed Kimballton DUSEL site is located in the Appalachian foreland fold-thrust belt, one of the classic foreland fold-thrust belts in the world. Others belts include the Canadian Rockies and Foothills which continue southward into Montana and Wyoming and northward into the Northwest Territories and Alaska, the southern Himalayas, the eastern Andes, eastern Urals and southeastern Verkhoyansk Mountains in Russia, and parts of the Alps and Apennines. A number of important basic concepts related to the structure of these belts were originally recognized and formulated in the southern and central Appalachians.

Foreland fold-thrust belts commonly form by compressive forces derived from the more interior parts of mountain chains. They form in sequences of sedimentary rocks often as strong or even stronger than most crystalline rocks, mostly in limestone and dolomite. Weaker rocks, for example shale, coal and evaporites, play a major role by allowing propagation of faults parallel to layering.

Foreland fold-thrust belts consist of a series of imbricate thrust faults that formed in the package of sedimentary rocks overlaying an undeformed crystalline basement. These faults propagate away from the interior of the mountain chain along weak zones in the sedimentary sequence and ramp (refract) upward across strong units. They commonly exhibit an overall listric shape and often merge at depth into a master décollement (weak zone) that forms a mechanical discontinuity immediately above the basement (Chapple, 1978; Boyer and Elliott, 1982).

Bedding planes occur throughout the rock mass at the Kimballton site. Spacing between bedding planes ranges from millimeters in the Martinsburg formation to tens of meters in the massive dolomites. Bedding planes are mechanical discontinuities which can be accompanied by fractures, but at the depths of the proposed facilities and in the strong rock units, they will most likely be closed and are not expected to pose problems in construction or jeopardize the integrity of the facility.

The DUSEL facility provides an opportunity to conduct short- and long-term experiments. Several kinds of research projects related to tectonics and structural geology can be designed for the Kimballton facility:
1) basic research spin-off related to the characterization and inventory of the existing structural features at the Kimballton site to assist engineering design and construction of the facility;
2) short-term and long-term basic research in structural geology; and
3) interdisciplinary research involving geophysics, geochemistry, hydrology, structural geology, and geotechnical engineering related to coupled processes.

Two examples of this type of study are dynamic experiments integrating structural geology, geochemistry, geophysical imaging, hydrology, and fracture mechanics.

1) Long-distance (hydro-) fracture propagation, fluid interaction geochemistry, fracture hydrology experiments located at the depth of the DUSEL facility will allow stimulation and observation of 3–D fracture propagation in several directions (up and down dip, along strike) into the adjacent rock mass with geophysical monitoring.
2) Smaller-scale (but still much larger than laboratory scale) fracture propagation-geochemistry-hydrology interactive experiment as a precursor to, or in parallel with, a petroleum generation experiment.

2.0 HYDROLOGY

A large majority of all existing groundwater resources originates from sediments and sedimentary rocks, therefore furthering our knowledge of the mechanisms and nature of flow and transport in this environment is critical for advancing the development of water-resources in the 21st Century. The hydrogeologic setting of the Kimballton site is unique among all proposed DUSEL sites because it provides a wide variety of structural features and rock types that offer hydrogeologists and hydrological engineers a far-reaching scope of research opportunity.

Fold and thrust belts occur worldwide, but flow dynamics along and across deeply buried faults is poorly understood. Experiments at Kimballton will be developed at various scales to study the role that thrusting plays in influencing the direction and magnitude of flow as influenced by anisotropy of bedding features, fracture orientations associated with brittle and ductile deformation, and resulting permeability patterns. We will also be able to study transport processes and possible compartmentalization associated with thrust faults. Seismic reflection images, vertical seismic profiles, and tomograms will provide details of the fault properties and geometry, which can be verified *in-situ*.

While Kimballton hosts localities with homogeneous rock units that possess massive bedding, limited fractures, and dry conditions that may be required for long-term "controlled dynamic-process" experiments, it also offers a unique opportunity to study a wide range of heterogeneous rock environments and related flow conditions. For example, we have the opportunity to investigate the hydrogeologic and petrophysical impact of a major inactive regional décollement. These features are universally common in fold and thrust belts worldwide, but the flow dynamics along and across deeply buried faults are poorly understood. Experiments will be developed at various scales to study the role that thrust faults have in influencing the direction and magnitude of flow as impacted by deformation style and related anisotropic fabric, fracture orientations and permeability patterns. We will also be able to study transport processes and possible compartmentalization associated with thrust faults. Seismic reflection images, vertical seismic profiles, and tomograms will provide details of the fault properties and geometry, which can be verified *in-situ*.

Other unique hydrogeologic opportunities include the investigation of unconformities and rock formation boundaries and their role on permeability and flow

characteristics, the nature of fractures and geochemical interaction of fluids with fracture surfaces as a function of overburden within a single geologic unit resulting from the repeated sequences of many sedimentary-rock units, and multi-phase flow in dual porosity and permeability settings. Characterization of hydraulic conductivity, at different spatial scales will also be possible. Coupling this information with major ion chemistry of waters upgradient (towards recharge areas), within the mine itself, and downgradient will help refine evolution of groundwater spatially, and temporally with age-dating assessment. Hypothesis-testing can be accomplished using local- and regional-scale coupled flow/heat/chemistry models. High resolution *in situ* stress measurements can be used to characterize the 3-d stress regime, and to discriminate local processes (e.g., neotectonic processes) from larger-scale deformation processes (such as mountain uplift/basin subsidence).

Controlled experiments require well-characterized rock conditions prior to perturbing the rock mass to create fracture networks to study the behavior of flow and the chemical interaction of fluids along fresh fracture surfaces. Large-scale experiments are planned including the creation of a hydrocarbon reservoir for the purpose of studying migration processes and investigating the role of microbes in terminal electron accepting processes in fractured-rock environments. Perturbations contained within the limits of such a homogeneous, massive, rock unit are necessary to contain the reservoir. Other experiments that require heaters, injection of mineralized fluids or contaminants would best be accomplished in a controlled engineered environment contained in such a geologic setting.

3.0 CARBON MANAGEMENT

Sequestration of CO2 in geologic formations is the most promising of all sequestration options for reliably storing amounts of CO2 that can begin to slow the accumulation of CO2 in the atmosphere. Current field-scale research is focused on demonstrations at "sites of convenience" such as enhanced oil recovery operations, depleted oil and gas fields, or brines in areas of prior exploitation. No studies are being conducted where specific processes are being tested at multiple scales under tightly controlled or monitored conditions.

Opportunities for research in the layer formations at the Kimballton site are well aligned with research priorities for CO2 sequestration in geologic formations as described in the DOE R&D plan for carbon sequestration. In particular, cross-cutting research needs in process understanding, monitoring methods and technology, and pilot field-scale studies are well suited for the Kimballton site.

Sequestration, although promising, will suffer defeat if scientific studies are neglected that focus on understanding processes at multiple scales, testing geophysical imaging of sequestered fluids, and developing and testing leak detection approaches and technology. No tests are currently being conducted where "failure" is being created. A site where the geologic system can be pushed to failure so that all the processes

associated with failure can be investigated is needed (all other demonstrations generate "null" results when no leaks, fracturing, etc are observed)

One unique aspect of the Kimballton site is the co-location of several 2-4 km deep cased boreholes immediately adjacent to large scale power plant sized atmospheric CO_2 point source emitters. Even more unique and ideal for carbon sequestration is that these multiple deep boreholes will be available for sequestration complemented by a near pure CO_2 phase from the calcining plant complemented by the more typical N_2/CO_2 smokestack emissions from the site coal burning generator with abundant power supplies all within a 0.5km radius within site boundaries. These unique attributes make Kimballton DUSEL the ideal site to transition from the scientific subsurface injections of pure CO_2 (e.g., the Frio experiment) to the more typical flu gas systems required for industrial scale CO_2 sequestration.

In addition to the transition from CO_2 to flu gas at a controlled well characterized site Kimballton also offers an ideal infrastructure for the following research studies:

1. Create multiple small engineered openings (e.g., could be as simple as boreholes); could create CO_2-reservoirs and also sampling boreholes around these at various distances with fluid samplers, pressure samplers, and other detection devices and sampling techniques for tracers and stable isotopes
2. Inject fluids of varying composition (relevant to CO_2 sequestration) at relevant P-T conditions (one could even envision controlling the P-T around the boreholes); should include multiple tracers for tracking the leakage and transport via both diffusion and bulk fluid flow
3. Develop longterm low maintenance *in situ* and near surface sensors for performance verification evaluating rates, pathways and impacts from heterogeneities
4. Monitor fracture development (maybe even alter pressure within a borehole over time to investigate failure modes); opportunity to do this from right next to the borehole to varying distances from the borehole
5. Image parallel boreholes using geophysical methods to test and improve the ability to image not just the presence of fluids, but changes due to transport, water-rock interactions, and biogeochemical reactions over time;
6. Sample from within and around boreholes over time to investigate fluid-rock interactions (geochemical and microbiology since introduced fluids will never be "sterile")
7. Develop creative detectors to be installed to "look" at micro-fracture development, biogeochemistry, and leak detection at the same time
8. Test the performance of borehole seals; in an actual sequestration system, the sealing of injection holes and past exploration/production boreholes will the be critical failure mode; we have the opportunity to create a series of boreholes and test various sealing materials and method with very fine-scale observations

Gaining advantage from the multiple several km deep DUSEL characterization boreholes for carbon sequestration eliminates CO_2 transportation issues and costs of

permitting and drilling holes at power plants. Importantly, strategies for advanced CO2 separation and or novel flu gas injections scenarios would be far more easily designed, implemented, and monitored at the comprehensive subsurface focused DUEL site. The local access to both nearly pure CO2 and the onsite transitioning to the more typical flu gas at the same site in the same formation using the same infrastructure is invaluable. **The Kimballton site thus represents millions of dollars in cost savings over other potential sites, with far greater ease for detailed scientific sequestration with near pure CO2 transitioning to flu gas scenarios.**

4.0 ORE FORMATION

The development of successful strategies to explore for new deposits of the many metals needed by modern industrialized society requires an in-depth understanding of the processes that lead to the formation of economic mineral occurrences. Geologists have learned much about ore-forming processes through studies of existing ore deposits. However, ore deposits represent the integrated history of processes that have occurred over hundreds of thousands to tens of millions of years, and it is often difficult to identify the individual processes and their relative timing in the overall ore-forming system. DUSEL offers a unique opportunity to study ore-forming processes in a controlled environment.

The Mississippi Valley-Type (MVT) hydrothermal deposits represent important sources for zinc, lead, copper, cadmium and other important base metals. These deposits are thought to form when warm, metal-bearing fluids flow from deeper portions of sedimentary basins to shallow and cooler regions. Several processes have been suggested as the depositional mechanism in these deposits, including decreasing temperature, fluid mixing, water-rock interaction, and combinations of these mechanisms. While one or more of these processes appears to be more likely in some deposits, a consistent model for ore-formation has not evolved.

We propose to simulate ore-forming processes in MVT deposits at Kimballton. A block of fresh rock approximately 10^6 to 10^9 cubic meters in size will be isolated. The physical and chemical properties of the rock mass will be characterized using a variety of invasive (drilling) and non-invasive (GPR, electric, seismic, etc) techniques. Following this initial stage, fluids having well-constrained properties (temperature, composition) will be injected into the rock mass. Quantitative collection and analysis of the injected fluids will be conducted to determine bulk changes as the fluid moves through the rock mass – this information will permit mass balance calculations to determine the total amount of metals removed as the fluids flow through the rock. Fluids with different physical and chemical properties will be injected into different parts of the rock mass to investigate the contribution of fluid mixing and fluid-rock interaction on the ore-forming process.

The active experiments are expected to last for several years to several decades. These experiments will involve researchers with expertise in structural geology,

tectonics, ore geology, rock mechanics, geophysics, seismology, geobiology, hydrogeology, mining geology and mining engineering, among others. At the completion of the experiments, the rock mass will be mined back, with continuous mapping and characterization of the face to identify the occurrence of metal mineralization within fractures. These results will be interpreted with respect to the known physical and chemical environment during fluid injection. These data will be used to develop a better understanding of ore-forming processes in MVT deposits, which in turn will contribute to the development of more realistic (and successful) models to explore for new deposits. Kimballton is the best location for these experiments because MVT deposits form in carbonate rocks such as those at Kimballton-DUSEL.

5.0 GEOPHYSICAL IMAGING

Although geophysical techniques are successfully used on a daily basis, the interaction details between seismic or electromagnetic waves and heterogeneous media perturbed at all scales are still unresolved. The well-known effects include anisotropy and scale- and frequency-dependent material properties. Geophysical experiments in conjunction with ground-truthing by mining back into the experimental volume will facilitate generation and validation of theories and numerical models to resolve these scaling problems.

Many geophysical methods are calibrated for use in clastic sediment environments only but not for carbonate environments which host, for example, the world's largest oil field (in Saudi Arabia)! We will establish a test facility for validation and calibration of geophysical tools and techniques.

At any DUSEL site, investigations in geoscience, biology, and engineering will require an extensive mapping of fractures and material properties for experiment planning, direct interpretation, and establishment of baseline datasets for timelapsed monitoring of perturbation experiments. Geophysical remote sensing techniques to image blocks between $1m^3$ and $1km^3$ in size will include seismic, electric, electromagnetic, and nuclear methods with surface, borehole, cross-borehole, and vertical profile geometries. Additional special interest targets will include the Narrows and St. Clair thrust faults beneath Butt Mtn. The Kimballton site is ideal for geophysical imaging research because of its repeated sedimentary structure and proximity to major, though tectonically benign, thrust faults.

Additionally, the DUSEL facility allows establishment of a multi-component seismic array in three dimensions to complement the EarthScope program for investigations of global seismicity and detailed studies of Earth's crust under the East Coast of the United States. This seismic observatory would also allow investigation of the interaction between seismic waves and complex of underground caverns as needed for monitoring of nuclear proliferation.

6.0 SEISMOLOGICAL RESEARCH

A deep underground laboratory can provide important data for studies of seismicity in the intra-plate tectonic setting. Eastern North America is situated in such a setting and has experienced major earthquakes in the past. Examples are the sequence of shocks in the Mississippi Valley in 1811-1812 (at least 3 shocks with magnitudes in excess of 7.5) Southeastern Canada in 1926 (magnitude 6.5), Charleston, South Carolina in 1886 (magnitude 7.0+) and a number of damaging shocks with magnitudes exceeding 5.5, in southeastern Canada, the Mississippi valley and along the trend of the Southern Appalachian Mountains, from Alabama to Giles, County Virginia. The largest historical shock to occur in the southern Appalachian region in historical times occurred near the Kimballton site in 1897, with magnitude estimated at 5.8.

Although the strain rates and frequency of occurrence of earthquakes in eastern North America is on average approximately 100 times smaller than in coastal California, the geological and historical record demonstrates the large earthquakes have occurred repeatedly in several active seismic zones. As a result, the region is exposed to non-negligible seismic hazard. The most important seismic zones in the east include the New Madrid seismic zone in the central Mississippi valley, the Wabash Valley seismic zone, Coastal South Carolina and the Appalachian region. The most active part of the Appalachian region extends from Giles County, Virginia (and the Kimballton site) to northern Alabama. Fundamental questions remain concerning why seismicity is concentrated in these areas. In particular, the role of fault zone permeability at seismogenic depths (5 to 25 km) has been postulated as a potential element in localization of the active seismic zones in eastern North America. At present, it is not know whether or not fluid flow can occur at seismogenic depths. If this is possible, the hydrologic conditions would effectively control the strength of faults, and the locations of earthquake activity. Monitoring fluid pressures in fault zones encountered at the Kimballton site to depths of 7000 feet or more could provide fundamental information.

Instrumental monitoring of seismicity associated with mining operations is an important developing technology for the mining industry. It has the potential to provide much information on the nature of the stress field and the failure mechanisms of the rock mass. This information can be used to develop improved mining strategies and reduce hazards associated with underground operations. Most underground seismic array monitoring programs are hampered by a lack of controlled experiments because they are usually conducted during the normal course of mining operations. The Deep Underground Laboratory offers an unusual opportunity to conduct carefully controlled experiments simulating a variety of different rock mass failure scenarios. Seismic array designs at Kimballton need not be constrained by mining operations, and the underground environment will be "quieter" than found in a typical active mine. This in turn will allow more effective data collection, and the ability to design controlled experiments. The data can be used to study two important aspects of the problem: 1) the nature of wave propagation in the underground mining environment, in which the scattering of high frequency seismic energy plays a dominant role, and 2) resolving the failure mechanisms of the rock mass. Experiments can be designed to simulate, for example, the sequential failure of mine pillars. Other controlled experiments using hydro-fracture can be used to determine stress field orientation, and could provide data to address questions concerning

the nature of stress changes and seismic moment. These types of experiments can potentially solve fundamental theoretical problems regarding scaling relationships between stress drop and seismic moment for a variety of seismic sources.

7.0 HYDROCARBON RESOURCES

Hydrocarbon resources constitute the main energy source in the world and most of the 'giant' reservoirs have passed their peak production using present technology. One needs to realize that, on the average, only 25 % of the known hydrocarbon content is produced; this limit been a function of the world price market, but also on the lack of efficiency associated with completion and production. Most of the advances in technology have been obtained via trial-and-error; hence, optimization is rarely achieved. One of the main reasons are the difficulties associated with validation as reservoir characterization efforts rely on indirect methods and most mechanisms are highly coupled, increasing the difficulties in pinpointing the culprit for poor performances or unpredictable responses.

DUSEL will provide a unique possibility to carry out fundamental research, validate field applications and test newly developed technologies within a well-defined and characterized geological environment; allowing also to 'mine-back' some treatments, if required. Obviously, from an oil-and-gas point of view, it is highly desirable that the selected site be in a sedimentary formation as these constitute 95% of the world reserves.

During the workshops organized as part of the S1-solicitation, the following topics were discussed as potential research/engineering applications that would benefit from having access to the Kimballton site:

A. Seismic Detection and Characterization of Heterogeneities

The study of seismic waves, natural or man-made, is a powerful tool for obtaining insight into the structure of the earth; seismic methods are used extensively, both in large- and small-scale investigations. The ever-improving quality of borehole seismic data (sonic log, sonic array, VSP) shows the importance of broad-range scale heterogeneities in the crust and the effect these variations have on the propagating wave. In the last few years the classical stratigraphic model has been complemented with random models that, through random variations of the material properties, account for these broad-range scale variations. These heterogeneities result from variations in lithology, pore fluid, saturation, porosity, pore pressure and stress. One problem for both seismic imaging and interpretation of these variations is that the resolution of what can be seen in the data depends on the wavelengths used relative to the scale of the heterogeneities. Not only does the resolution depend on wavelength, but also the travel time. Hence, inferred velocities depend on the scale of such measurements as well as rock and fluid properties. An understanding of how seismic waves are affected by heterogeneities is important for correctly interpreting features in seismic sections; an understanding that can be obtained through numerical modeling.

Within the context of DUSEL, it is proposed to focus on the geometrical heterogeneities resulting from random layering containing a viscous liquid and their influence on measurable wave velocities and densities. Wave propagation in random layered media depends on parameters such as wave frequency, layer thickness ("geometry") and the physical properties of the layers (elastic constants, densities, viscosity, etc.). These physical properties vary spatially due to rock and fluid inhomogeneities. Depending on the ratio of seismic wavelength to layer thickness, λ/d, the velocity dispersion and its accompanying attenuation, caused by scattering (geometry) and intrinsic attenuation (rheology), will vary.

The goals would then be:
 i. to develop the mathematical technique for calculating the dispersive characteristics of P- and S-waves and the attenuation for various type of media (inhomogeneous, anisotropic) based on first principles;
 ii. to provide numerical modeling of the frequency characteristics of body waves for various media; to predict the behavior of dispersive characteristics (velocities, specific attenuation) with depth for low frequencies based on high frequency experimental results (sonic and sonic array borehole data); and,
 iii. to explain surface seismic data and show the possibility of distinguishing the various types of attenuation mechanisms (geometry and viscosity).

The ultimate goal of these calculations would be to understand the possibility of distinguishing the causes of attenuations (scattering or viscosity) in P- and S-waves.

The mathematical methods developed would need highly controlled experiments for verification. Thus far, most of the experimental work has been carried out at the core-scale and requires scaling in order to apply the results to the field-scale. Properly designed experiments at the Deep Underground Science and Engineering Laboratory could provide the data required to evaluate these techniques in the field. By its nature, the limestone formation at Kimballton already contains a number of fractures. The fluid pressure inside a fracture could be increased in stages and seismic waves at a variety of frequencies could be generated. Devices in wellbores, on the surface and in the mine shafts could be used to record the seismic response and the mathematical models could be tested to see if their response matches the actual response.

B. Drilling Optimization

The petroleum and geothermal industries are developing ever deeper and more difficult reservoirs requiring unique and expensive drilling facilities. Daily rates in excess of $100,000 for drilling rigs are not unheard of. Although automation is slowly being applied in the field, it consists mostly of data transmission to a central location; hence, mainly monitoring a series of measured parameters. But as far as weight on bit, torque, and mud circulation are concerned, experience and trial-and-error are still the approach used in the field. Moreover, when the rate of penetration drops below a certain economic limit, it is usually left to the crew to decide upon the potential cause; often leading to

pulling the drilling string to the surface. When completing 15,000 ft+ wells, such a measure corresponds to approximately a loss of one day for the roundtrip.

Recent developments in fiber optics have resulted in the possibility not only to 'see and illuminate' the dark environment, but also to measure pressure, temperature, fluid and particle velocities. It would, therefore, be feasible to develop a downhole 'package' having the capabilities to make decisions, based on the data collected at the drilling horizon. For example, if an unusual high pressure gas zone is encountered and is detected, it is quite conceivable that some packers could be inflated, isolating the overpressured zone. The drilling process would then stop and a signal could be sent to the surface requesting further action. This would definitely increase safety. By the same token, the visual aspects could detect the efficiency of rock comminution and adapt the drilling parameters to encourage shear or tensile failure rather than compressive crushing. In other words, this project is to develop downhole intelligence in order to optimize penetration rate and reduce overall drilling costs.

The advantages of having access to a well-defined underground research facility such as DUSEL are obvious as the mine will allow the validation of the concepts developed in this project. Boreholes could be drilled between drifts using this "intelligent drilling" technology, providing additional geological information. The geologic formations at Kimballton would lend themselves more directly to deep, sedimentary rock formations of interest to the wet geothermal reservoirs exploration as well as the petroleum industry.

C. Lithology Recognition from the BHA (Bottom Hole Assembly) Vibrations

An understanding of rock properties is fundamental in civil, mining and petroleum engineering. In the petroleum industry, the knowledge of rock properties is essential for hydrocarbon resource estimations, drilling process design, oil and gas production optimization, and enhanced recovery operations. Thus, problems related to rock classification, rock bit selection and performance optimization, and wellbore stability are essential for the optimal and economic management of natural resources.

Most of the recent developments in drill bit design have been made through the utilization of new materials that extended the life of the bits and allow their application to harder and more abrasive formations. Drilling problems associated with excessive bit vibrations have been recognized. Moreover, the developments in bit design have not eliminated the most severe problems that occur while drilling through changing lithologies. The only way to successfully drill such boreholes is to adjust parameters (for instance, weight-on-bit, rotational speed or pump pressures) during drilling. In addition, industry has recognized an increased need for extended-reach and horizontal drilling to improve productivity and reduce cost. Thus, directional bit-steering becomes a crucial need. At present, downhole measurements allow detection of excessive bit vibration only. No method has been developed to detect formation changes while drilling so that appropriate drilling parameters can be adjusted to steer the bit. As a result, sudden and unexpected bit damage and/or unnecessary tripping operations often occur.

Results of experiments using a single polycrystalline diamond compact (PDC) cutter, performed at Montana Tech, have shown that it is possible to predict bit performance under given conditions by measuring the forces and moments at the bit face. These forces and their dynamic characteristics could also be estimated based on vibrations of the bottom-hole assembly. It has also been demonstrated that the drilling force dynamics associated with the cyclic nature of rock destruction while drilling is directly related to rock lithology. By implication, if the variations in cutting forces could be detected and interpreted in real time, then a new and useful diagnostic tool would be available during drilling. As a result, it would be possible to detect the changes in rock drillability, as well as to differentiate the changes in rock properties from the changes in bit wear and well conditions. In order to take advantage of this possibility, a dynamic model of rock/bit interaction incorporating the bottom hole assembly vibrations as a function of bit design, rock lithology, drilling parameters and well conditions needs to be developed.

In order to develop the dynamic rock/bit interaction model it is necessary to use different bit designs in different rock lithologies using variable drilling parameters and well conditions. An instrumented downhole diagnostic sub that allows measuring temperature, wellbore pressure, weight-on-bit, rotational speed and torque, as well as bit displacements and accelerations would need to be designed and built. The proposed methodology of data analysis would use a neural network to identify material lithology where the inputs are operational parameters, well conditions and bit design characteristics. At the same time, an analytical analysis would be required to develop a dynamic bit model accounting for the stress distribution in the bit body and in the rock at the rock/bit cutter interface as a function of the bottomhole assembly characteristics. For this, the IDEAS software could be used to model the reactive forces, displacements and accelerations. Simulations could be run to verify both the model of the bit and the model(s) of rock failure. The developed models could then be used in the neural network analysis as the additional input data that should provide better drilling process predictions. The developed methodology of rock lithology identification should also significantly improve bit performance and assist in optimization of drilling process based on data from offset wells.

One of the goals of this engineering project, therefore, would be to develop tools and techniques to allow the detection of lithology changes while drilling using the vibrations from the drill string bottomhole assembly. An additional goal would be to use this lithology information to control drilling parameters to ensure that the drilling is being conducted safely and in an economically optimal manner.

Lithology and rock properties while drilling are very difficult to identify because access to the rock material being drilled is generally only available through small cuttings, logs and cores obtained or analyzed after the well has been drilled. Since rock properties and rock behavior are a function of the depth and geological conditions, the processes, which depend on rock properties are very difficult to design and/or control. Thus, the majority of the research has been limited to rock sample testing under simulated *in situ* stress and temperature conditions, studying the effect the rock properties have on the tools used in the field and studying the stability of the wellbores and

underground openings. Most of this research aimed at studying the effect of rock properties on the different rock-dependent processes cannot find practical applications. This is due to the limited scope of the individual projects, limited laboratory or field data available and/or lack of the specific conditions for verification of the theoretical solutions. Usually, laboratory tests are very expensive and do not reproduce the full-scale processes.

On the other hand, in the field some parameters are not measured or recorded. Also, the range of the field data is limited to cases with optimal and/or reasonable operational conditions and cases where an extreme change in the magnitudes of some of the parameters is not allowed. For most of such engineering research, it is required to follow the very specific scenarios of the tests. Usually, such scenarios are not of practical interest. Also, some of the tests need to have the results from several if not many wells, which causes the research to be very expensive and time consuming. Moreover, some of the test conditions may not be comparable and/or complete, thus useless for new developments.

Access to different levels in a mine such as Kimballton (Upper Campus depth: $\approx$ 1,750 ft, Middle Campus depth: $\approx$ 3,500 ft, and Lower Campus depth: $\approx$ 7,300 ft) allows testing different rock lithologies under different *in situ* conditions. Drilling relatively short, thus less expensive wells, allows fast testing of different bits while applying variable operational parameters. It is also extremely important to have the possibility of rearranging test scenarios including allowing repeat tests.

D. See-ahead of the Bit

One of the most expensive remedial workovers in the petroleum and geothermal industries results from encountering unexpected geological conditions such as a fault, an overpressured horizon, etc… Such conditions always result in cost overruns in order to save the well, or can even result in loosing the well altogether. In addition, an unexpected rise of gas bubbles through the mud column can jeopardize the safety of the drillers by causing devastating fires on the rig floor. Attempts have been made by the tunneling industry to investigate geological conditions prevailing ahead of boring machines. Deep Penetrating Radar and Acoustic Tomography, for example, have had limited success in providing the engineers with advance warning, sufficient to adapt the support system to the new conditions.

It is proposed to review the different existing seismic, electric and magnetic technologies; especially their assumptions and limitations with respect to depth of penetration as well as accuracy with respect to formation characterization. Some technologies will probably have to be extended to determine some specific important characteristics such as strength and roughness. In addition 'miniaturization' will play an important role in order to apply such technologies, or combination thereof to deep oil and gas drilling. The obvious advantage of having access to a deep three-dimensional mine consists in the fact that surface drilling can be conducted from any drift to validate the theoretical developments as well as testing the concepts via mineback operations. In

addition, drilling deep boreholes from the surface will allow researchers to tackle and solve problems related to data transmission to the surface by using wireless technology.

E. Gas Storage in Caverns and Mines

Natural gas transportation facilities and end users usually have limited ability to adjust to often unpredictable consumption and supply changes in a timely manner. To quickly respond to changes in natural gas demands and to ensure uninterrupted gas supplies, suitable storage facilities are often a necessity. Gas is stored in order to even out pipeline loads and to take advantage of fluctuations in gas prices. In addition, a likely source for global warming appears to be the increased greenhouse gases that have been produced by the burning of fossil fuels. Prudence requires that mitigation methods to prevent additional global warming need to be investigated. Storage of these greenhouse gases in underground repositories is one of several available options.

Current methods for underground gas storage include (partially) depleted oil and gas fields, aquifers and salt caverns. A potential repository for gas may be abandoned mines in relatively impermeable rock formations. Storage in salt caverns and abandoned mines are believed to behave like pressurized containers; and therefore, these storage facilities have the advantage of potentially high deliverability flow rates. Furthermore, man-made salt caverns can be sized for individual needs by solution mining. Typically, salt caverns are located 600 to 1500 m below surface and are kept at operating pressures of about 5 to 20 MPa. They typically can accommodate inventories of $3x10^7$ to $15x10^7$ standard cubic meters. Abandoned mines cannot be easily sized, but may have an even larger storage capacity and are potentially accessible from the surface through mine and elevator shafts. Storage of gas in abandoned mines has been attempted. However, leakage rates have generally been unacceptable and the mines shut down after initial tests. In addition sealing of the storage cavern via positive fluid pressure gradient has not always been successful due to the potential 'champagne effect' whereby gases can flow in fractures against the liquid gradient.

The gas physically residing in a storage cavern, referred to as cavern inventory, is mainly a function of the cavern pressure, temperature and volume. To be able to account for inventories present and to capture leakages and/or anomalies in cavern behavior, the theoretical cavern behavior has to be modeled as accurately as possible so that it can be compared to metered values. Several inventory models are available with varying degrees of sophistication. There is presently no model that correctly accounts for all potential sources for gas loss in these storage facilities. The best example of the importance of having models that account for all losses is the Hutchinson, Kansas explosion that was a result of leakage from a gas storage facility. This explosion killed two people, destroyed two businesses and several homes, and destroyed or damaged more than 25 other buildings.

Extension and/or development of a full physics inventory control model should be relatively straightforward. The physical phenomena that are important in the monitoring of storage of gas in salt caverns are fairly well recognized: compositional gas mixtures and real gas behavior; thermodynamic effects due to gas expansion and compression;

phase separation and condensate build-up; heat and mass exchange with the surrounding salt; and cavern volume change due to cavern creep. The two phenomena that are least understood are the loss of gas to the surroundings and the volume change due to creep. Loss of gas to the surroundings could be due to losses through micro fractures or through the mechanical system serving the storage facility (ineffective cement bond, loss of casing integrity, valve and connection losses downhole and at the surface, etc.).

More importantly, this model would be the starting point for a model to monitor inventory in abandoned mines. Presumably, the mechanisms for loss would be similar in abandoned mines with the exception being that mines generally have multiple openings to the surface, many of which are known. Appropriate seals for these openings would need to be developed and tested. In addition, most abandoned mines are in hard rocks that are more likely to be fractured than the salt caverns as the hard rocks are not plastic and do not "heal". Any cyclic loading may further open the existing fractures. Therefore, gas loss through fractures, both through preexisting fractures and through fractures induced by excavation and operation, also needs to be characterized. Laboratory and large-scale experiments would provide necessary information on the appropriate methods for modeling the inventory of gas in these systems. In addition, one of the major issues in subterranean disposal of CO_2 is how fast will gas flow through water-saturated fractures; simply returning to the atmosphere a few years or decades from the time of injection.

Materials and equipment for the conversion of abandoned mines for gas storage can best evaluated through field testing. The Kimballton Mine provides an ideal location for such a field test. A section of one of the shafts could be sealed and charged initially with air tagged with a tracer to sufficient pressure to test the seals. Monitoring devices could then be placed in other areas within the same shaft as well as nearby shafts to detect the tracer. Pressure and temperature measurement within the sealed portion of the mine would mimic a field application. Inventory cycles could then be run and simulated to verify the models.

F. Microbial Enhancement of Oil Recovery (MEOR)

MEOR relies on microbes to ferment hydrocarbons and other nutrients to produce one or more by-products that enhance oil recovery. In general, those microbes already exist in the reservoir and nutrients, such as sugars, phosphates, or nitrates are injected to stimulate the growth of selected microbes. These microbes, in turn, can generate surfactants, polymers, alcohols, solvents and carbon dioxide that help to displace the oil. The microbes along with some by-products can plug off water filled channels and force the oil to migrate through other larger pore spaces. For *in situ* processes, the microorganisms must not only survive in the reservoir environment, but also produce the chemicals necessary for oil mobilization.

A number of field experiments have already been conducted, with mixed success, this implies that the called-upon mechanisms have some inherent limitations. However, a number of spin-offs of such technology have already been identified such as:
    * waste remediation via microbial 'digestion'

* refining of hydrocarbons containing paraffin and/or asphaltine deposits
* enhanced waterflooding requiring the transport of nutrients over long distances
* profile control and sweep improvement via selectively plugging high permeable zones
*remediation of paraffin deposits and scale control
 *near well-bore removal of water blockage

Access to three sedimentary 'campuses' located at different depths in the Kimballton mine would allow investigations of these limits. Selective injections of a variety of nutrients under different reservoir conditions with subsequent evaluation of the results by mineback and/or overcoring would definitely provide some insight and allow optimization of such treatments.

Wave Propagation in Layered Rocks

Background

Over half of the world's proven hydrocarbon reserves exist in carbonate rocks (Palaz and Marfurt, 1997) even though carbonates make up only 20% of the sedimentary rock record. This fact alone means that the performance of geophysical and petrophysical tools in carbonate settings are of the utmost importance and the development of new techniques is vital to the nation and the world's energy supply.

Although a huge literature exists on geophysical imaging in carbonates and the petrophysical properties of carbonates, few if any of these methods or images has ever been tested against the ultimate in ground truth—an observer walking, standing, making direct measurements inside a carbonate reservoir. This was reinforced recently (March 15-19, 2004) at a research symposium on carbonate-reservoir characterization and simulation. All speakers noted "…..all models are approximations, noting that in the attempt to model subsurface reservoir, we deal with upscaled and remotely sensed data." (Freazel et al., 2004). At the Kimballton Mine we can remotely sense a volume of fractured limestone using both conventional and new, innovative imaging methods and then take the ultimate step, not available to previous investigators, of mining into the volume of fractured rock.

A large number of geophysical and petrophysical experiments can be performed above and around a target zone in the fractured limestone and, more importantly, this work will contribute to the underlying sciences of subsurface imaging and petrophysics. Below we outline several experiment scenarios with ground-truth provided by carefully placed and executed mine-back operations. In most cases a single, well thought out mining scenario would provide ground-truth for many geophysical imaging and petrophysical measurement experiments. Furthermore exciting and profound investigations will occur at the intersection between petrophysics and imaging.

Geophysical Imaging

Seismic Imaging
The predominate (98%) geophysical imaging techniques used in the hydrocarbon industry are seismic techniques and for good reason. Seismic methods provide reasonable resolution at large depths of penetration; therefore a large program of seismic imaging is suggested here. In all cases we propose to image the fractured limestone and volumes of fractured limestone and mine-back operations will eventually provide ground truth for the images.
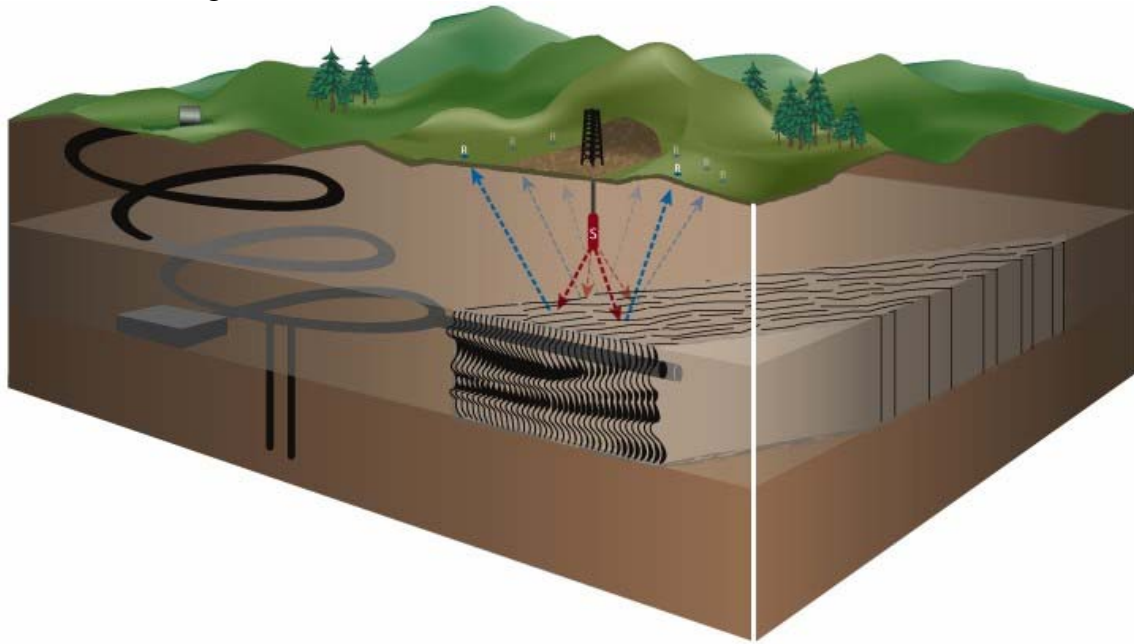
This portfolio of imaging research is broken into two components. First, there are those experiments that will be run on volumes of fractured limestone with water in the fractures and pores. A second class of experiments would be run on a separate volume of fractured limestone with oil in the pores and fractures accurately simulating an oil reservoir. Here, data acquisition can be conducted in a time-lapse manner as oil is displacing water in the fractures and pores, then again as the oil is pumped out of the "reservoir".

Water as the Pore Fluid
A volume of fractured limestone is, in general, a zone of lower seismic wave velocity and specifically a zone of velocity anisotropy. Therefore we can treat the target as a simple low velocity zone, a region of azimuthal anisotropy for compressional waves, and especially a zone of shear wave anisotropy. All three can and have been used as an imaging mechanism; furthermore, the resolution of each method increases as the frequency of the illuminating energy rises. Yet in every case geophysicists have not seen rigorous ground truth for any of these subsurface images.

Here we are imaging in-situ conditions of pore fluid and fracturing with the mine-back operations identifying the accuracy of the imaging methods, especially the increase in resolution (vertical and horizontal) as the frequency of the illumination increases.

Compressional Wave Imaging—Stepping Upward in Resolution
1) Image with compressional wave (P wave) surface seismic (reflection) 3-D
2) Image with P wave vertical seismic profiling (VSP)
(reflection and transmission), walk away, upper edge of frequency band
rises approx. 50%
3) Image with P wave reverse vertical seismic profiling (RVSP), 3-D, upper edge
of frequency band rises approx. 100% + over (2).
4) Image with P wave crosswell tomography and reflection, upper edge of
frequency band rises approx. one order of magnitude.

Shear Wave Imaging—Stepping Upward in Resolution
1) Image with shear wave (S wave) surface seismic reflection 3-D
2) Image with S wave VSPs (nine component VSPs) walk-away, (reflection
and transmission), upper edge of frequency band rises approx. 50%
3) Image with S wave RVSPs, 3-D, upper edge of frequency band rises approx.
100% over (2)
4) Image with S wave crosswell tomography and reflection, upper limit, today, of
S wave downhole sources is approx. 1,000+ Hz.

Obviously, each of the above methods yields information about the rock properties of the target in addition to imaging that target. This is especially true of the S wave methods. They will provide knowledge of the anisotropy of the fractured limestone.

Two Phase Fluids--Gas and Water allows Time-Lapse Imaging
By injecting methane into the fracture volume we can create a realistic hydrocarbon reservoir with interesting imaging and petrophysical problems. One of those fundamental questions concerns "patchy saturation" of the fluids in the fractures. It has long been known that the bulk modulus and bulk density of a two phase medium are complex functions of the properties of the two phases, if they are uniformly distributed throughout the matrix. But, uniform distribution is high unlikely in real rocks, it is much more likely that "patchy saturation" exists where whole regions of the formation have one phase in place and the other phase predominates elsewhere. Therefore the velocities observed will be a function of the wavelength of the illuminating energy.

The Kimballton Mine and the imaging program outlined above allows a unique set of experiments to test these theories. Here we will ratchet up in resolution (smaller wavelengths) and document the observed velocities with the final measurements being made just behind the mine face with innovative NMR tools.

Oil, Water, and Air—Three Phase Conditions allows Time-Lapse Imaging
Oil can be pumped into a zone of fractured limestone from below as water is being extracted from above, thus speeding up the normal migration of oil. If a gas, say,

methane, is present, a three-phase, hydrocarbon reservoir can be created in the fractured limestone. Imaging as suggested above could be done in a time-lapse manner (4-D) as the reservoir is being created and then, again, as the reservoir is produced.

The major science lies in the mine-back operation as it tunnels in from the massive limestone region (background medium) through the edge of the image, then into the fractured rock region (the target). Obviously, the three-phase conditions most closely represent reality. But, in either situation the important scientific issues concern the accuracy of the above images in all respects--shape, size, and rock properties. As the resolution increases does the accuracy of the determination of all features (shape, size, rock properties) increase uniformly?

The amount and location of oil remaining after primary production methods have been exhausted is especially important.

Underlying Science--Imaging
Many fundamental science questions are being asked in the above imaging experiments, the primary one being the issue of what constitutes the "edge" of a target when the target is a volume created by, or composed of, a "distributed" parameter, such as fluid filled fractures. Obviously, the "edge" is frequency dependent, i.e. it depends on the frequency of the illuminating energy. Furthermore, the "edge" also depends on the type of illuminating energy, P waves or S waves. Since the fractures are aligned the "edge" depends on the polarization of the incident S waves.

The series of experiments proposed above cover all of the theoretical cases cited here and the mine-back operations will provide the ultimate ground truth.

Petrophysical Research
A reservoir in fractured limestone with two or three phases of fluids in the pores and fractures is an ideal petrophysical research laboratory especially given the ability to mine into the study zone. Furthermore the capability of making measurements in a time-lapse manner makes the facility extremely valuable.

Four boreholes, three vertical and one horizontal, will be drilled into and through the Kimballton Limestone with borehole-wall, imaging logs run in all of them. Then two vertical holes will be cased in steel, with and without cement, another in PVC, with the horizontal borehole being cased in steel, prior to any new fluids being pumped in. Logging measurements and zero offset VSPs (some decimated at a later time to represent check shot surveys) constitute the usual suite of data for velocity determinations.

Underlying Science—Petrophysics

Inversion for Acoustic and Elastic Impedance—The Fundamental Trend is Missing
Given seismic data it is important to derive the velocity and density profiles that are embedded in the seismic section. This is done by noting that the reflection amplitudes are a function of the velocity and density contrasts that exist across a reflector (interface).

Integration of a seismic trace yields an estimate of the interval velocity but only the variations in velocity are obtained (those on the order of the frequency of the seismic data), the fundamental, slowly changing trend of the interval velocities is lost.

If we look at our VSP, RVSP, and crosswell data (see above) we will get the more rapidly changing velocity structure of the earth, but the basic trend of velocity is still missing. However, in a mine setting we can acquire a form of data, impossible to obtain otherwise, that will fill in this gap.

At Kimballton we can deploy a fixed three dimensional array of broadband seismometers in the mine surrounding a zone of study. With this large sensor spacing the very low frequency portion of the velocity "spectra" is now available from passing seismic waves generated by distant earthquakes thereby filling the gap in seismic velocity inversion determination. In fact a dense 3-D array can measure the spatial derivatives of displacement yielding direct measures of the divergence and curl of the displacement field.

$$\text{div} \quad \partial u/\partial x + \partial v/\partial y + \partial w/\partial z$$

$$\text{curl} : (\partial w/\partial y - \partial v/\partial z)i + (\partial u/\partial z - \partial w/\partial x)j + (\partial v/\partial x - \partial u/\partial y)k$$

where u, v, and w are the displacements in the x, y, and z directions and i, j, and k are the unit vectors in those three directions. Only a mine setting such as the Kimballton Mine can provide the large-scale, three-dimensional, seismometer array surrounding a "laboratory" of exploration scale science thereby providing a complete velocity profile, inverted solely from seismic waves, that can be favorably compared to logging and *in-situ* measurements. More importantly, this type of study has no value outside the mine if it is not done in sedimentary rocks.

The Up-Scaling Problem
The problem of determining the bulk petrophysical properties of a rock mass given measurements on the core and logging scale is especially difficult in fractured formations—upscaling works until the first fracture enters the picture. Long wavelength measurements such as seismic measurements are helpful but their scale is too large. Here we will use cross well seismic methods, which are rarely used, to fill. But, the greatest knowledge, "take-away knowledge" will come during the mine-back operations. Here the number, size, and orientation of the fractures that were included in the bulk properties (porosity, permeability, velocities etc.) determination will be seen for the first time.

Studies at the Intersection between Geophysical Imaging and Petrophysics—Permeability Anisotropy and Shear Wave Anisotropy
Between seismic imaging and petrophysics lies an extremely valuable question concerning seismic anisotropy and permeability anisotropy, namely is permeability anisotropy aligned with seismic anisotropy? The Kimballton Mine is an excellent setting to investigate this question.

Using the S wave methods outlined above one can determine the seismic anisotropy of the fractured limestone.

The permeability anisotropy can be determined by injecting dyes into the regional flow of water and examining the tainted limestone during mine-back operations.

<u>Underlying Science—Numerical Modeling of Seismic Wave Propagation</u>
Efforts are currently underway (Pride et al. 2003, Berryman and Pride, 2003a; Berryman and Pride, 2003b) to understand the relationship between seismic amplitudes and permeability. The relationship between permeability and velocity anisotropy is indirect probably due to alternate layering of zones of high porosity and permeability (low velocity) with higher velocity layers of low porosity and low permeability.

CO2 Sequestration
Carbon dioxide sequestration will occur in sedimentary rocks, not in igneous and metamorphic formations. Imaging and monitoring the sequestration will be a major component of the program world wide. Can geophysical imaging, in particular time-lapse imaging satisfy these demands, especially the serious geochemical interactions between CO_2, water, and limestone? In addition can we identify the nature of fingering, and our ability to image that fingering with existing imaging methods? The Kimballton Mine will allow us to test all of the imaging methods listed above and test them against the ultimate ground truth—mine-back observations.

Observations on Mine Faces
Above I have been very cavalier in the assertion that "mine-back" observations will provide us with ground truth that has never been available to the seismic imaging community. While this is true advances in those techniques and methods must occur simultaneously with all other research efforts. In particular, we must be able to "see" several inches (centimeters) into/behind the rock face, into the rocks unaltered by the mining machinery and explosions. Only there can we make valid observations of fluid type, degree of saturation of multiphase conditions, and density of fractures.

Advancements in nuclear magnetic resonance imaging will provide such fluid sensitive images at shallow distances behind the mine face. Since the device can be large (compared to borehole NMR tools) it will be possible to use powerful magnets in innovative geometries to achieve the ground truth imaging necessary.

Conclusions

- Results can be taken away--applied to important geophysical imaging and petrophysical problems around the world.

- Only the Kimballton Mine Project can attract funding from sources other than NSF thereby reducing the overhead expenses for all.

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8.0. FLUID FLOW AND TRANSPORT IN FRACTURED MEDIA

Despite a large amount of research that has been conducted over the past number of years, prediction of fluid flow in fractured porous rock masses continues to be highly problematic primarily due to the length scales involved. In most instances, flow in the fractures is the primary flow path to wells and to the water table. Viscous and gravity forces generally dominate the bulk fluid transport and act at a fairly long length scale, while capillary forces act on a short length scale and may either impede or aid flow in the fracture. What is less known is the mechanisms that control the volume of fluid that gets to and the time that it takes to reach the well or aquifer especially in rocks that contain a network of interconnected or partially connected discontinuities in a porous medium.

In 1996, the National Research Council published a book entitled "Rock Fractures and Fluid Flow". The questions posed in the technical summary succinctly define a number of research areas that are required. These are:

1. *"How can fractures that are significant hydraulic conductors be identified, located and characterized?"* Sub items within this area are improved geologic and fracture mechanical description of fractures, delineation of the hydrologic and crack properties of the fractured system, geophysical methods (the specific subject of another white paper), and hydraulic and tracer testing.
2. *"How do fluid flow and chemical transport occur in fractured systems?"* Sub items within this question were conceptual modeling, mathematical and numerical modeling and *in situ* flow and transport experiments.
3. *"How can changes to fracture systems be predicted and controlled?"* Sub items here include laboratory studies of coupled behavior in a single fracture, *in situ* testing and procedures and mathematical models of coupled phenomena.

Because the Kimballton Mine is located in a limestone formation, a porous medium that already contains a number of fractures, this unique site would complement the experiments carried out in the Stripa site in Sweden, the Underground Research Laboratory in Manitoba, Canada and would dovetail nicely with sites at Mirror Lake, New Hampshire and the Conoco Borehole Test Facility in Oklahoma. A number of research projects would require the characterization of the flow behavior of these fractures. The facility would offer a unique capability to perform field-scale *in situ* experiments that could be readily viewed either through mineback or through tracer testing. All three questions specified by the NRC would be enhanced by experiments conducted at this DUSEL site.

9. PROPAGATION AND MINE-BACK OF HYDRAULIC FRACTURES

From outcrop observations and the few mineback field experiments, it is well known that *in situ* discontinuities affect the propagation of hydraulically induced fractures. In general, the resulting geometry reveals an offset of a certain magnitude which is, presently, impossible to predict. On one end of the scale, this offset can be infinite; in which case the induced fracture is "contained". This would be the ideal situation if one wants to keep stimulation treatments within the producing reservoir, avoiding growth into the upper and lower barren barriers. On the other end of the scale, the offset could be nil; in which case the induced fracture has essentially "ignored" the presence of the preexisting discontinuity. This is ideal if one considers the problems associated with the transport phenomena, especially the placement of the associated proppants. In other words, the petroleum industry would like the fracture to be contained in one direction, while avoiding offsets in the other perpendicular propagation direction.

About thirty years ago, a number of preliminary laboratory tests where performed on composite parallelepipeds which revealed that the 'arrest' criterion was very much a function of contrasts between the properties of the materials. Later on, some coal bed methane projects involved mining the hydraulic fracture back and revealed both containment and offset, speculating that the behavior of the discontinuity played the most important role as well as the pumping rate. Thus far, no theoretical approach has been able to provide sufficient guidelines for field treatments.

A research goal, therefore, is to understand the fundamental mechanism(s) that control fracture propagation in a medium containing randomly distributed discontinuities. This goal will be achieved by conducting theoretical and experimental studies:

(i) *Theoretical*: Using commercially available finite element and boundary element codes, it is proposed that an existing fracture be simulated with all its attributes: cohesion, angle of friction, normal stiffness and shear stiffness; and to study - both in 2D as well as 3D- the evolution of the stress concentration factor as an induced fracture approaches at a certain angle. There is no doubt that the preexisting discontinuity will 'sense' the approaching fracture and that the original stress distribution along the fracture will start to be affected. If one considers, for example, the shear stress distribution, it will change from uniform to bi-modal. Hence, one of the peaks (only symmetrical for a fracture approaching @ 90°) could conceivably exceed the shear strength of the joint, leading to a secondary fracture initiating in the second medium prior to the initial fracture reaching the discontinuity. Such a mechanism, if verified, could explain the offsets and one should gain some insight on the parameters governing their magnitudes.

(ii) *Experimental*: A number of servo-controlled laboratory experiments could be conducted on stacks of blocks subjected to triaxial loading conditions. A polyaxial frame of 10,000 psi differential capacity is indeed available; this equipment has seven independent loading systems, allowing the various lithologies to be subjected to different lateral stress conditions. Recent experience with joint castings will also allow varying the roughness of the existing discontinuities. The central block would contain a small pressurized borehole from which a hydraulically induced fracture would be propagated. This experimental phase would be carried out to validate some of the theoretical developments.

Another important issue is related to understanding the mechanism(s) governing hydraulic fracture propagation. It concerns the conditions prevailing at and near the crack tip, especially in the case of porous formations. Here again, the problem is fully coupled as the fracture toughness value, the local transient pore pressure as well as the fracturing fluid viscosity affect the fluid lag (i.e. the distance between the crack tip and the fluid front). Even though a few theoretical and numerical solutions have recently been proposed, the field validation is still lacking.

The Deep Underground Science and Engineering Laboratory will provide unique opportunities for this particular project in that the limestone formation at Kimballton already contains a number of fractures which, hopefully, will have been characterized at least as far as their attitude is concerned. It would be easy to drill some short holes from the existing mine workings in a direction which will be dictated by the regional and local *in situ* stress tensor. After propagating a hydraulic fracture, any mineback could accurately record the offsets, and by inversing the problem, the characteristics of the intersected discontinuities could be back-calculated. A large underground shear test could then validate the computed data.

As far as the fundamental research on 'crack tip mechanism(s)', the Kimballton site is close to ideal as the available sedimentary horizon allows for the strong coupling between fluid flow and rock deformation.

10. CAVERN STABILITY

A substantial portion of the nation's infrastructure is likely to be sited underground because of energy costs, urban crowding and vulnerability of critical subsurface facilities. Economic, efficient, environmentally friendly and safe development of underground space will require an improved ability to engineer the geologic environment. Because of the prevalence of sedimentary rock in the upper continental crust, much of this subterranean infrastructure will be sedimentary formations.

The planned Deep Underground Science and Engineering Laboratory (DUSEL) provides a unique and exciting opportunity to develop, test and validate new and innovative techniques for tunneling. DUSEL will be unique in that it will require the construction of large caverns located at depths approaching 7000 ft. Although there are many tunnels at large depths, they are typically small, while large caverns, such as the 62 m span Olympic Cavern in Norway, are in shallow formations. The construction of the access tunnels and caverns for experimental facilities will pose several challenges that need to be addressed by new technologies for geological characterization, tunnel design, and tunnel excavation and support. Lessons learned from building DUSEL can be used to improve tunneling technology. Rock failure in underground mines and tunnel construction continue to claim lives, and the tunneling industry is still beset by cost overruns and frequent failures. These problems can be reduced by better knowledge of rock mass behavior and improved tunneling technology.

To gain improved knowledge on rock mass behavior, it is proposed to use the caverns and portions of the access tunnel as "research tunnels" during construction. By converting parts of DUSEL into "research tunnels" different types of studies can be carried during the construction and use of the tunnels and caverns. These studies include:
1) comprehensive geological and geotechnical characterization for rock mass modeling,
2) instrumentation and monitoring of the rock mass, the tunnel support system, and the tunneling equipment during the construction (Figure 1),
3) using and testing different methods of excavation and different types of support systems along different parts of the tunnel, and
4) comparing different tunnel analysis methods amongst each other and with the observed performance.

Major technological developments expected from the research to be carried out in the DUSEL "research tunnels" include development of novel and innovative technologies for:
1) advanced geologic and geomechanical modeling of rock masses,
2) visualizing and interacting with computational models of tunnel excavation

3) digital imaging and analysis for geologic characterization of rock masses,

4) remote measuring and monitoring of tunnel response during construction and

5) monitoring stress changes within the rock mass due to excavation using computer tomography. It will also be attempted, in collaboration with the tunneling industry, to apply and evaluate new excavation and support methods which increase the speed and reduce the cost of tunnel construction.
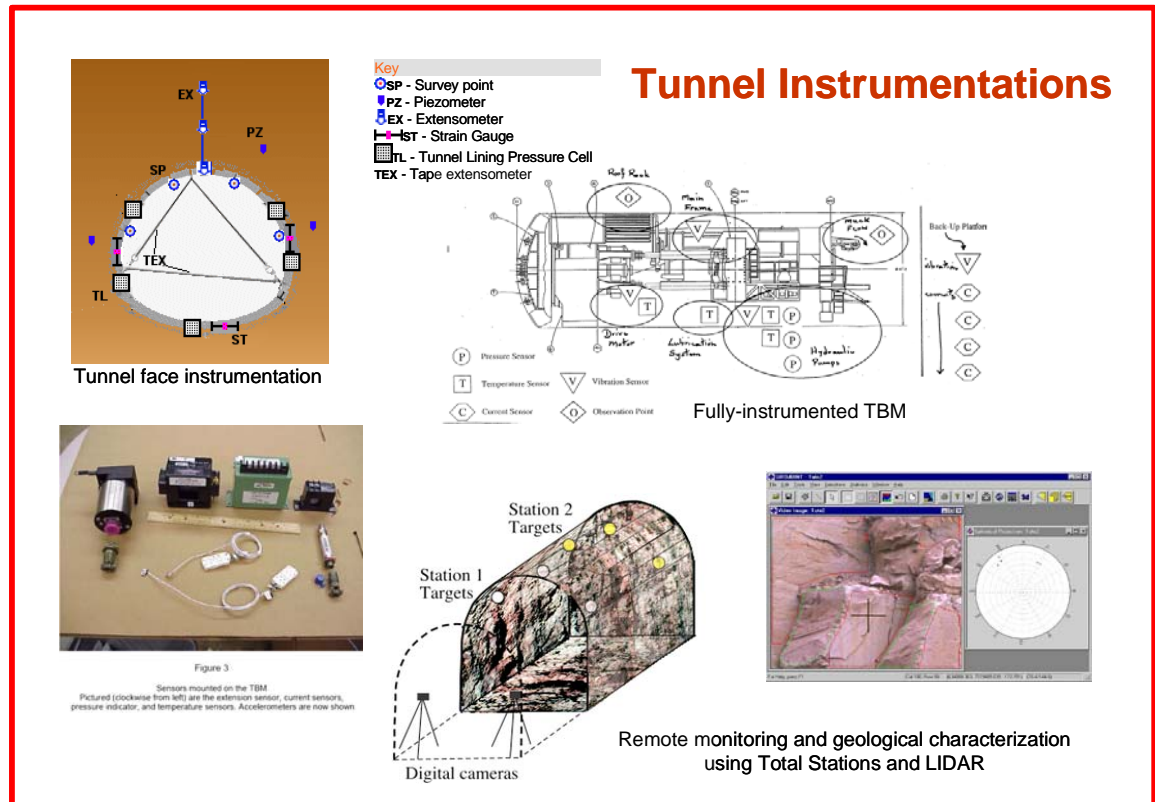
Figure 1 – Sensor technologies for remote and direct measurement of tunnel response during and after excavation.

11. TIME AND DISTANCE SCALING LAWS

When considering a fractured medium one automatically introduces a scaling effect. Hence, extrapolation of laboratory data becomes questionable. DUSEL will provide an intermediate scale between lab and EarthScope; hence, critical data to develop proper scaling laws.

An extensive body of knowledge has been generated in the laboratory on the behavior of rock materials. The experiments are often conducted on specimens of limited size, from few centimeters to very few meters, and over a short duration of time, from minutes to very few months. DUSEL offers the distinct opportunity to work at a large scale over an extended period of time where laboratory observations could be compared

with field measurements, and perhaps most importantly where differences due to scale and time effects can be detected and accounted for in a theoretical framework. At the deep underground site proposed a large a number of discontinuities (bedding) under the water table will be accessible for observation and testing. We propose to investigate long term effects on coupled flow and mechanical stresses related to the deformation of the rock matrix and to slip along selected discontinuities. Large scale testing can be accomplished by applying fluid pressure over a large volume of rock, of the order of 100 m^3, using the natural discontinuities of the rock as boundaries where pressure is applied. We envision three types of tests:

      1) long term where the objective is to gather information about stress, strain, and permeability relaxation over extended periods of time, of the order of years, and investigation of subcritical crack growth;

      2) short term where we induce hydraulic fracturing on the intact rock and slip along frictional discontinuities; and

      3) a combination of short and long term tests, focusing on slip and healing processes on frictional discontinuities. An array of borings can be drilled through the rock mass reaching the target discontinuities; some of the borings will be used to impose pressure conditions and others to monitor displacements, excess pore pressures, total stresses, and acoustic emission.

      The goals of the research are:

      1) validate laboratory experiments;

      2) quantify scale effects;

      3) quantify time effects;

      4) determine effects of slip on flow of fluids; and

      5) provide a theoretical framework for slip along frictional discontinuities.

Because of the known discontinuities, including the Narrows and St. Clair Faults, as well as bedding planes associated with sedimentary rocks, the Kimballton site is ideally suited for these experiments.

12 TEMPORAL STRESS-STRAIN STUDIES

An extensive body of knowledge has been generated in the laboratory on the behavior of rock materials. The experiments are often conducted on specimens of limited size, from few centimeters to very few meters, and over a short duration of time, from minutes to very few months. The results show that the strength of intact rock decreases with the duration of the test, that the rock creeps (under constant stress) or relaxes (under constant displacement) (Wyllie, 1992; Hudson and Harrison, 1997; Goodman, 1989). Shear tests conducted on bedding discontinuities on a sandstone-siltstone-mudstone sequence (Tan, 1993) with a duration of 1 to 1.5 months showed that shear strength of the discontinuities was significantly reduced with time. The opposite effect has also been found (Scholtz, 1990): discontinuities that had been sheared to their residual strength showed an increase of shear strength over time (healing). A complicating factor is that rock behavior is scale dependent. Strength and stiffness of rocks, rock masses, and discontinuities decrease as the size of the specimens increase.

Laboratory experiments conducted at Purdue University on rock specimens (Mutlu and Bobet, 2004, 2005) indicate that slip initiation along pre-existing frictional discontinuities (faults) can be well predicted following fracture mechanics theories. We have found that the critical energy release rate, GIIC, can be used as an indicator for slip initiation. However GIIC is not a material property, but strongly depends on the normal stress applied to the discontinuity, on the frictional properties of the slip surface, and on the slip required to decrease the frictional strength from peak to residual. Numerical experiments indicate that mode II loading (slip) in undrained conditions (a rapid process in saturated materials where no dissipation of excess pore pressures occurs) decreases the compressive and tensile stresses ahead of the tip of the fault, while the shear stresses remain unchanged, thus favoring mode II propagation over mode I. These observations have been made at the laboratory scale, and while we are confident that the fundamental mechanisms for slip initiation and pore pressure response to external loading have been well identified, validation at a large scale is required.

DUSEL offers the distinct opportunity to work at a large scale over an extended period of time where laboratory observations could be compared with field measurements, and perhaps most importantly where differences due to scale and time effects can be detected and accounted for in a theoretical framework. At the deep underground site proposed a large a number of discontinuities (bedding) under the water table will be accessible for observation and testing. We propose to investigate long term effects concerning coupled flow and mechanical processes on the rock matrix and on selected discontinuities.

Large scale testing can be accomplished by applying fluid pressure to the existing discontinuities over a large volume of rock, of the order of 100-1000 m3. We envision three types of tests: (1) long term, where the objective is to gather information about stress, strain, and permeability relaxation over extended periods of time, of the order of 10 to 30 years, and investigation of subcritical crack growth; (2) short term where we induce hydraulic fracturing on the intact rock and slip along frictional discontinuities; and (3) a combination of short and long term tests, focusing on slip and healing processes on frictional discontinuities.

An array of borings can be drilled through the rock mass reaching the target discontinuities. Figure 1 shows an schematic of the experiment layout. Some of the borings will be used to impose pressure conditions (see inset in Figure 1) and others to monitor displacements, excess pore pressures, total stresses, and acoustic emission. Different magnitudes of loading can be tried by increasing the pressure on the boreholes, and different volumes of rock can be tested by placing seals and packers at different locations along the borings and by increasing the number of boreholes that are pressurized. This setup allows one to run short term tests as well as long term tests by maintaining the fluid pressure over the period of time desired. With this method a discontinuity can be chosen and isolated with packers; as the discontinuity is pressurized, opening along the discontinuity, slip, flow, etc. can be monitored at a number of locations through the boring array. The system also offers flexibility as new borings can be drilled

when needed or when other experiments, not envisioned at the beginning of the project, are deemed necessary.
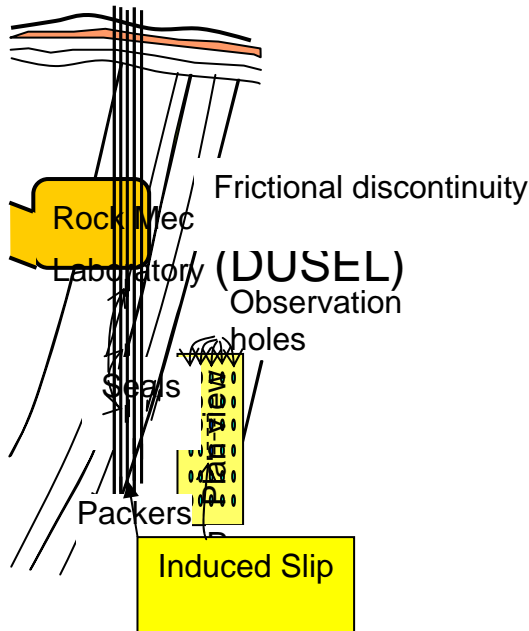
Figure 1. Schematic of experiments

Figure 2 illustrates how measurements can be obtained. Pressure transducers, strain gages, inclinometers, acoustic sensors, thermocouples, etc. can be placed at different locations along the boreholes to measure stresses, total and pore pressures, displacements, and acoustic emission on a large volume of rock surrounding the test area. The objective is to systematically and over a long period of time collect and store data in a format that can be easily accessed and interpreted through different disciplines.

Specimens of intact rock and of discontinuities can be obtained almost continuously during borehole drilling. Laboratory experiments and in situ experiments will provide the basis for comparison between laboratory and field scales. An added outcome from this research will be quantification of disturbance effects during sampling, as results from the laboratory are compared with actual in situ results.

The goals of the research are: (1) validate laboratory experiments; (2) quantify scale effects; (3) quantify time effects; (4) identify the mechanisms of slip along frictional discontinuities; (5) determine effects of slip on flow of fluids; and (6) provide a theoretical framework for slip along frictional discontinuities.

Results from this investigation will be relevant to a number of disciplines, including rock and materials engineering, geology, geophysics, earthquake engineering, and geological engineering,

Figure 2. Instrumentation
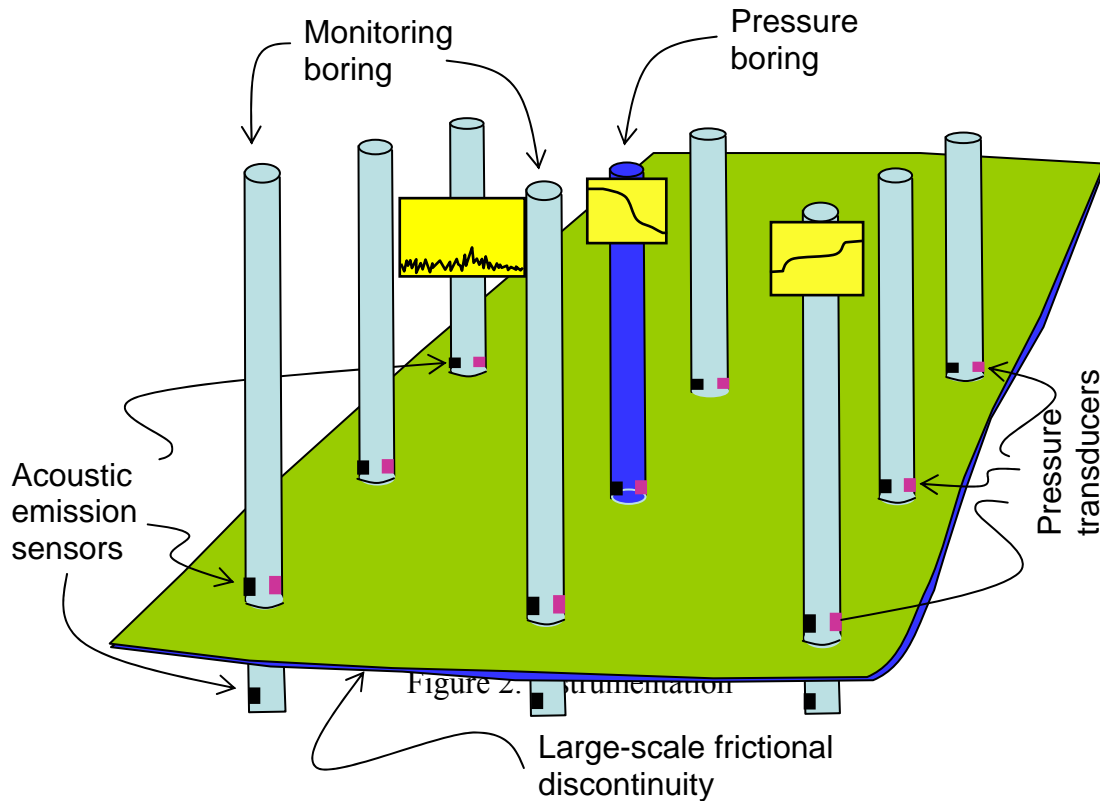
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12. MINING TECHNOLOGIES

The demand for minerals continues to grow, resulting in the need to extract them from greater depths. While mining is currently occurring at depths up to 3.5 km in South Africa, much research is needed to improve the safety and efficiency of deep mining operations. Alternative ventilation and hoisting techniques need to be developed. Additionally, valuable research for mining at any depth can be conducted at a long-term, dedicated facility. High-speed excavation and robotic operation are two examples of this. Another example of innovative research at a DUSEL site is the development of advanced monitoring techniques for excavation in highly-stressed rock. As mining extends to greater depths, support pillars are under increasing loads. This section of the proposal will describe an example of this type of experiment in greater detail.

Innovative monitoring methods, towards a "transparent Earth," are required to safely excavate in a highly-stressed rockmass. Prediction of rock failure has been an elusive goal for the geo-engineering community. Catastrophic failure extends to all aspects of rock mechanics including tunnels, mines, rock slopes, earthquakes, waste repositories, and bridge and dam abutments. Accomplishing the ultimate goal of predicting these catastrophic failures will result in significantly reduced fatalities, lowered construction costs, and increased environmental protection.

Rock failures (e.g. earthquakes) are associated with the redistribution and concentration of stresses due to excavation, gravitational forces, inhomogeneities, or crustal movement of the earth. To predict rock failure, it is quite helpful to monitor the redistribution of stresses within the rock. Recent computational power has allowed this to be done using elastic waves and tomographic imaging. The basic principal is that ubiquitous microfractures within the rock are closed under increased loading, allowing the elastic wave to travel at a greater velocity and with less attenuation (Terada & Yanagidani, 1986; Scott et al., 1993; Maxwell & Young, 1996; Westman et al., 2001). Using tomography to image this property, the redistribution of stress can be inferred, allowing identification of areas closer to failure. This has been shown clearly in the laboratory but has had only very limited testing at the field scale.

Computer tomography will be used to map stress changes and material properties ahead of the tunnel face during construction and within pillars as a long-term experiment. Seismic tomography uses seismic energy to obtain an image of the interior of a body. The common application is the CAT-scan used in the medical field, although the concept is nearly 100 years old (Radon, 1917). Tomography was eventually adapted to the medical field (Hounsfield, 1973; Cormack, 1973) and to the geosciences (Dines & Lytle, 1972).

For this project, seismic tomography will be used to image geologic structure ahead of the tunnel and stress redistribution in experimental pillars.

This experiment will put the method of imaging stress-induced changes within rock masses on a sound theoretical and practical basis. It requires a DUSEL, as deep, long-term, dedicated access is not available at current underground tests sites. Beyond the obvious direct applications, the project results will significantly assist educational efforts from the elementary level geology lessons to rock mechanics courses at the university level.

Laboratory studies will be conducted initially to calibrate field results. Elastic waves will be propagated through laboratory samples of rock from the field site, under several combinations of triaxial stress, simulating loading conditions at different depths. The influence of the loading conditions on the velocity and attenuation of the seismic wave in the lab will allow calibration of field data.

The *in situ* component of the experiment includes the construction of multiple pillars at different depths and the incorporation of tomographic monitoring results to predict failure. By constructing pillars at increasing depth, the effect of increasing stress can be clearly determined. At least three pillars will be constructed at approximate depths of 1000, 3000, 5000, and 7000 ft. *A distinct advantage of the Kimballton site is that several rock types can be tested at various depths, as shown in Figure X.*
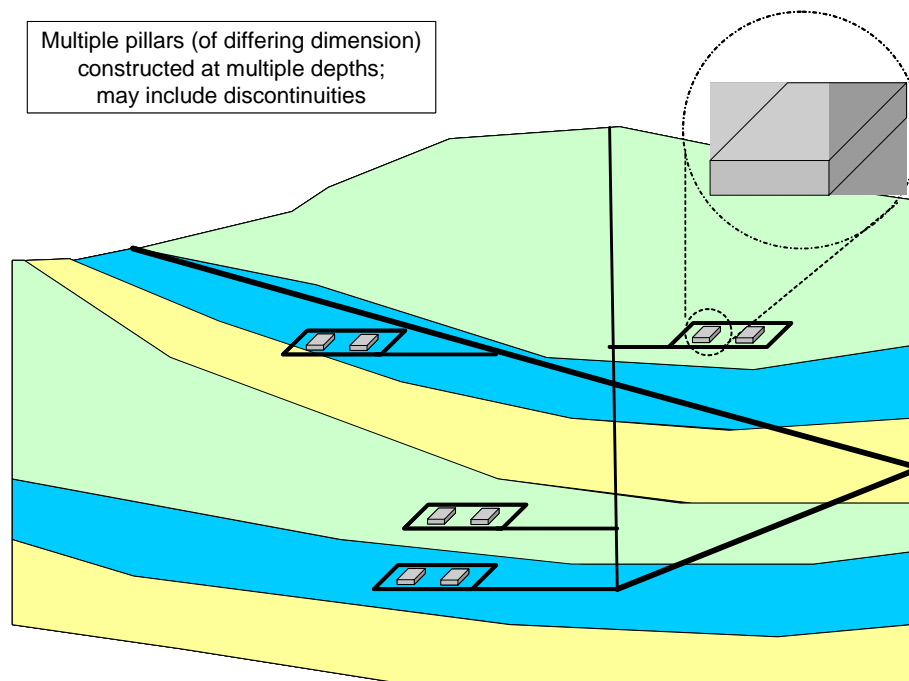
Figure X. Schematic diagram showing proposed layout of Transparent Earth: Stress Monitoring experiment.

13. GEOMICROBIOLOGY

The 2001 American Academy of Microbiology report on geobiology (Nealson and Ghiorse, 2001) emphasized needs for longterm studies of deep subsurface microbial ecology. The 2002 Earthlab report (>>>) identified subsurface microbial ecology, biogeochemical, and abiological processes as major foci for investigating life at depth.

Geomicrobiology at Kimballton draws its strength from intimately linked multi- and inter-disciplinary teaming at the project onset. Interdisciplinary planning and integration from project initiation ensures that the entire subsurface will be pristine upon joint bio-geo-DUSEL-activities building from the nearby Kimballton knowledge and infrastructure. All Kimballton drilling and coring campaigns will be coordinated and tagged with tracers to monitor and quantify and tag contacted fluids. Should that taggant fingerprint be encountered in future fluids, close scrutiny could determine their pristine vs. compromised characteristics. The tagging technologies will include drilling fluid tracers such as non-toxic ionic and mixtures of specific perfluorocarbon tracers. Cooperative linkages between the mechanic interdisciplinary investigations will continue throughout the characterization phase and will model multidisciplinary collaborations throughout the DUSEL scientific activities.

Geomicrobiology research proposed at Kimballton includes:
1) examining ecology of subsurface communities approaching the limits of life at great depth, high temperature, elevated pressure, low nutrient bioavailability, and after long term sequestration;
2.) investigating lithology, geochemistry and interface boundary constraints on subsurface ecosystems; and;
3) coupled biogeochemical processing, scaling, fluid transport, and energy flux along with their associated impacts on biologic phenotypic and geneotypic adaptations or alterations. Two phases of research are considered: site and construction characterization lasting ~ 10 years overlapping with and followed by longer term DUSEL science from ~2010 thru 2030.
These are discussed below in further detail.

1)   Ecology of subsurface communities approaching the limits of life at great depth, high temperature, elevated pressure, low nutrient bioavailability, and after long term sequestration.

Angled and vertical drillings from conduits and deep DUSEL laboratory spaces will interrogate disparate subsurface microbial communities extant in the hydrologically and geologically isolated sedimentary rocks, fractures and pore fluids. Deepest penetrations will approach the $120^{o}C$ isotherm, likely coring less than 3 km beneath the lowermost laboratory. Importantly, because we tagged all holes and fluids penetrating the deeper formations at Kimballton, we can certify the pristine nature and lack of human or meteoric inputs into the deep subsurface microbial community and ancient waters.

This 'greenfield' attribute with ancient pristine waters at the temperature limits of life is a unique advantage of the geo-micro- collaborations at Kimballton. The limits of life will investigations will characterize the pristine and ancient environments using 21st century microbiological, molecular, genomic, geochemical, and isotopic tools quantifying the community size, structure, diversity, ecophysiology and energy flux, resources, and ecological genomics of the extant ecosystem. Novel organisms, genes, and products will be new resources for biotechnology exploitation and provide insights into the commonality of gene evolution and origin.

Unique to Kimballton are repeating units of the same formation at greater depth, pressure, temperature and compaction. Consolidated carbonates, clays and silts are folded and buried such that the same lithological units are repeated with depth. These Kimballton attributes offer a unique opportunity for *in situ* examination of T, P, and depth within lithological structures.

Core and bore holes for site characterization and construction of underground plus excavations will provide numerous coordinated interdisciplinary explorations. Deep coreholes from the deepest underground laboratory will access the ancient water and approach the limits of life. It is hypothesized that organic rich shales may exhibit better microbial preservation and ecology than dense low permeability carbonate rocks. Within the rock strata the biogeochemical processing may be dominated by the fractured higher fluid flux zones. The extant microbial communities and their genomic complements will be libraried for potential exploitation in biotechnology as well as in coupled process experiments below.

One hypothesis developing from S. African investigations is that there may be a shift from diverse anaerobic heterotrophic communities to low diversity communities dominated by anaerobic autotrophic after the electron donors shift from photosynthetically derived and deposited electron donors to abiogenic produced geogas derived from water-rock interactions and radiolysis.

2.) Investigating lithology, geochemistry and interface boundary constraints on subsurface ecosystems; and associated biogeochemical processes.

Kimballton's multiple repeating units of heterogeneous sedimentary rock offers a unique opportunity to examine the roles of interfacial boundaries as controlling entities of subsurface ecosystems. Clay and silt formations with elevated organic carbon will be a source for the dissolution of organics (Chapelle). The carbonate units may provide minerals and nutrients with water fluxing between fractures and along the interfacial boundaries. Within the individual repeating units the lithology, compaction, fracture density and size as well as flow may pose limitations on biomass, diversity, and microbial activities. Geochemical differences in ionic strength, metals and radiolysis (eg., K, U) may well constrain the microbial ecosystem and its functioning.

From deeper depth, temperature and pressure abiotic rock-water interactions produce reduced gases such as methane, carbon monoxide, ammonia, and or hydrocarbons (geogas) (TC,….) .

Recent advances in ecological uses of genomic libraries and microarrays coupled with proteomic and metabolomic characterizations enables ecogenomics examination of the important genes within ecosystems and understanding how those genes and their gene products result in biogeochemical processing. Accordingly all genes, clones and products will be libraried and available for bioprospecting, biotech and gene evolution analyses. Longterm isolated subsurface communities have adapted and evolved, but the extent and rate are not understood. Developing 21st century technologies enable identification of slight evolutionary alterations in genes and functions, their produced proteins and macromolecules and ultimately differential impacts of organismal functions.

3)   coupled scaling, transport, water, and energy flux processes with their associated impacts on biologic phenotypic and geneotypic adaptations or alterations.

Kimballton's multiple and repeating interfaces provides a unique contrast for scaling impacts, greater than other DUSEL sites combined. Interfaces are known to harbor orders of magnitude greatest flow and flux than competent materials deep within strata. The numerous interfaces at Kimballton site maximizes opportunities for examining interfaces and comparisons with competent bulk strata. Scaled experiments will examine coupled bio-, geo-, hydro-, physio-logical and chemical processing at the mm to >10 m and up to km scales. With depth, formational changes, and increasing temperature and pressure the coupled reactions change as will contrasts between the bulk and interfacial zones. It is hypothesized that the bulk of the diversity and >3 orders of magnitude more reactivity are anticipated in the interfaces as compared to reactivity in bulk strata. Within lithologically similar strata depths, T, P and scale may well impact and correlated with strata integrity and quality. With increasing D, T, P, and compaction will result in less and poor quality bioavailable organics. Outcomes will include less biomass and lower microbial activities and lower growth rates with long life spans. It is hypothesized that metabolic plasticity enabling populations to tightly couple syntrophic relationships with communities gaining advantage from multiple electron donors, and acceptors. Biogeochemical coupling also extends to the dissolution/nucleation and precipitation of minerals and would be integral to the natural and perturbed water-rock-microbe interactions in reservoirs, petroleum deposits, and perturbed blocs.

No other DUSEL site has this comprehensive deep pristine environment with heterogeneity. Additionally, the low thermal gradient at the site allows more samples to be retrieved for each targeted isotherm.

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See also Earthlab report (link in Appendix M)

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Appendix E: Supplementary Science Book
Physics

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A plan for physics in the next decade in DUSEL has been developed with a portfolio of specific science directions in several recent physics and astronomy surveys including:

1. the ongoing NSF S1 Solicitation process
    (http://www.dusel.org)
2. the APS Study on Neutrino Physics (2004)
    (http://www.aps.org/neutrino/)
3. the National Research Council Report of the Neutrino Facilities Assessment Committee (2003)
    (http://books.nap.edu/catalog/10583.html)
4. the National Research Council Report on "Connecting Quarks with the Cosmos" (2002)
    (http://books.nap.edu/catalog/10079.html)

The Kimballton team of physicists has actively contributed to the above reports, particularly the S1 process and the APS study. Their experience in this science is based on participation in and development of the concepts and the science and technology of almost every major underground experiment world-wide.

The S1 process has identified an array of frontier physics/astrophysics questions such as:

- search for proton decay
- CP violation in the neutrino sector probed by long baseline high energy neutrinos
- the fundamental nature of neutrinos (Majorana/Dirac) probed uniquely via double beta decay
- the precise formulation of the neutrino mass/mixing matrix using neutrino beams from terrestrial devices and the sun
- real-time spectroscopy of proton-proton solar neutrinos and measurement of the neutrino luminosity of the sun
- probing the nature of dark matter in the Universe
- interior structure of the earth probed by antineutrino emission from U and Th and other sources inside the earth
- detailed astrophysics of stellar explosions via neutrino observations
- observation of supernova relic neutrinos.

Typical experiments called out in the S1 process that address these questions fall into broad classes of size of detectors/experiments, technology and optimum depth. Solar neutrino detectors are of medium size (100-1000 tons), using a variety of conventional and cryogenic technologies and they require depths of 2000-4500 mwe. Double beta decay experiments, as well as dark matter detectors, are relatively small (<1 ton), use a variety of detection technologies, (particularly those based on cryogenics) and need a deep site (>6000 mwe). All the other topics above need very large (100 kilotons -1

megaton) devices based on water Cerenkov, liquid scintillation or liquid argon technologies operating at moderate depths (~4000 mwe). The open nature of the questions and the high cost of experiments such as the large scintillation and Cerenkov detectors stress designs that permit multi-science functions. They are thus designed to be sensitive to long baseline detection of high energy neutrinos from terrestrial accelerators situated at optimal distances and for proton decay searches, geophysics and supernova astrophysics and cosmology. The Kimballton-DUSEL laboratory is being designed to accommodate any of the physics experiments envisioned in the S1 infrastructure matrices.

In addition to the broad requirements listed above, there are specialized requirements for particular experiments - low radon background from surrounding rock, adequate clean facilities, and capability for handling large volumes of cryogens. The existing Kimballton mine already has stable, old caverns up to 15 x 30 x 100 m in size at a depth of 1700-2300 mwe that have adequate electrical services. Experiments can already be accommodated in such caverns—e.g., a pp-neutrino sensitive solar neutrino detector (such as LENS, see below). Our conceptual design plan will include a main laboratory at 4500 mwe depth that will provide facilities for the typically large multifunctional experiments (such as HSD, see below). A deep laboratory at 7500 mwe depth will potentially house experiments up to 15x15 x 15m, e.g., dark matter and double beta decay experiments (see S1 report).

The planning of the DUSEL-Kimballton laboratory will accommodate an initial suite of experiments under the guidance of the S1 process and a Kimballton Science Advisory Committee from a slate of experiments identified by normal review processes. The likely requirements in the longer-- 30 year-- outlook will depend on what we learn from experiments in the short term. Future experiments will likely require even larger detectors than those presently discussed. A conscious effort will be made in the design layouts to allow for expansion of the facilities for future science.

The Kimballton-DUSEL physics team has been actively developing specific physics experimental projects for some time, independent of the DUSEL developments. The physics questions addressed in these projects cover almost every topic in the S1 list above. The team is especially excited and enthusiastic about Kimballton-DUSEL because it brings an attractive new dimension to these plans by the proximity of the mine to several home laboratories of the team. This important aspect will obviously enhance intellectual and technological activity in a variety of tangible and intangible ways. Some of the projects of interest are described below.

Double-Beta Decay to Excited States
(TUNL, Duke U)

In order to extract a value for the neutrino mass from zero-neutrino double-beta decay ($0v2\beta$) data, information on nuclear matrix elements (NMEs) is required. There is an important distinction between theoretical models used to predict nuclear matrix elements

for double-beta decay (2ν2β) transitions to the ground state and those that estimate NMEs for transitions to excited final states. The ground-state matrix elements are, in general, functions of the proton-neutron particle-particle strength parameter g_{pp}. The strong dependence on g_{pp} grants a large amount of freedom to a given model in choosing an appropriate value of g_{pp} in such a way that the model's predictions for decay half-lives conform to experimentally measured half-lives. On the other hand, 2β transitions to excited final states involve NMEs that are much less sensitive to g_{pp}. Therefore, a measurement of the half-life of the 2ν2β decay to an excited 0^+ final state constitutes a more severe test of theoretical models, while at the same time making these transitions easier to predict.

Recently, it was proposed that the Pauli exclusion principle may be violated for neutrinos, and consequently, neutrinos obey at least partly the Bose-Einstein statistics. Bosonic neutrinos may form the cosmological Bose condensate which may account for all (or part of) the dark matter in the universe. The "wrong" statistics of neutrino has far reaching consequences. The possible violation of the Pauli principle for neutrinos can be tested in the 2ν2β decay. One of the most sensitive tests is the ratio of the transitions to the excited 0^+ state and the ground state.

The ground state 2ν2β transition rate has been measured very well for ^{100}Mo. At Kimballton-DUSEL we plan to improve the measurements for the half-life of the transition to the excited 0^+ state by detecting the 539.5 keV and 590.8 keV gamma rays in coincidence (see Fig.1). Currently, such an experiment is being performed on ground level in the basement of the Duke Physics Department. A move of the existing apparatus (Fig.2) to Kimballton will greatly improve the background observed in the present measurements, resulting in a much improved determination of the present value

$$T_{1/2}(0\nu + 2\nu) = [\,5.0\ ^{+1.0}_{-0.7}\ (\text{stat}) \pm 0.5\ (\text{syst})\,] \times 10^{20}\ \text{years}.$$

Due to the coincidence requirement a large depth is not required in order to reduce the cosmic-ray induced background to the required level. Therefore, even the existing caverns at the Kimballton mine are ideal for this type of experiment.
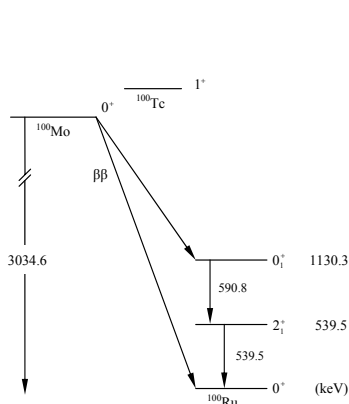
Figure 1. Level scheme of ^{100}Mo double-beta decay.
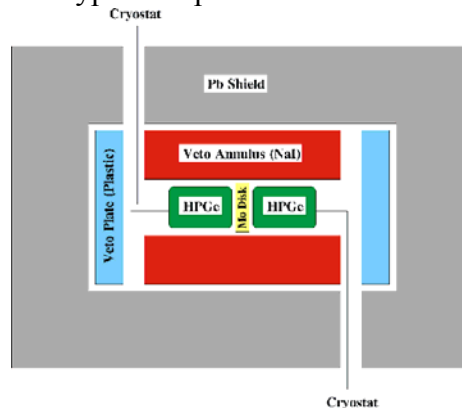
Figure 2. Double-beta decay apparatus consisting of two HPGc detectors with Mo-disk, NaI annulus and plastic scintillators (active cosmic-ray veto) and Pb shielding.

Astrophysical Nuclear Reaction Studies Underground
(A. Champagne (UNC), Jeff Blackmon (ORNL)

Stars spend most of their lives producing energy quiescently through a series of rather well defined stages of nuclear burning. The ashes left behind are what cause stars to evolve and thus nucleosynthesis is a key ingredient in studies of stellar structure and evolution. Measurements of nuclear reactions are combined with stellar models to interpret observations of elemental and isotopic abundances in stars, the interstellar medium, meteorites, etc., which then provides information about the inner workings of stars that is not directly accessible. This work has implications beyond the scope of stellar astrophysics. For example, one way to study the evolution of galaxies is through analyses of stellar populations. Stars can provide information about the timescale for formation of structure in the universe. The latter stages of stellar evolution can be used as a laboratory for fundamental physics. All of this is ultimately based on some understanding of stellar evolution. The improving precision and sensitivity of these observations have revealed very detailed information about stellar interiors and a number of surprises, and represents a major challenge to nuclear physics. The cross sections of interest are incredibly small and experimental sensitivity is severely limited by cosmic-ray induced backgrounds. An underground laboratory therefore provides an ideal environment for low-energy accelerators designed to measure nuclear astrophysics cross sections.

Every reaction to be measured presents unique technical challenges and no single approach is guaranteed to work in every case. Therefore, an underground accelerator facility must be flexible in the beams and energies that it provides. For this reason, we envision 2 separate, complementary facilities. The first would be a high-current (10 mA pulsed), low-energy (< 300 keV) proton accelerator. This is intended for measurements where the physics demands very low bombarding energies and where beam-induced backgrounds are not a limitation. The second facility would be a heavy-ion accelerator, capable of producing beams of up to 0.2 mA with energies of up to 6 MeV, for measurements in inverse kinematics (for example, shown in Fig. 3). This accelerator would be coupled to a high-efficiency recoil separator. This system would be used for measurements where a clean tag on the residual nucleus is required to improve sensitivity. Both accelerators would be instrumented with a suite of detector and target systems that could be configured to suit the needs of a particular measurement. The laboratory would be located at a depth of at least 3,000 mwe and would occupy a volume of 15 x 20 x 5 m^3 (L x W x H).

Fig 3 One possibility for a heavy-ion accelerator is a single-ended Dynamitron similar to that shown here.

LENS-Sol
[Hahn, Min-fang Yeh, Garnov (BNL), Benziger (Princeton U), Champagne (UNC), Galindo-Urribari, Blackmon, Gomez (ORNL), Barabanov, Gurentsov, Kornoukhov, Bezrukov (INR Moscowa) Gavrin, Abdurashitov, Kopylov (INR Troitsk); Raghavan, Vogelaar, Pitt, Grieb, Zhang Chang (VT)]

The aim of LENS-Sol is to directly observe the low energy (<2 MeV) spectrum of solar neutrinos including those from the basic pp-fusion in the sun and thereby make a precision measurement of the neutrino luminosity of the sun. The result impacts with high discovery potential on topics in particle physics [neutrino phenomenology (tests and improved precision of the neutrino-mass mixing structure, neutrino magnetic moment), non-standard interactions in particle physics, CPT invariance] as well as solar astrophysics (precision tests of solar models including search for hidden sources of energy other than fusion reactions in the sun). While LENS-Sol operates via CC-based neutrino detection (only electron-flavor) other pp-neutrino sensitive experiments have been proposed [CLEAN (http://mckinseygroup.physics.yale.edu/clean/) , HERON (http://www.physics.brown.edu/physics/researchpages/cme/heron/LTD_home.html)] based on electron-scattering.

The LENS-Sol experiment is based on the neutrino capture reaction with the element indium (with 96% of the isotope A=115) that presents a low threshold of only 114 keV for the capture. The reaction is favorable because it yields: 1) the incident neutrino spectrum directly with the spectrum of the electrons emitted following neutrino capture since $E_e = E_\nu$ -114 keV; 2) The low threshold enables observation of the pp neutrinos (0-420 keV); 3) the capture reaction supplies a unique tag of the neutrino capture reaction via the delayed coincidence of a cascade of two gammas that follow neutrino capture. The experimental spectrum observable in this reaction is shown in Figure 4.

The major background arises from the natural radioactivity of indium via emission of bet-rays with a maximum energy of 500 keV. In particular, bremsstrahlung (BS) of these betas can seriously mimic the neutrino capture tag The problem of suppressing this

background has recently been solved via two major breakthroughs: 1) the development of a high-quality In-loaded liquid that combines a). sizable In loading ~8%; b) high scintillation efficiency (40-60% of the solvent light efficiency; c) very long light transmission lengths ~8m; and d) chemical and optical stability over periods ~1 year and 2) Analysis strategies that effectively exploit the assets of the liquid scintillator above. The experimental arrangement envisages an In mass of ~20 tons and scintillator mass of some 300-400 tons. The experiment can be performed at relatively moderate depths of ~2000 mwe without interference from cosmogenic backgrounds.

The detector is modular, based on an array of longitudinal modules. A conceptual design achieves this design in a tank of the scintillator that contains a cage of light pipes (see Figure 5) The optical segmentation is made via multilayer foils that pipe light via both total internal reflection and specular reflection to photomultipliers at either end of the tank.

Solar Nu Signal Spectrum (SSM-LoCNO)
(Det Eff Incl: pp 0.35; Be 0.85; pep 0.9;
N13 0.85; O15 0.9) Det. Res Incl.
600pe/MeV)
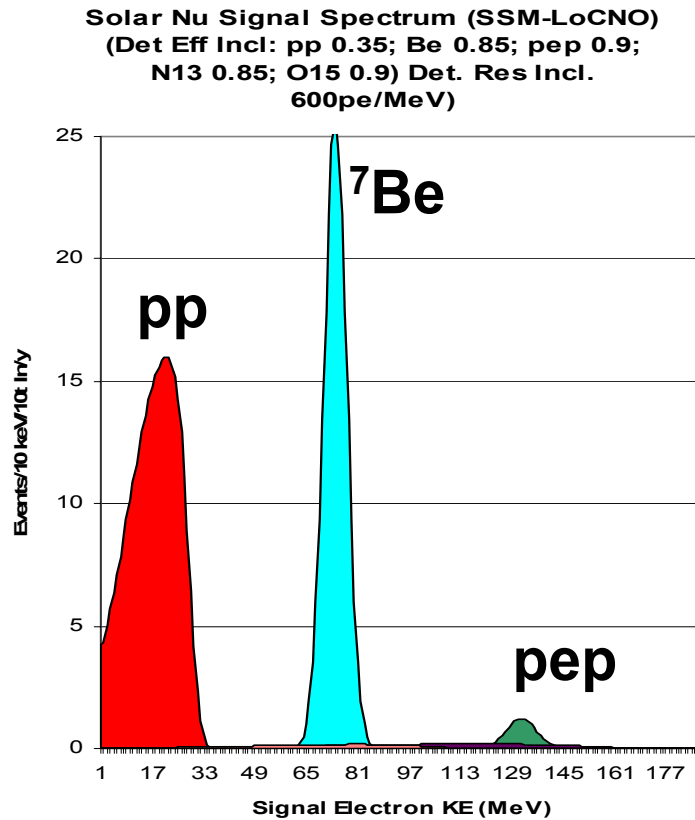
Figure 4: Solar neutrino spectrum observable in practice in LENS-Sol
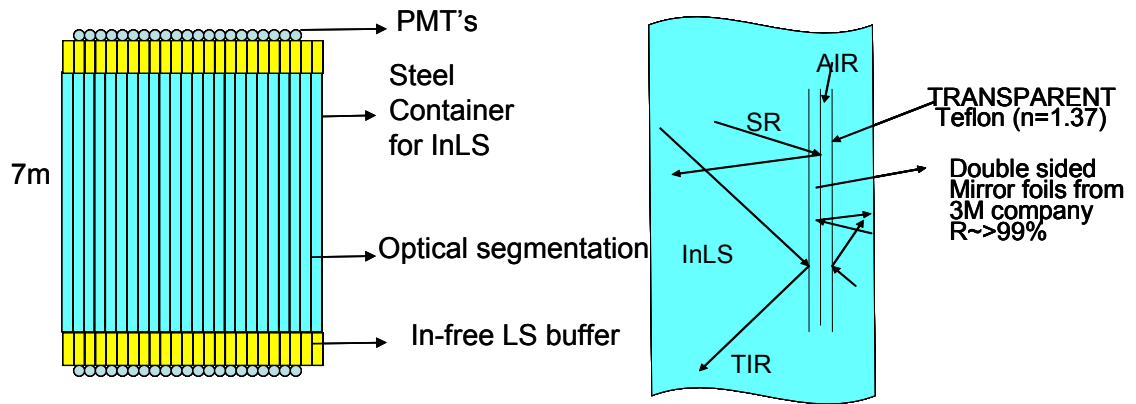
Figure 5: Conceptual design of LENS-Sol. The optical segmentation in the detector tank is achieved by a cage of light pipes that convey the signal light to the PMT's via TIR and specular reflection.

Hyper Scintillation Detector (HSD):
[Learned, Pakvasa (U Hawaii) Svoboda (LSU) Feilitzsch, Oberauer (Tech. U. Munich), Scholberg (Duke U), Vogelaar, Pitt, Takeuchi, Lay Nam Chang , Raghavan (VT)].

The objectives of the detector will cut across a wide swath of frontier questions in basic science that can be answered only by a detector of this type. The science portfolio of HSD includes topics in:
1. Geophysical structure and evolution of the Earth studied via global observation of anti-neutrinos from the earth's interior
2. Supernova astrophysics   and cosmology (observation of live supernovae; detection of the supernova relic background)
3. Elementary particles: (deep search for the decay of the proton; long baseline experiments using high energy neutrinos from BNL or Fermilab.

The basic advantages of this multi-disciplinary scintillation approach are:
1) sensitivity to events of *both low and high energy,* ranging 4 orders of magnitude from ~100 keV to ~1 GeV;
2) high sensitivity to heavy particles that are invisible in Cerenkov detectors;
3) high sensitivity to antineutrinos that can be specifically tagged by capture on protons (of importance to all the above topics).

The concept of a very large detector of this kind can be best justified if it is shown to address a wide swath of frontier questions in several disciplines. The HSD satisfies this criterion exceedingly well. The science questions 1) and 2) can be addressed only in a scintillation type device sensitive to low energies (as opposed to Cerenkov or liquid argon technologies. In addition it brings comparable sensitivities to question 3) with a detector mass some x10 smaller than a Cerenkov detector.

Geophysical Neutrinos in HSD

The fundamental aim of this research is to determine the validity of present geophysical models via "whole earth" data. The key foundations of the present model are 1) the heat budget of the earth; and 2) the distribution of radioactive elements in the earth's interior; 3) the relative abundance of U, Th conforming to solar system abundances.

Geophysical antineutrino research is at the same stage as the beginning of solar neutrino research for understanding the solar interior with the advantage that powerful detection technology already developed in the context of the latter are now at hand. The above objectives are uniquely well served via a network of massive antineutrino detectors placed suitably at favorable locations The proposed HSD with 100 kT of LS will be the most massive detector. Current estimates show that in the main campus of the Kimballton-DUSEL at a depth of ~4000 to 4500 feet, it may be possible to reach an antineutrino flux sensitivity down to a few antineutrinos/cm^2/s even at ~5 MeV.

The earth is a rich source of antineutrinos of energy 0-10 MeV that are observable in HSD with high discrimination against background because of the availability of a secure delayed coincidence neutron that can tag the positron signal of the antineutrino capture reaction on protons in the scintillator.. The geophysical sources are listed in the Table below and illustrated in Fig. 6

Source of Antineutrinos	Location
Radioactivity of U and Th	Crust, Mantle
Fission Reactor?	Core
Commercial Power Reactors	Surface
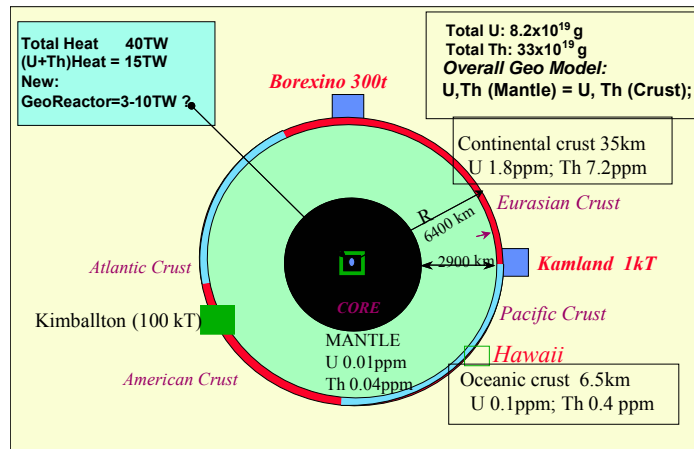
Fig. 6 Internal Energy Sources in the Earth and their Distribution
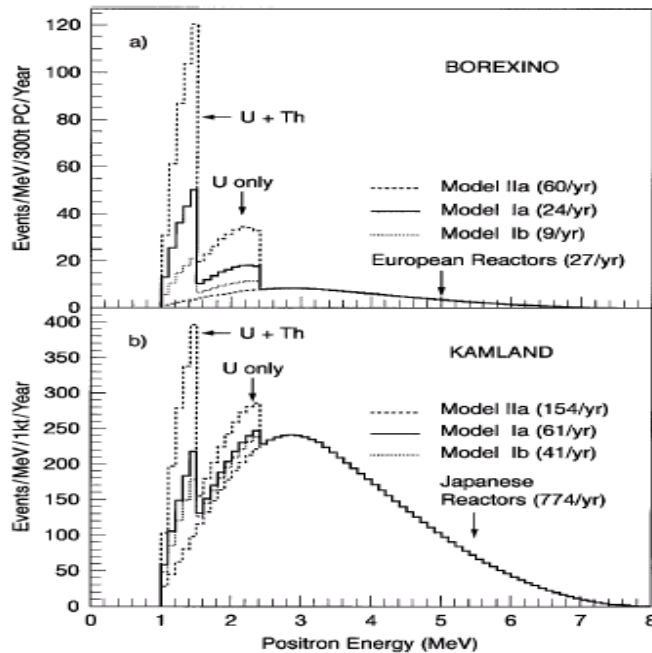
FIG. 2. $\bar{\nu}_e$ (positron) signal spectra from the Earth and from nuclear reactors at Borexino (a) and at Kamland (b). The signal rates point to several years of measurement for data of statistical significance to different aspects of geophysical interpretation.

Reactor bg/Kt/yr

Kamioka: 775
Homestake: 55
WIPP: 61
San Jacinto: 700
Kimballton: ~100

(RSR et al PRL 80 (635) 1998)

Fig. 7 Antineutrino spectra predicted for different geophysical models in BOREXINO and KamLAND.

Antineutrino spectra predicted by different models of the U, Th distribution in the earth are shown in Fig. 7. The spectra also depend on the location of the detector. The Kamioka location, while interesting because it is at the interface of continental and oceanic crusts, suffers from the close proximity of powerful surface nuclear reactors. The Borexino detector will have low reactor background, however it has too low a target mass to be sensitive to low fluxes in certain models. The background at Kimballon-DUSEL is expected to be low enough and the detector mass large enough to produce definitive results on the geophysical neutrino problem.

Supernova Astrophysics & Cosmology in HSD

a) Live Detection of Supernovae (SN): SN1987A showed the astrophysical importance of observing ν emission from exploding stars. The next observation needs to be much more detailed with spectroscopic inventories of the different types of neutrino species emitted in these events. The large mass of HSD makes an ideal SN ν detector with the following neutrino detection modes:

1) Antineutrino capture on protons can deliver the $\bar{\nu}_e$ component.
2) NC excitation to T=0 states in ^{12}C (15 MeV) in the LS facilitates the detection of neutrinos of all flavors.
3) ν-electron scattering (ES) provides a signal based on both NC and CC.

The SN burst is the overall tag for all these events. Individual tags available in the above reactions (except ES) help separate the flavor components of the neutrino emission. Thus a complete inventory of ν species can be made of a future SN event.
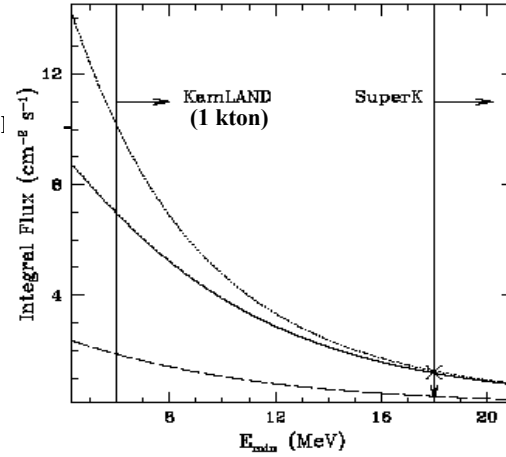

Fig. 8 Integral rates of supernova relic antineutrinos above a threshold E_{min} for different SRN models (L. E. Strigari et al, astro-ph/0312346). Relatively higher rates at low energies (inaccessible to SuperKamiokande) are observable in HSD (x100 larger detector mass compared to Kamland). It is the low energy rates that are sensitive high cosmological red shifts.

d) Supernova Relic Neutrinos (SRN):

The occurrence of SN that produces a ν flux detectable in earth devices is relatively rare. However, there should exist a diffuse, isotropic background flux of relic neutrinos from all *past* Type II SN (SNII) in the observable universe that could provide a new source of information on a) the basic picture of core collapse of SNII not only locally but also at high red shifts (z>1); b) the rate of occurrence of SN (proportional to star formation rate and the metal enrichment rate). The low SRN fluxes mandate detection of only the $\overline{\nu}_e$ component of the flux. Thus large detectors such as SK, KamLAND can be considered for the purpose, with the new possibilities available from HSD.

The spectrum of SRN, (see L. E. Strigari et al, astro-ph/0312346), is a typical Fermi-Dirac shape extending up to 30 MeV with integral fluxes >10 MeV typically in the range of 2/cm^{2}s. The interesting part of the spectrum is at low energies because of the sensitivity to red shifted $\overline{\nu}_e$ from far away SN and also because of the higher fluxes available in that window. However, the window contains also higher background. Thus, main advantages of HSD come into serious play in the problem. Fig. 8 shows the sharp increase in the integral SRN flux detectable in low threshold detectors such as KamLAND. It is estimated that KamLAND could make a 1σ detection of the SRN in 5ktY of data. The x10 target mass of HSD and its powerful $\overline{\nu}_e$ tag could reduce the time-to-discovery to <1yr of counting. HSD thus offers the greatest potential for the discovery and spectroscopy of SRN.

Proton Decay in HSD and other Large Detectors based on Cerenkov and Liquid Argon Technologies)

Large detectors (such as UNO and LANDDD) have been proposed for the rarest of events of interest to particle physics—viz. proton decay. Details of such proposals are accessible at: (UNO: http://ale.physics.sunysb.edu/uno/, LANDDD: http://puhep1.princeton.edu/~mcdonald/nufact/nrc_lanndd.pdf)

In this section we stress features particular to HSD. The main advantages in the scintillation approach to proton decay comes from:

1. The scintillation signal is x50 larger than the Cerenkov signal. Thus low energy spectroscopy of events down to 100 keV in energy becomes possible..
2. Heavy particles with energies below the Cerenkov threshold (see table below) can be observed with high sensitivity.
3. Low energy cascades correlated in time and space are particularly valuable for observing complex reactions cleanly and with low background.
4. Ultrapurity of organic LS solvents is technically much more feasible than water.
5. The technology of LS is established with >50years of experience and kton class detectors have been constructed and operated (comparable to Cerenkov and in contrast to LAr technology).

Triple Tag for p→K⁺ + $\bar{\nu}$

K⁺ (T=105 MeV)

↓

63.5%   12.8 ns   21%

↓   ↓

μ+ ν (T μ+ = 152 MeV)   π⁺ π⁰ (T π⁺ =105 MeV)
                             (T γ 135 MeV)

↓   ↓

2.2 μs   2.2 μs
e⁺ νν   e⁺ νν

Typical Cerenkov thresholds
- **Electron T=0.262 MeV**
- **Gamma E=0.421 MeV (Compton)**
- **Muon T=54 MeV**
- **Pion T=72 MeV**
- **Kaon T=253 MeV**
- **Proton T=481 MeV**
- **Neutron T~1 GeV (elastic scatter)**

The relevance of HSD to proton decay can be illustrated by its application to observing the prominent decay mode p→K ν(bar) (see table above). Observation of this mode in the Cerenkov approach suffers from the fact that the initial K is below threshold and the only

means is via the $\pi^+ \pi^o$ mode where the π^+ is just above threshold so that one depends heavily on the electromagnetic shower of the π^0 supplemented by the 6.3 MeV γ emitted when a proton hole state in ^{15}N. The efficiency then drops to ~8% so that one requires very large masses ~1 Megaton. The scintillation approach offers direct "gold-plated" events with a triple tag (see figure above) that allows all the members of the K and its decay cascade to be observed from proton (or neutron) decay. The efficiency is improved by ~x10 so that a 100 kT detector may be viable.

The additional low energy facility for proton decay arises uniquely in HSD from low energy sensitivity. A new approach to nucleon decay free of specific modes is to look at the highly excited residual nucleus (e.g. ^{11}C following neutron decay). The residual nuclei reach the low energy and ground states providing time-space correlated radiation that can tag the entire decay regardless of specific modes.

Long Baseline Neutrino Oscillations

The recent discovery of neutrino masses and mixings through solar, atmospheric, and reactor neutrino oscillation experiments has provided new clues to solving the mysteries of the Standard Model. Flavor mixing in the lepton-sector, together with the well-known mixing in the quark-sector, may lead to a new understanding of what `flavor' is, why there are three generations of fermions, and where their mass hierarchy comes from. CP violation in the neutrino-sector could potentially be large enough to account for the matter-antimatter asymmetry in the universe. A precise knowledge of the masses and mixing parameters will point to the higher energy theory that would explain, and replace, the Standard Model.

Assuming three-generation mixing, neutrino oscillations are sensitive to six parameters[1]: three mixing angles: θ_{12}, θ_{23} and θ_{13}; two mass-squared differences: $\delta m^2(21)$, $\delta m^2(23)$ and the CP-violating phase: $\delta(CP)$. Our current knowledge of these parameters is summarized as [2,3,4]: $\delta m^2(21),=(7.1^{+1.2}_{-0.6})x10^{-5}$ eV^2; $\delta m^2(23) = (1.9\sim3.0)x10^{-3}$eV^2; $\tan^2 \theta_{12} = 0.42\pm0.1$; $\sin^2 2\theta_{23} = 0.9$; $\sin^2 2\theta_{13} <0.1$ with $\delta(CP)$ completely unknown. In order to measure these parameters with better accuracy and also to determine the yet unknown sign of $\delta m^2(23)$ and the value of the CP-violation phase $\delta(CP)$, several long-baseline (LBL) neutrino oscillation experiments are being planned which will observe the appearance of flavor converted species from ν_μ and $\nu_{\mu(bar)}$ beams created at accelerator facilites such as Fermilab, BNL, CERN, KEK, and JPARC.

Determining the sign of $\delta m^2(23)$ and the value of $\delta(CP)$ requires the detector to be placed at one of the appearance peaks which occur at

$$1.27[\delta m^2(23)(eV^2)L (km)]/E_\nu(GeV) = \pi(n+1/2)$$
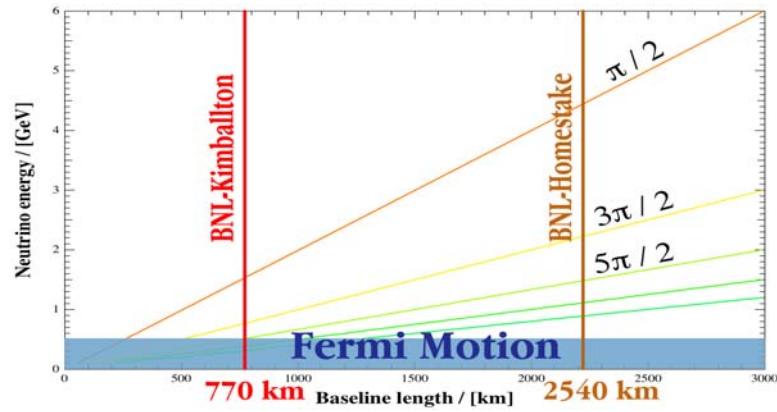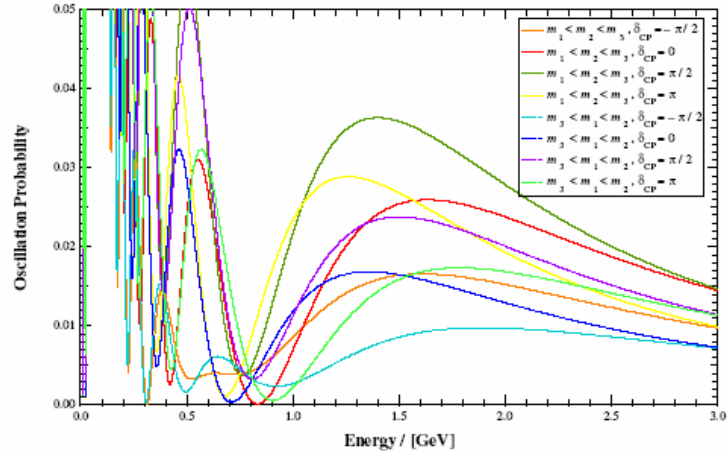
Fig. 9 (upper) Baseline length vs. neutrino energy relation. (Lower) ν_μ -->ν_e oscillation probability for a BNL-Kimballton experiment vs. neutrino energy
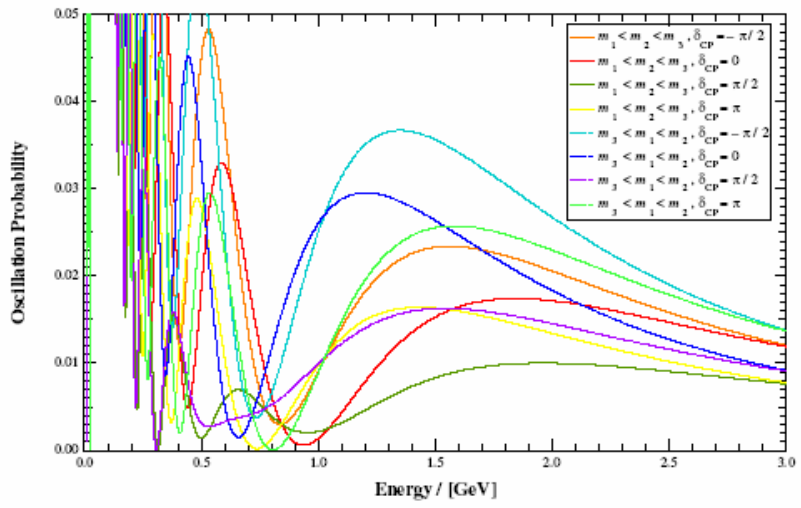

Fig.10 ν_μ(bar)$\rightarrow$ ν_e(bar) oscillation probability for a BNL-Kimballton experiment

13

For $\delta m^2(23) = (1.9\sim3.0)\times10^{-3} eV^2$ and L=770 km, the distance of Kimballton-BNL, the first appearance peak (n=0) occurs in the energy range $E_\nu = 1.9$ GeV (see Fig. 6). This value is above the 0.5-1GeV bound below which detection is limited by the Fermi motion in nuclei and overlaps precisely with the planned wide band neutrino beam from the upgraded AGS accelerator [5]. This makes Kimballton the ideal location to place a detector that takes advantage of the BNL beam.

This is in stark contrast to the JPARC to Super-Kamiokande (T2K) experiment, for instance, which has a baseline of L = 295 km. In this case, the corresponding peak is expected in the energy range $E_\nu = 0.45$-0.72 GeV, below the Fermi motion bound so that only the higher energy tail of the oscillation peak is available for analysis.

To obtain an idea of what type of signal can be seen at Kimballton, we present the expected $\nu_\mu \rightarrow \nu_e$ and $\nu_\mu(bar) \rightarrow \nu_e (bar)$ oscillation probabilities in Fig. 9 and 10 for the parameter choice $\delta m^2(23) = 2.5\times10^{-3} eV^2$ and $\sin^2 2\theta_{13} = 0.04$ with all other parameters set to their respective central values. The dependence of the probability profile on the sign of $\delta m^2(23)$ and the value of δ(CP) is shown. Due to matter effects, the probability for the normal (inverted) hierarchy is enhanced (suppressed) for neutrinos, and vice versa for anti-neutrinos. However, CP-violation effects obscure the separation, and there is degeneracy between the possibilities: $m_2 < m_3$, δ(CP)<0 and $m_2 > m_3$, δ(CP)>0. Lifting of these degeneracies can be accomplished through the careful measurement of the energy profile of the probabilities [6,7]. The Minakata-Nunokawa plot in Fig. 11 [6] also shows the energy- and δ(CP) dependence of the oscillation probabilities and illustrates how the degeneracy can be resolved through measurements at different energies.
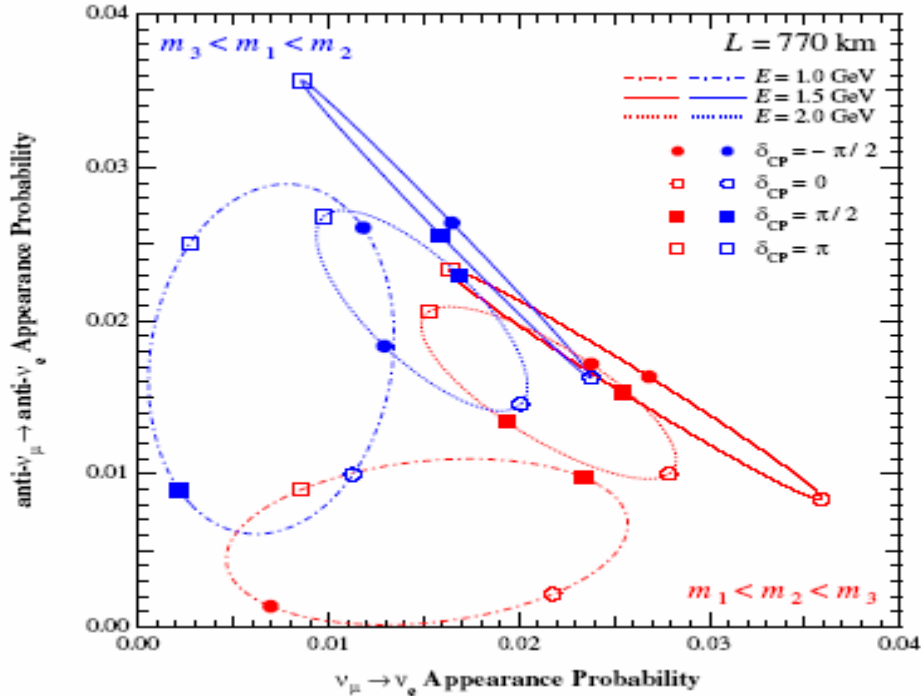
Fig. 11 Minakata-Nunakova plot for E = 1.0, 1.5 and 2 GeV

An estimate of the number of events for a BNL→Kimballton experiment is shown in Fig. 12 for a 500~kton water Cherenkov detector for 5 years of data taking. Given the proximity of Kimballton to BNL, the number of events is significantly higher than if the detector were placed elsewhere. The problem is whether this signal can be separated from the background, the most significant of which is the neutral current π^0 events which mimic electron appearance. However, this background is common to all Cerenkov detectors that work in this energy range (1-3 GeV), such as Super-Kamiokande and NOνA [8]. Preliminary studies for the UNO detector [9] conclude that this particular background can be controlled.

It is in this context that a liquid scintillation approach with HSD may be considered relevant. In this detector (100 kT), though the mass is lower, the background problems above can be bypassed especially in ν_μ(bar) → ν_e(bar) appearance experiments. The ν_e(bar) can be detected in HSD via delayed coincidence neutron tag and the energy resolution is superior to Cerenkov detection. The ν_μ(bar) flux at the accelerator is not significantly different at ~1GeV from that of ν_μ. (see Fig. 13 for expected rates at Kimballton HSD). Thus the baseline, the energy range and the almost background free detection of the ν_e(bar) signal makes a coherent experimental basis for a 100 kT HSD for LBL studies at Kimballton despite a lower signal rate because of the lower detector mass. The HSD is thus cost competitive to the proposed Cerenkov and Liquid Argon detector approaches with much higher masses up to 1 megaton, operating at very long baselines ~2500 km with much higher intensity neutrino beams.

15
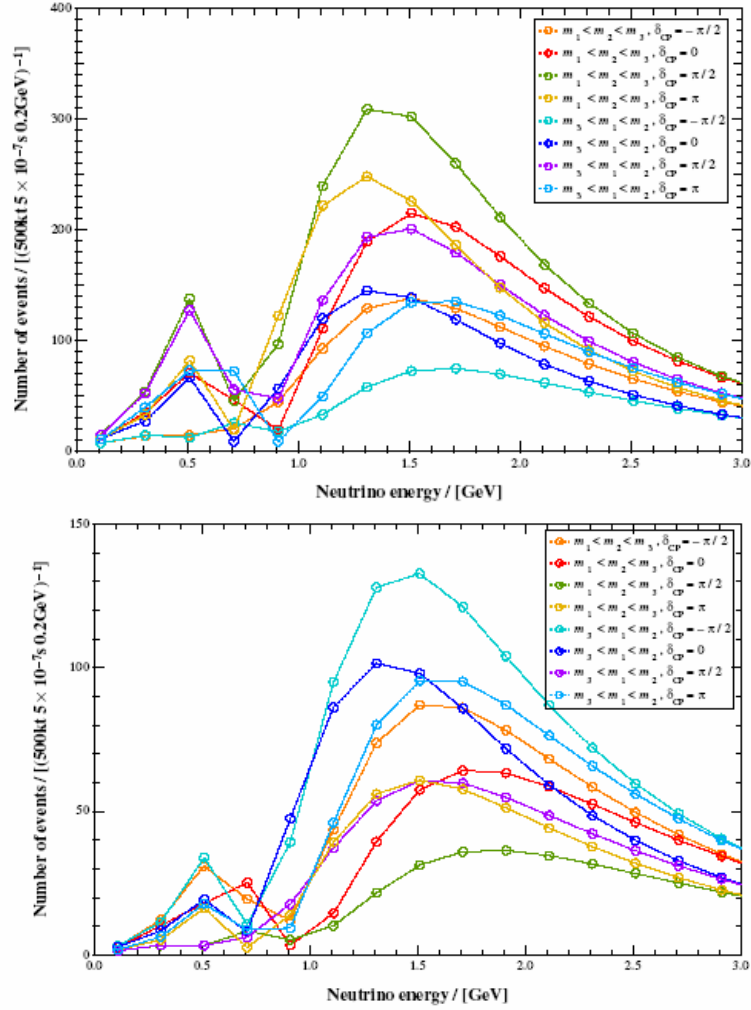
Fig. 12 Expected rates for a BNL-Kimballton experiment with 500 kton water Cerenkov detector. $\nu_\mu \to \nu_e$ (upper) and $\nu_\mu(\text{bar}) \to \nu_e(\text{bar})$ (lower) figures.
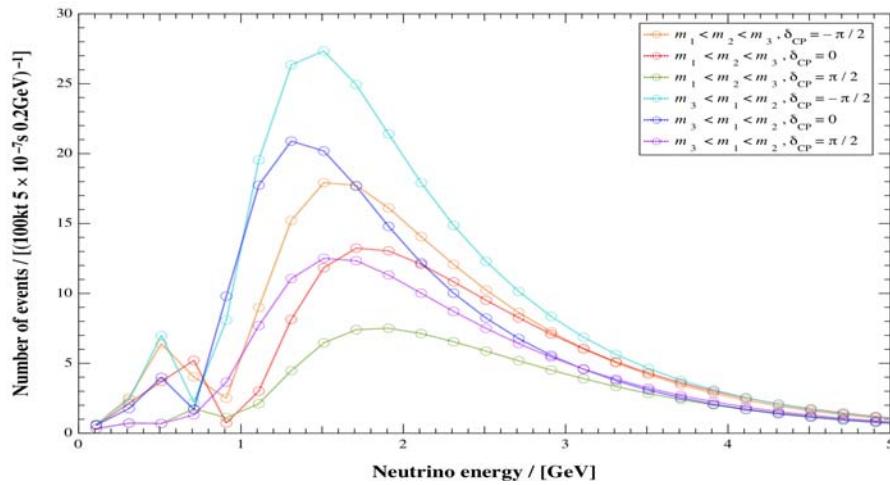
Fig 13 Expected $\nu_\mu(\text{bar}) \to \nu_e(\text{bar})$ appearance signal for a BNL-Kimballton experiment with 100 kT scintillation approach (HSD
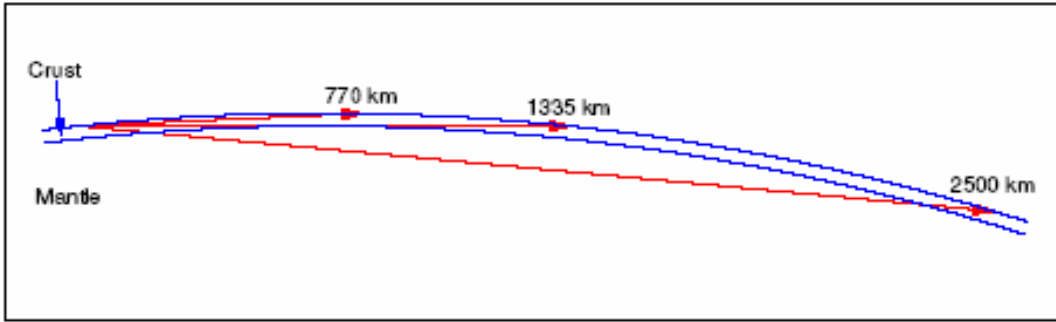
Fig. 14 The trajectory of the neutrino beam through the earth depending on the baseline length. The earth's crust is taken to be 35 km thick.

In the above discussion, the matter effect was assumed to be completely known. However, once the sign of $\delta m^2(23)$ is determined, a careful comparison of the $\nu_\mu \rightarrow \nu_e$ and $\nu_\mu(bar) \rightarrow \nu_e(bar)$ rates is necessary to determine $\delta(CP)$ to high accuracy. This also requires one to disentangle the genuine CP-violating effects from the fake CP-violating matter effects, which demands a good understanding of the density profile of the matter that the beams go through. This may become a problem once the baseline length exceeds ~1300 km since beyond that distance the beam will have to traverse the Earth's mantle to reach the detector [10] (see Fig. 14). Ref [11] has analyzed the potential impact the uncertainty on the matter effect will have on the extracted CP-violating phase, and they conclude that a meaningful separation between fake and genuine asymmetries will be difficult beyond ~1000 km.

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[9] *Feasibility Study on _e Appearance Experiment Using BNL VLB Neutrino Beam with UNO*", C. Yanagisawa, talk at the DUSEL Workshop, Boulder, CO, Jan. 5-7, 2005.

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Appendix F: Safety and Health Plan

The mission statement for safety and health at Kimballton is as follows: *Through proactive training and proper facility design by experienced engineers, the life safety and health each individual working at Kimballton DUSEL will not be compromised.* This guiding vision will be used during each engineering phase, construction and operation. During S-2, health and safety issues will be addressed and appropriate programs implemented through the following tasks.

1. Specific codes, standards and regulations applicable to Kimballton DUSEL include the International Building Code (IBC); International Fire Code (IFC); International Mechanical Code (IMC); the State of Virginia Uniform Statewide Building Code and Fire Prevention Code; and, the National Fire Protection Association (NFPA) code, under which the facility is classified as an underground building.

2. Develop and incorporate design-level life safety elements including, but not limited to: multiple routes of egress to underground spaces; smoke proof areas of refuge, along access routes; smoke detection, control and exhaust systems; sprinkler systems; emergency power and lighting; personnel tracking sensors, and other elements.

3. Implement worker safety training and monitoring procedures. Activities at Kimballton DUSEL are regulated by the Occupational Safety and Health Administration, the Mine Safety and Health Administration and Division of Mines, Minerals, and Energy. Starting with S-2, the management structure of Kimballton DUSEL will include a Safety and Health Officer that will report directly to the project Director. Programs and plans for training scientists, engineers and student scientists working on site characterization and engineering studies will be developed. Contractors and consultants will be required to show proof of training. The Virginia Tech Office of Environmental Health and Safety Services will assist the project team in the initial stages of preliminary engineering to coordinate worker health and safety procedures and monitoring.

4. Develop common health and safety procedures with mine portions of the laboratory. This will require that DUSEL personnel conducting S-2 characterization and engineering studies in the mine have safety training from the National Mine Health and Safety Academy.

5. Develop containment designs, emergency response procedures and protocols for handling of any flammable materials, cryogens and oxygen-displacing gases.

6. Develop procedures for safe transport of materials from the surface to the underground laboratory and incorporate these into the facility design.

Appendix G: Permitting

A permitting study was initiated to identify the lead agency or jurisdiction controlling permit issuance, requirements for obtaining these permits and establishing points of contact. During S-2, the project team will continue this process.

Access. The portal and surface campus are located on property owned by the Chemical Lime Co. (CLC). The underground campus and access tunnels will be located on land that is part of the Jefferson National Forest and owned by the U.S. Forest Service. This land is designated multi-use and is presently used for timber production. The Forest Service maintains a fire tower and public hiking trails on the top of Butt Mountain but all facilities are primitive. The towers are designated as Historic Landmarks with VA Department of Historic Preservation. We have engaged the New River Valley Ranger District in permit discussions and successfully obtained permits from them for the geophysical imaging. We will require an additional permit during S-2 for drilling and other characterization site work.

Construction. Giles County has jurisdiction over construction permitting. They are enthusiastic about this project and have stated that they look forward to working with the project team to minimize any delays in permitting.

NEPA Process. While not specifically a permit, successful completion and review of the National Environmental Policy Act (NEPA) process is required for federally funded projects before many agencies will issue permits. The NEPA checklist analysis was completed to provide a preliminary evaluation of the likely impacts to the human and ecological environment from DUSEL development. During S-2 the formal NEPA process will begin that identifies potentially significant impacts, addresses mitigation measures, solicits public comment, and determines if impacts are significant enough to require a full Environmental Impact Statement (EIS) be prepared.

Soil Erosion and Sediment Control. Soil Erosion and Sediment Control plans are required of land disturbing activities. These plans provide engineered measures to prevent sediment from leaving a construction site, either due to water or air transport. Formal approval of the plan by the local Soil Erosion and Sediment Control District is necessary prior to issuance of a construction permit.

Air Quality. Air quality permits may be required for fugitive air discharges during construction and for normal ventilation discharges during operation. This process will include an assessment of the quantities of fugitive dust emissions that will potentially be generated as well as plans and procedures for both reducing (controlling) and monitoring dust emissions. The specific requirements for air quality permit will be discussed in detail with US Environmental Protection Agency Region III (USEPA) and the Virginia Department of Environmental Quality (VADEQ).

Water Quality (*discharge permits and certifications*). Sections 404 and 401 of the Clean Water Act regulates discharges of 'dredged material' into navigable waters of the US and allows for

protection of wetland from degradation due to discharges. These permits may be necessary during construction for potential discharge into Little Stony Creek. The US Army Corps of Engineers and the VADEQ have jurisdiction over these permits and they can involve requirements for public notices and comment from other agencies.

Section 402 of the Clean Water Act created the National Pollutant Discharge Elimination System (NPDES) to limit discharges into streams, rivers, and bays. In Virginia, VADEQ administers the program as the Virginia Pollutant Discharge Elimination System (VPDES). VPDES permits are required for *point source* discharges and some non-point discharges (stormwater) to surface waters. Stormwater discharge VPDES permits for construction-related activities will be required where disturbances of more than one acre. The US Environmental Protection Agency has authority for review of applications and permits for 'major' discharges, based on discharge quantity and composition. It is unlikely that operations at Kimballton DUSEL will constitute a 'major' discharge.

***Rock Disposal**.* The rock material excavated from the Kimballton site will be either limestone, dolomite or shale. Options for disposal of this material include: 1) re-utilization, 2) stockpiling in vacant quarries located nearby, and 3) stockpiling underground. In addition to the state highway serving the Kimballton mine, an existing and active railroad siding exists near the portal that gives an added means with which to transport excavated material. S-2 studies will provide an opportunity to address these alternatives and explore other options.

1. Reutilization. This option is potentially exciting as it employs 'green engineering' ideals and aspects of it are potential research projects. The limestone and dolomite materials are of high strength and are unweathered. Based on the project team's geotechnical engineering experience, the materials are expected to meet the durability requirements of the Virginia Department of Transportation for abrasion loss and soundness (AASHTO T103/104, T96). Therefore the material can likely be used in highway projects and other non-highway construction.

   One attractive option for reutilization is the proposed major expansion of the Interstate 81 corridor from the Maryland-Virginia border to the Virginia-Tennessee border now being considered by the Virginia General Assembly. The project seeks to mitigate the severe safety problems that currently exist. Construction is anticipated to extend into the year 2018, which encompasses the development period of Kimballton DUSEL.

   If this material is sold, a Mining Permit may be required from the Virginia Department of Mining and Mineral Resources. In addition, non-competition concerns will need to be addressed among the regional highway material suppliers.

   Shale materials are typically not used in highway projects but could be used for backfill in non-critical applications or stockpiled. Based on available geologic and mineralogic information the majority of the shale does not contain significant amounts of pyrite or mineralization. The absence of mineralization will be confirmed by periodic rock testing and monitoring using standard methods (i.e., acid base accounting analysis). If mineralization is

found in the tested material, the material will be disposed of using best management practices to avoid the potential for environmental impacts.

2. Several open, unused quarries exist in close proximity to the portal site may have sufficient capacity to store the spoil generated from this project. Depending on the actual distance it might be possible to transport the material using trucks, conveyor, or a combination of conveyor/rail. According to VADEQ, the disposal of rock materials and soil is given a conditional exemption from the solid waste rules under section 20-8060-E7 of the regulations. Discussions with VADEQ will continue during S-2 regarding the requirements for stormwater runoff control.

3. The third option is to store excavated materials in unused mine excavations underground. Under these conditions, permitting requirements for underground storage of excavated rock materials would be evaluated on a case-by-case basis.

Appendix H: Risk Analysis

Herbert Einstein (MIT)

1.   Introduction

Management of the planning, design, construction and operation of the DUSEL must take into account uncertainties at different levels and occurring in different phases. Examples of sources of uncertainty are

- Political and regulatory uncertainties, including future changes
- Geology and other environmental conditions
- Construction processes
- Operational (management) processes
- Experimental technology
- Experimental errors

These uncertainties will affect the cost and time to build the laboratory, the layout and design of underground laboratory space, the operating costs and the potential for future expansion, as well as opportunities for research. It is absolutely essential that the uncertainties and their effects are clearly identified and that the DUSEL management plan includes processes that directly address uncertainties and their consequences. Developing the structure of these processes and management plans will be a central part of the proposed Phase 2 work.

Fortunately, the methodology for risk assessment, risk analysis and risk management is well established, and practical applications to similarly complex projects have already been demonstrated. As a matter of fact, several members of the project team (Einstein, Mauldon, Imhof, Dove) have been involved in research and practical applications related to uncertainty assessment - and to related risk analysis. The following proposal and what will be actually done is based on this experience.

2.   Development of Uncertainty (Risk) Assessment – Risk Management Structure and Processes

The basic structures and processes will be developed in Phase 2; detailed development and applications will follow in Phase 3.

2.1   Uncertainty Identification/Assessment

A number of processes will be developed through which uncertainties will be identified. The best example for such a process are the risk assessment/analysis workshops conducted by the Washington State Department of Transportation for its major projects (see Reilly et al., 2004). Similar processes have been applied for other projects such as

the Great Belt Tunnel in Denmark, a VECP for a section of the Boston CAT project and others. The processes usually consist of assembling experts and having them identify critical components of a project, estimate consequences of malperformance and the associated uncertainties (probability of occurrence). The assessments are then reviewed by an (or several) independent but technically equally knowledgeable facilitator to remove inconsistencies and to make sure that all components have been identified and assessed. This is then returned to the experts for review. Several rounds of this uncertainty assessment process are usually conducted. It is also possible to conduct detailed research and analysis for some aspects for which the experts indicate that their knowledge is not adequate or sufficiently detailed.

Such processes will be applied to look at the different aspects of the project such as those listed in the introduction (political and regulatory, geology, etc.). In other words, different groups of experts will be assembled. The processes will start at the aggregate level and then work toward the details, where adding other aspects or splitting into several groups is possible (e.g. experts on a particle physics experiment).

The assessments of the different groups are combined by the facilitators to arrive at an overall combined assessment of uncertainties and risks. This aspect is somewhat different and goes beyond the experience with such processes mentioned in the introduction. (Those projects were mostly infrastructure oriented, i.e. they include politics, regulations, geology, construction and operation but not the experiments which characterize the DUSEL.) This will require some technical development work.

In Phase 2 we will, therefore, create the structures for the different uncertainty assessment processes and we will develop the structure for the overall assessment. It has to be emphasized that the detailed development of these processes will follow at the beginning of Phase 3 prior to their applications.

Very important in all this is the inclusion of a feedback mode through which the processes and the data/information used in the processes will be updated as the planning, implementation and operation of the laboratory moves along!

2.2   Risk Assessment/Analysis

The processes mentioned in 2.1 include the identification of possible malperformance (as a matter of fact, it will be the identification of deviation from expected performance which can be both positive and negative). The consequences are usually expressed in terms of cost and time but can also be expressed in form of multi-attribute utilities (see e.g. Keeney and Raiffa, 1978). They will be determined based on experience, historical data and specific analyses (see below). The uncertainties and consequences will then be combined in the risk assessment/analysis phase. This can be done formally (quantitative probabilistic risk assessment) or semi-formally (characterization of risks relative to each other). Again, this will be done starting at the aggregate level and then working toward more details.

An example of a very successfully applied procedure of the intermediate and detailed level are the DAT (Decision Aids for Tunnelling) (see eg. Einstein, 2004). They allow one to assess geologic and construction uncertainties and their financial and time related consequences. The results can be expressed in form of cost-time scattergrams (Fig. 1a, b) or any other graphical/analytical representation. The scattergrams shown in Fig. 1b are those for the Gotthard Base Tunnel in Switzerland, a 4 billion sfr (2.5 billion$) project. While, so far applied mostly to tunnels, the underlying concept and methodology of the
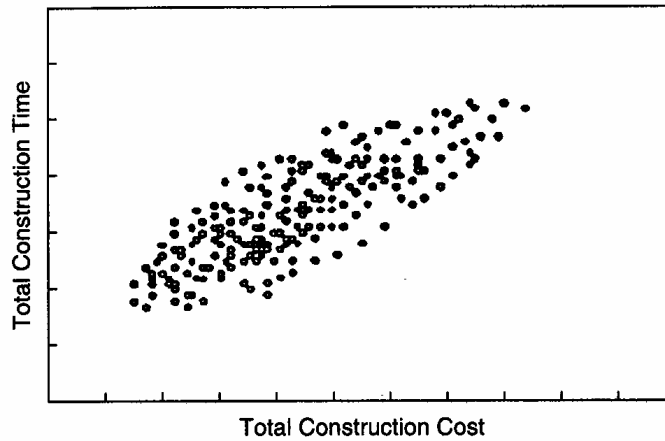
Figure 1a. Generic Cost-Time Scattergram
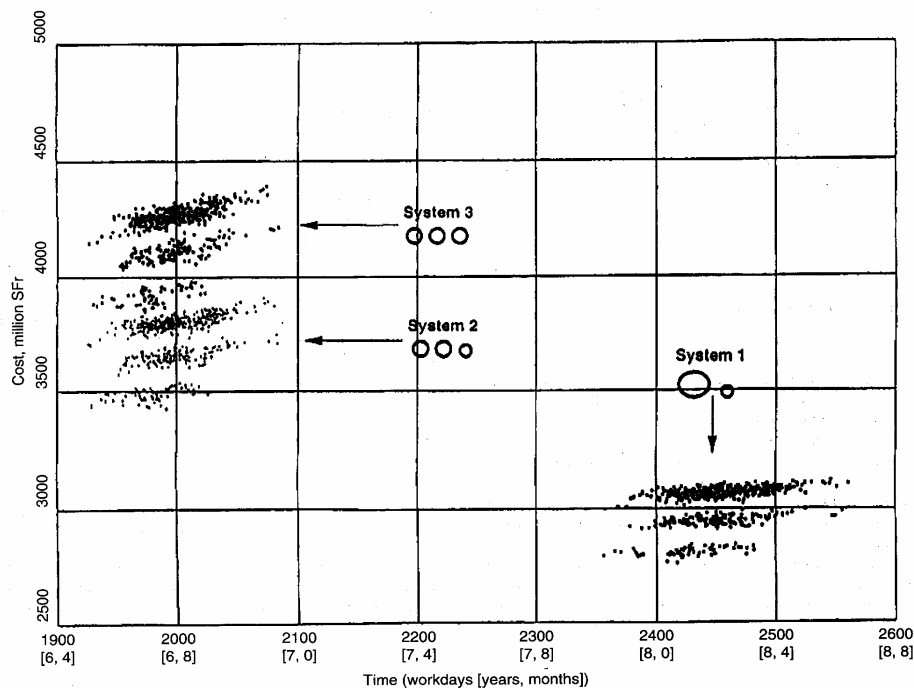
Figure 1b. Cost-Time Scattergram for Gotthard Base Tunnel
- Comparison of Different Tunnel System

DAT can be applied to any networked process, i.e. the DUSEL construction and operation.

The identification and initial development of appropriate risk assessment and analysis tools will be a major task of the Phase 2 DUSEL work. Final development will then take place during the initial portion of Phase 3.

2.3   Risk Management and Mitigation

With the structures, processes and tools discussed above, the DUSEL management and the funding agencies will be provided with the complete information on the overall uncertainties and associated financial and time related risks as well as other (environmental e.g.) risks early in Phase 3. The identification processes discussed in Section 2.1 will also include the identification of countermeasures, their mitigating effects and the associated uncertainties (a countermeasure may not reduce the risk with 100% certainty). Countermeasures can be either active (reducing the initial uncertainties) or passive (reducing the consequences) or both.

A structure, again based on established methodology and, to some extent, on practical applications will be developed in Phase 2 which will allow one to assess the effect of countermeasures in reducing the risks. This will in its practical implementation in Phase 3 allow the decisionmaker to examine the effect of different countermeasures. Examples are additional exploration to reduce geologic uncertainties, requesting legal rulings regarding regulations to reduce associated uncertainties, technical modifications of experiments.

Since it will be impossible to remove all uncertainties prior to construction and operation of the laboratory, it will be necessary, as has been mentioned in Section 2.1 to have a feedback process in place. Specifically, the planning, construction and operation components which are very uncertain will be monitored. (For instance the geology during construction). Countermeasures for deviating performance will be planned and if the monitored performance will indeed deviate beyond a set limit, the countermeasures will be put in place. This process is known as "updating" in decision making under uncertainty and its practical application in infrastructure implementation is known as the "observational method". The underlying concept and methodology is thus well known and practical processes are used to quite an extent. They will have to be expanded to fit the DUSEL and then developed in the necessary detail. Also, it will be very important to fit this into DUSEL management processes. Again, the structure will be prepared in Phase 2 with the details developed early in Phase 3.

3.   Concluding Comments

Decision making under uncertainty is a well established process in management and it has also been extensively used in a number of technological domains, in particular large infrastructure construction and operation. The methodology which includes quantitative risk assessment, - analysis and - management will be used in the DUSEL. The associated practical processes will make it possible to consider all uncertain factors ranging from politics and regulations to running the experiments. They will be developed starting at

the aggregate level and moving into details. This will give the funding agencies and the DUSEL managers a complete and controllable picture regarding the uncertainties and risks, as well as providing them with the tools to reduce and monitor the risks during construction and operation.

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Einstein, H. H. 2004. The Decision Aids for Tunnelling (DAT) – An Update, Transportation Research Record, No. 1892, pp. 199-207.

Keeney, R.L.; Raiffa, H. 1976. Decision Analysis with Multiple Conflicting Objectives, Wiley and Sons, N.Y.

Reilly, J.; McBride, M.;Sangrey, D.; MacDonald, D.; Brown, J. 2004. The Development of a New Cost-Risk Estimating Procedure for Transportation Infrastructure Projects, Civil Engineering Practice, Vo. 19, No. 1.

Appendix I: *Preliminary* Design & Constructability

1.0 Preliminary Design Concepts

The DUSEL at Kimballton design involves several competing criteria. The main access and chambers should be in the most competent rock mass: the middle Ordovician and Knox Dolomite limestone units (see Appendix C for construction suitability). The layered rock formations map nicely into a central campus with a depth of 4000 mwe, and a deep campus with a depth of 6000 mwe (see Appendix B). Several access options exist which allow one to avoid tunneling through the Martinsburg formation and yet study this formation from both above and below. A potential access route is shown in Figures 1 and 2. Figure 1 shows a plan view of the region, while Figure 2 shows the geologic cross-section along these two paths.

A competing factor is the cost of tunneling. From the proposed portal elevations to the peak of Butt Mountain, there is a rise of over 2000 feet, meaning that one must have a decline of about 5500 feet to reach an overburden of 7500 feet. Access options include vertical shafts and inclined tunnels. The former have the lowest cost, while the latter, depending upon decline, offer the best access, at an increased cost due to extra length.

Another consideration is the optimization of science capabilities of the laboratory. Access for imaging studies and mine-back are important features of DUSEL. Likewise, passing through the Narrows Fault allows studies of known discontinuities on a broad range of scales (as described in Appendix E). In addition to this, one needs ready access to the Physics Halls, and the manifest ability to expand the facility over the course of time without unduly disrupting ongoing experiments. The Kimballton design strives to fully integrate all the science disciplines throughout the facility and not simply cluster everyone around expensive deep physics space.

Yet another factor is the availability of facilities at the two portal locations selected (see Appendix A). The Kimballton (or Goldbond) site (Fig 1) is somewhat less developed, but makes direct use of Chemical Lime property and mine, while the Hoges Chapel site is closer to the VT campus and Giles County has offered use of a 650 acre parcel of land just off of Rt 460.

The Kimballton team has studied these options in consultation with CNA, and developed 11 options (Figure 3). After an initial evaluation, the optimum design currently is Option 11. This involves two tunnels, 8.3m in diameter, with a decline of 18%, giving a total tunnel length to the full depth and back of 16.8 km. Tables 1-3 show horizontal and vertical distances and tunnel lengths between the different campuses for this option. Such a steep decline (and thereby reduced length and cost) can be accommodated using either a cog-wheel transport system, or else rubber-tired Kiruna vehicles (see description at end of this appendix). Either system would allow commercial

vehicles to be transported to the Central Campus, and perhaps even directly to the Deep Campus. However, guests would likely only visit the Central Campus on a routine basis,
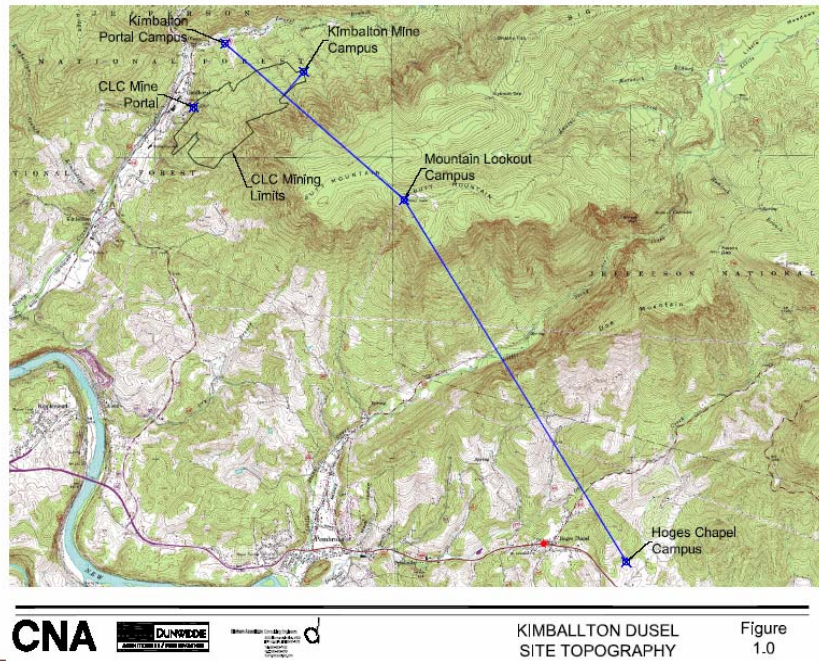

Figure 1. Site plan showing location of potential portals and campuses, as well as outline of current mining at Kimballton mine.
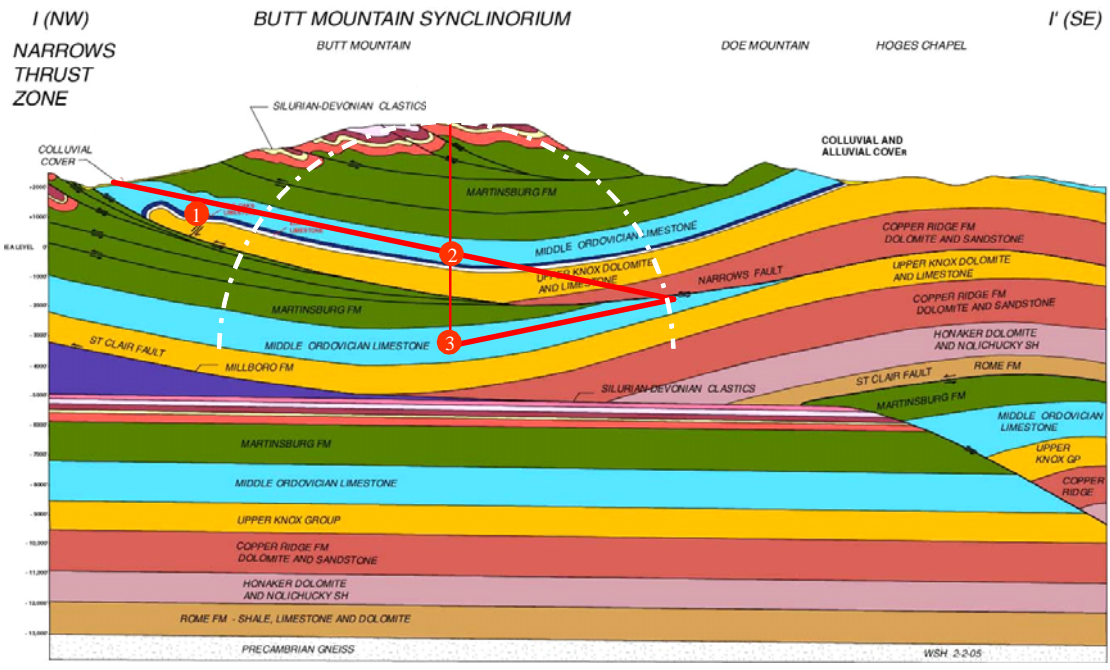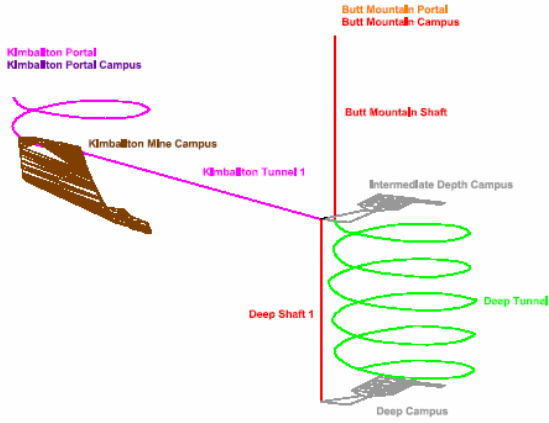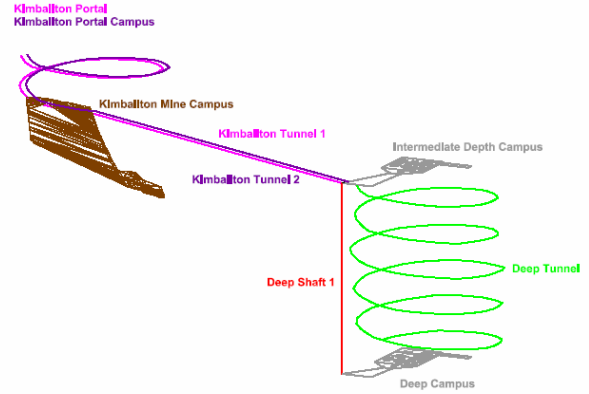
Figure 2: Butt Mountain Synclinorium, showing access and vent tunnels of Option 11; shallow (1), central (2), and deep (3) campus locations; and 6000 mwe boundary. Grade is 18% − total length 8.4 x 2 km; use cog-wheel or rubber tired electric vehicle ferry trucks e.g.: Kiruna
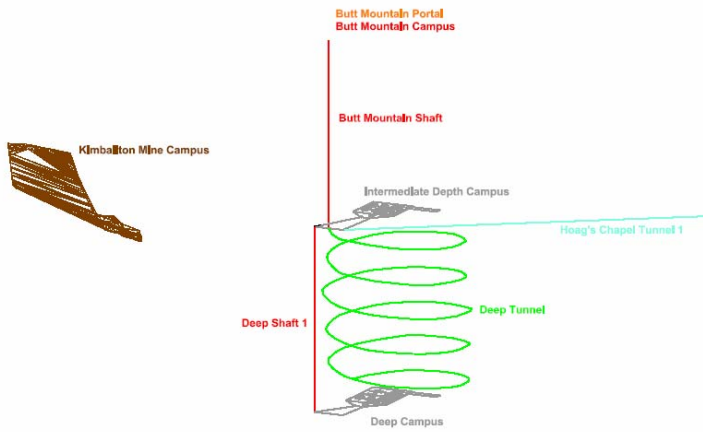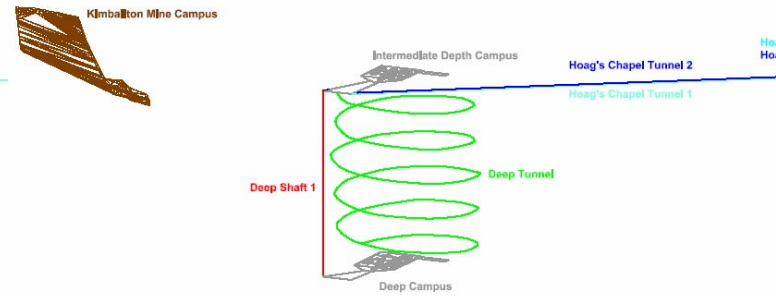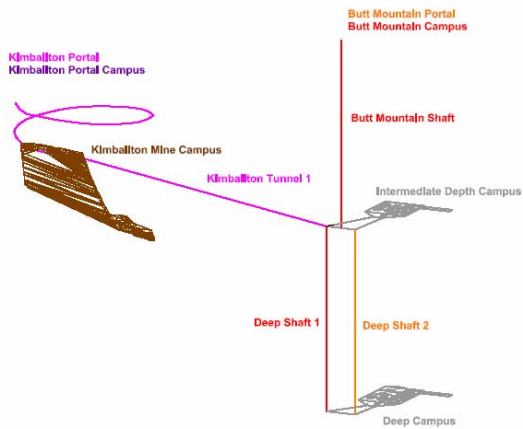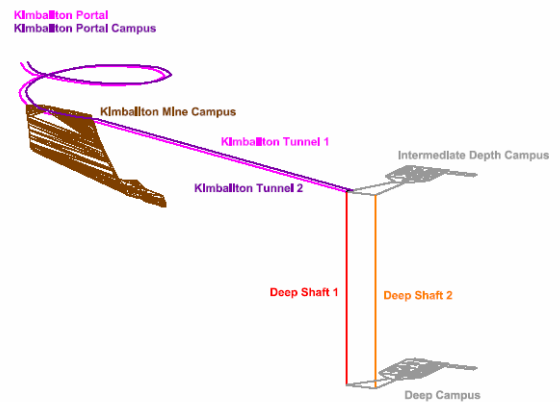
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Option 1

Option 2

Option 3

Option 4

Option 5

Option 6

Option 7   **Option 8**

Butt Mountain Portal
Butt Mountain Campus

Butt Mountain Shaft

Kimballton Mine Campus   Kimballton Mine Campus

Intermediate Depth Campus   Intermediate Depth Campus
                                                                                    Hoag's Chapel Tunnel 2
                                  Hoag's Chapel Tunnel 1   Hoag's Chapel Tunnel 1

Deep Shaft 1   Deep Shaft 2   Deep Shaft 1   Deep Shaft 2

                  Deep Campus   Deep Campus

Option 9   **Option 10**

Kimballton Portal   Kimballton Portal
Kimballton Portal Campus   Kimballton Portal Campus

      Kimballton Mine Campus   Kimballton Mine Campus
                      Kimballton Tunnel 1   Kimballton Tunnel 1
                                Intermediate Depth Campus   Intermediate Depth Campus

                                    Hoag's Chapel Tunnel 1   Hoag's Chapel Tunnel 1

Deep Shaft 1   Deep Tunnel   Deep Shaft 1   Deep Shaft 2

                                                                                Deep Campus

Option 11

Mountain Lookout

Central Campus

Kimballton Mine   Mine Connection
                       Drift
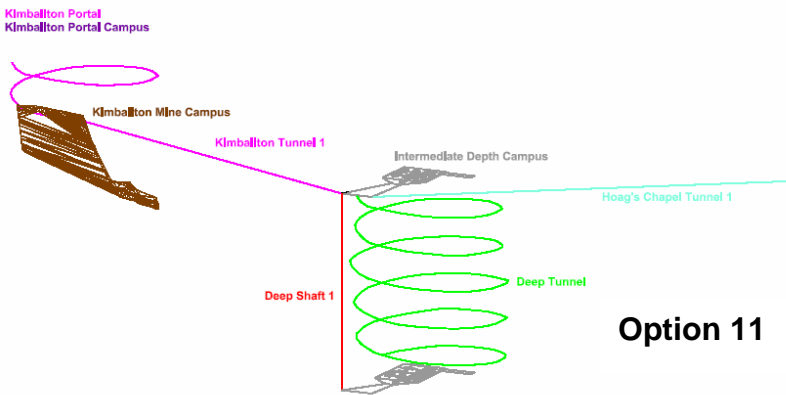
                                                            Deep Campus

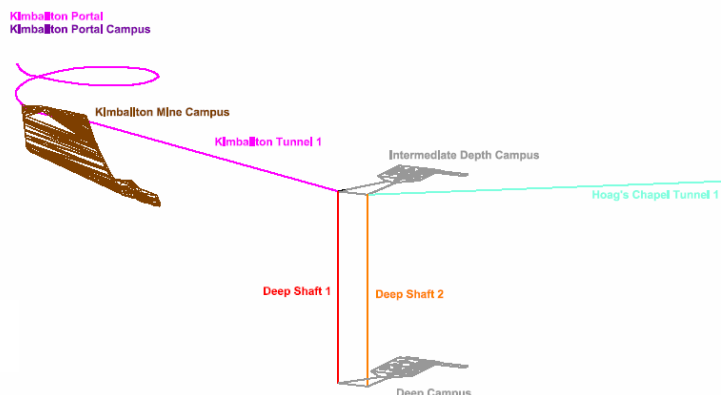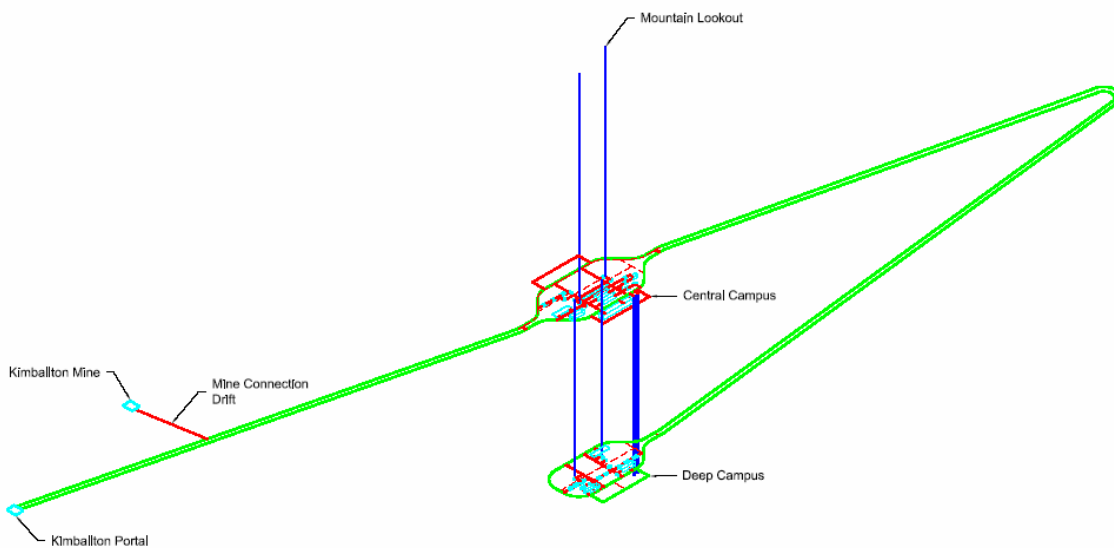Kimballton Portal

Figure 3. Eleven access options initially considered for Kimballton DUSEL. Option 11 is
currently the preferred design.

Appendix I
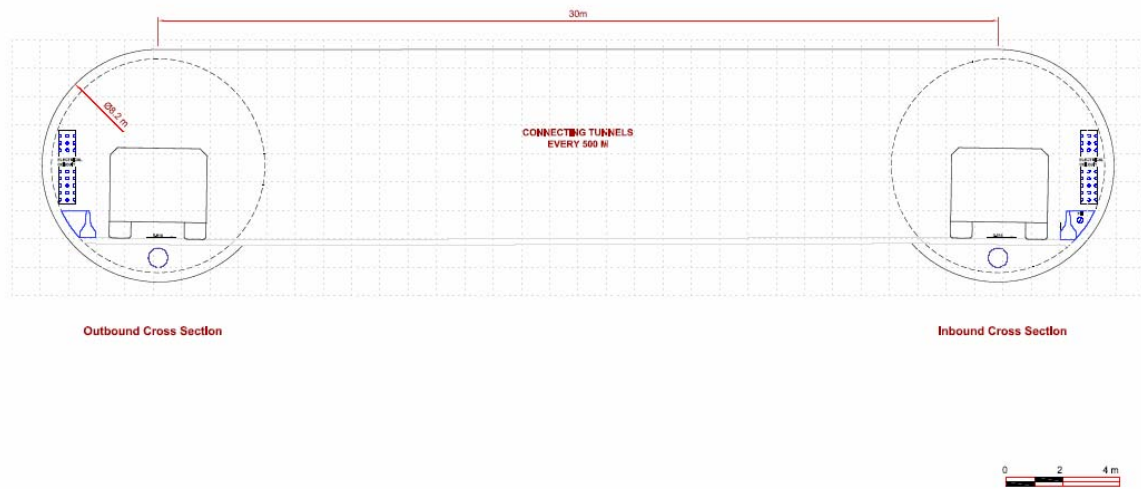
Table 1 – Relative Horizontal Distances

Location	Mountain Lookout	Central Campus	Deep Campus	Kimballton Portal Campus	Kimballton Mine Campus	Hoges Chapel Portal Campus
Mountain Lookout	0	0	0	3672	2509	6551
Central Campus	0	0	0	3672	2509	6551
Deep Campus	0	0	0	3672	2509	6551
Kimballton Portal Campus	3672	3672	3672	0	1295	10115
Kimballton Mine Campus	2509	2509	2509	1295	0	9048
Hoges Chapel Portal Campus	6551	6551	6551	10115	9048	0

Table 2 - Elevation Differences

Location	Mountain Lookout	Central Campus	Deep Campus	Kimballton Portal Campus	Kimballton Mine Campus	Hoges Chapel Portal Campus
Mountain Lookout	0	1280	2280	658	953	658
Central Campus	-1280	0	1000	-622	-327	-622
Deep Campus	-2280	-1000	0	-1622	-1327	-1622
Kimballton Portal Campus	-658	622	1622	0	295	0
Kimballton Mine Campus	-953	327	1327	-295	0	-295
Hoges Chapel Portal Campus	-658	622	1622	0	295	0

Table 3 - Required Tunnel Length

Location	Mountain Lookout	Central Campus	Deep Campus	Kimballton Portal Campus	Kimballton Mine Campus	Hoges Chapel Portal Campus
Mountain Lookout	0	NA	NA	NA	NA	NA
Central Campus	NA	0	5556	3672	2509	6551
Deep Campus	NA	5556	0	NA	NA	NA
Kimballton Portal Campus	NA	3672	NA	0	1639	NA
Kimballton Mine Campus	NA	2509	NA	1639	0	NA
Hoges Chapel Portal Campus	NA	6551	NA	NA	NA	0

Figure 4. Potential typical section for tunnel and cross-cut.

and a vertical lift between the Central and Deep Campuses would be used for routine access to the greater depths. Figure 4 show a potential cross-section for the tunnels. Two shafts from the Deep to the Central Campus to the top of Butt Mountain will be used for ventilation and emergency access/egress, respectively.

The concept for the campuses themselves incorporate many features already developed by the DUSEL community, and will be optimized to best capture the science modules

identified in the S1 report. It is notable, however, that the Kimballton strategy incorporates a Shallow Campus (associated with the existing Chemical Lime mine), a Central Campus, and a Deep Campus. Renderings of a preliminary design for the Central and Deep campuses are shown in Figure 5. Having multiple campuses has the advantage of providing locations for early/mid/later times and low/medium/high cost space. Many of the science modules do not require the full 6000 mwe cover, and SNOLab offers space for first generation (smaller) deep physics experiments. Further, having three campuses means that for cost-reasons, not each campus will be equally developed, but it allows for better long-term co-existence of multiple disciplines.
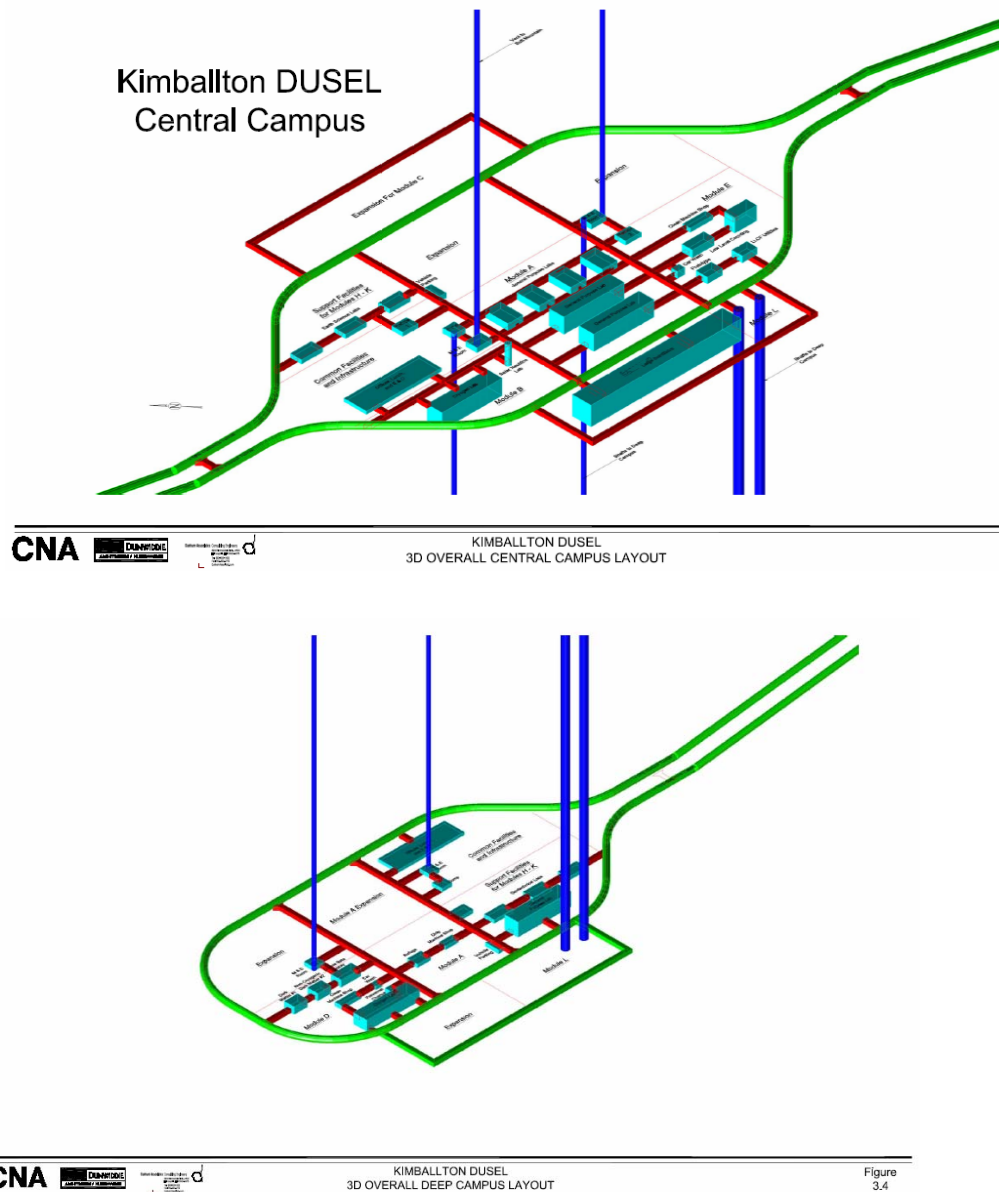
Figure 5. Preliminary concepts for Central and Deep Campus. The actual number of initial halls would be significantly less than shown, and the two large vertical shafts between the campuses are included to represent the intrinsic potential for *n-nbar* and atmospheric experiments.

2.0 Constructability

Tunnel construction will, together with the laboratory equipment, be the largest fixed cost component and it will be the major determinant regarding time to completion. A detailed development of construction processes and the associated cost and time estimation will, therefore, be a central part of the Phase 2 work. As in the remainder of this proposal, the purpose of these comments is to set the stage for detailed work in Phase 2 (and Phase 3 if applicable).

2.1 Design

The currently preferred design is Option 11. The tunnels have internal diameters of 8.2 m and provide access for people and equipment transport. In addition, a double shaft for ventilation (3 m diameter) and people access (7.5 m diameter) from the top of Butt Mountain to both campuses will be constructed.

Option 11 is preferred because the access tunnels are strongly inclined (18%) which reduces the tunnel length from 40 km with 8% inclination to roughly 17 km; on the other hand, the steep incline requires the use of (commercially available!) electrically powered vehicles for transport. (They are described in detail in an attachment to this appendix) No construction cost estimates are given since this needs to be evaluated in Phase 2 but the fact that Option 11 has the shortest access tunnel length also implies that it has the lowest construction cost of all options.

Clearly, much additional work on tunnel design will be conducted in Phase 2. A detailed table of contents, included as an attachment to this appendix, indicates the components of this design work. An important part of the design work will be the evaluation and consideration of uncertainties as discussed in Appendix H.

2.2 Construction

While the general design of the final facility and details of tunnel/cavern design have received a preliminary assessment (Section 1 of this appendix as well as in Appendices C and H), a few additional comments on specific construction issues are necessary. The access tunnels will be excavated by Tunnel Boring Machines (TBM's). The rock conditions are ideally suited for TBM's in that the openings will require no or minimal support during construction and will be in rock which can be easily excavated and has low abrasivity. Progress in the 100 m/week to several 100 m/week range can be expected. The shafts will very likely be excavated by raise boring (pilot boring downward followed by raise boring). The Campus tunnels can be either excavated using the TBM's or with drilling and blasting. The Campus caverns will be excavated by drilling and blasting, the larger ones using heading and benching or multiple drift excavation.

The feasibility of creating underground openings of the desired sizes has been addressed in Section 6 of Appendix C applying well established empirical relations (Q

and RMR methods) and supported by the evidence in the present Kimballton mine. Phase 2 will expand this evaluation on the basis of additional data from the geotechnical exploration (see also Appendix B) using the empirical approaches but also analytical/numerical methods.

Detailed work is required to decide how best to combine access tunnel, shaft and campus tunnel/cavern construction. For instance, it is possible that once the shaft location is reached at the Central Campus that TBM work is temporarily stopped to allow for maintenance while one or both shafts between the Central Campus and the top of Butt Mountain are excavated.

2.3 Concerns

There are, also, potential problems that need to be addressed. The first is that downward inclined tunneling poses safety problems for the workers regarding sudden water inflows. This situation can be mitigated by excavating the two parallel tunnels simultaneously and with frequent crossovers. While, in principle, increasing safety to an acceptable level, details of the actual tunneling process need to be worked out. The safety conditions will be somewhat improved once the Central Campus location is reached and at least one of the shafts has been constructed.

Another issue regarding downward inclined tunnels is ventilation. In principle, under high temperature conditions, it is best to use the tunnel for fresh air supply and ducts for used air removal. While not a problem in horizontal or gently inclined tunnels, this may not be doable in inclined tunnels, especially in the summer months; again a detailed consideration of different options is necessary.

Tunnelling involves major transportation activities in that muck has to be removed and construction material supplied. Transportation in steeply inclined tunnels is an issue. Muck transport is probably best handled by conveyor belts and for this the 18% inclination is not a problem. (Muck transport would be doable with the above mentioned electric trucks but is more efficient with conveyor belts.) Supply of materials (concrete, steel) will be done by the electric trucks. One possibility here is that part of the Central Campus may initially be used to install a concrete manufacturing plant (see also below).

A significant problematic issue regarding any underground excavation is the disposal of the excavated material (spoil). The material is usually not contaminated and can be disposed of without restriction. However, the large volume (over 1 million m^3 solid rock for the access tunnels alone) poses problems. Several possibilities exist in the case of Kimballton, including: disposal in the existing mine openings, and disposal in an adjacent open pit quarry. Two other options for partial disposal of mine spoil are: using the spoil as aggregate to manufacture the concrete used for the DUSEL facility. This is being successfully done in the Swiss Transalpine tunnels. The other is to sell the limestone spoil to Kimballton mine for commercial use.

This brief review indicates which construction related areas need substantial development in Phase 2 and possibly 3. As has become apparent from the comments above, much of what has to be developed is associated with uncertainties. Consideration of this will thus be essential (see Appendix H.)

3.0 Current Status and Continuing Work

The design for DUSEL at Kimballton is converging. Several designs have been considered, and a preferred option has been identified. Preliminary efforts have studied the site from geological and engineering standpoints. These efforts, though, are clearly preliminary. The DUSEL S2 solicitation calls for a proposal that describes a team's "plan for developing the conceptual design of the DUSEL." Work will continue so that uncertainty in the design and construction is minimized.

The Kimballton team has significant experience in underground construction and the management of large projects. As such, we understand the process to convert the above general ideas into appropriate Work Breakdown Structures, Resource Loaded Time and Cost estimates, and other well recognized project management tools. This is an ongoing task throughout the S2 process.

To expedite this transition, we have engaged CNA Consulting Engineers (a firm used by several other DUSEL proponents – and also to develop the S1 requirements) and other firms with significant management skills. We include below preliminary reports which will form the basis for developing a more complete conceptual design as required by the S2 solicitation.

Attachment 1: Draft Project Table of Contents
Attachment 2: Preliminary Draft Work Breakdown Structure
Attachment 3: Kiruna Haulage Trucks
<Attachment 4: Preliminary Draft Code Review (separate link on main page)>

Attachment 1: Draft Project Table of Contents

Table of Contents

1 Introduction

2 Project Work Breakdown Structure (WBS)

The Project WBS is a tool used to develop the project's scope, cost, schedule and design issues. The capital cost WBS will cover the range of project components necessary for the access alternatives envisioned in September 2004. It will also include the major systems necessary to support laboratory occupancy and operations. The Project WBS is broken down into six major categories.

2.1 WBS Section 1.0 Land Acquisition, Easements, Usage Fees & Insurance

WBS Section 1 is included to cover costs necessary for land acquisitions, easements, usage fees and insurance. Based on the limited amount of information available and current design state, these costs have not been calculated or included.

2.2 WBS Section 2.0 Surface Facilities

WBS Section 2 itemizes cost related to surface construction activities, including access roads, site work, surface buildings, surface infrastructure and development of rock disposal sites.

2.2.1 Surface Site Work

Based on the limited information available on the proposed site and existing utilities a lump sum price of five million dollars has been estimated for surface site construction costs. Typical activities under this section include road improvement, site clearing & grubbing, site excavation and development and extension of major utilities to the site such as water, storm and sanitary sewer service.

2.2.2 Surface Infrastructure

WBS Section 2.2 addresses the costs for surface infrastructure systems such as building heating, cooling, electrical, communications, compressed gas, water distribution and sewer.

2.2.3 Science, Physics and Administration buildings

WBS Section 2.3 estimates the required building facilities at 125,000 square feet of space. This space would like consist of a series of buildings dedicated to a wide range of functions from Education and Outreach to experiment lab space.

2.2.4 Rock Disposal

WBS Section 2.4 addresses the costs associated with the surface disposal of waste rock generated by tunnel and cavern construction activities. The 1.3 million cubic meters of rock will need to be disposed of off site. Provided that the majority of the facilities are constructed within Limestone formations, the waste rock will have limited value when crushed to a size suitable for construction purposes. The disposal costs have been limited to trucking costs, assuming that the crushing costs are offset by the resale value of the product.

2.3   WBS Section 3.0 Underground Access

WBS Section 3 addresses the costs associated with the construction of underground access, including ventilation shafts and TBM bored tunnels.

2.3.1   Portals

WBS Section 3.1 addresses the cost related to the construction of the portal structures. Due to the limited amount of site information, a lump sum cost of five million dollars was estimated for this construction. The construction will likely consist of a reinforced concrete cut and cover box structure. The portal structure will also require sump and pumping control room to handle the inflow and discharge of water entering the portal and tunnels.

2.3.2   Tunnels

WBS Section 3.2 addresses the cost related to the construction of the inbound and outbound tunnels. Each tunnel is estimated at 8.23 meter diameter and 9228 meters long.

2.3.3   Shafts

WBS Section 3.3 addresses the cost of constructing ventilation shafts from the Mountain Outlook to Central Campus and from Central to Deep Campus. The current design envisions two intake and two exhaust shafts. The 3 meter diameter shafts will be excavated by raised-bored construction and concrete lined.

2.4   WBS Section 4.0 Underground Facilities

WBS Section 4 addresses the costs associated with the construction of the Central Campus caverns and connecting tunnels and the Deep Campus caverns and connecting tunnels.

2.4.1   Cavern Excavation by Drill and Blast

The cost estimate assumes that all caverns are excavated by drill and blast methods, using smoothwall blasting procedures to maintain the integrity of the rock. All caverns are assumed to be excavated using one 8-meter top heading, and zero or more benches depending upon total cavern height. The top headings are drilled horizontally and require longer cycle times due to the installation of roof rockbolts and shotcrete. Cavern benches are drilled vertically and have shorter cycle times, due to less rock support.

2.5   WBS Section 5.0 Systems

WBS Section 5 costs include facility systems such as HVAC, fire protection, plumbing, electrical and materials handling. A complete list of systems is described in the WBS in the appendix.

2.6   WBS Section 6.0 Permits, Fees and Professional Services

WBS Section 6 covers costs related to permits and professional service fees.

The WBS cost estimate is included in Appendix X for reference.

3 Preliminary Design Criteria

3.1 Major Project Features

Refer to the Project Work Breakdown Structure in Section 2.

3.2 Science Design Criteria

3.2.1 General

1. Satisfy to the extent possible the science program and infrastructure requirements developed by the NSF Solicitation 1 investigation
2. Physics & earth science facilities should be integrated but modular

3.2.2 Physics

1. Provide for scientific opportunities in physics at the following locations:
   a. In the existing Chemical Lime mine
   b. At intermediate depth of about 4,000 feet
   c. At depths up to 7,500 feet to 8,000 feet
2. Provide for construction of an UNO-scale cavern or other large nucleon decay and long baseline experiment
3. Provide both clean room and normal office clean conditions

3.2.3 Earth Science

1. Provide cubic kilometer concept, ground truthing & mineback
2. Provide geomicrobiology science opportunities
3. Encounter same rocks at different depths

3.2.4 Public Access

1. Project design provides for public access:
   a. To the Visitor's Center
   b. To the Central Campus
   c. To the Deep Campus—???

3.3 Occupancy

3.3.1 Background

Six phases in the laboratory life cycle are:

1. Mining & ground support (including shotcrete and floors);
2. Outfitting (systems installation & commissioning);
3. Cleaning;
4. Experiment Installation;
5. Experiment commissioning; and

6. Experiment operation.

7. Experiment decommissioning.

3.3.2 Occupancy Assumptions

3.3.3 Occupancy

1. Occupancy shall be as follows:

   a. Kimballton portal campus—TBD

   b. Kimballton mine campus—TBD

   c. Butt Mountain campus—TBD

   d. Hoges Chapel campus—TBD

   e. Intermediate Depth campus—TBD

   f. Deep campus—TBD

3.4 Codes & Standards

3.4.1 Structural Codes

3.4.2 Fire & Life Safety

Codes

1. International Building Code, 2000 version

2. Virginia modifications to IBC

3. Virginia Tech & Giles County modifications to the above

4. National Fire Protection Association (NFPA)

5. Mine Safety & Health Administration (MSHA)

6. OSHA

7. Virginia Division of Mines, Minerals, Energy

8. NFPA U.G. Building

9. Road Tunnel Standards

Direct Implications

1. Large ventilation flows for unrestricted access

2. Compartmentalization

3. Two means of egress (or a refuge room)

4. Egress distances

5. Multi-pass ventilation

See Section 9 for additional details.

3.5   General Access

3.5.1 Access Availability

3.5.2 Tunnel Access

1. Drive in to at least Intermediate depth campus, i.e. minimum restrictions on entering the facility

2. Access tunnel grade of 8 percent

3. One- or two-way traffic in the entrance?

4. What traffic is allowed to use the entrance tunnel(s)?

5. Provide space for a cryogen vent

6. Tunnel diameter

3.5.3 Shaft Access

Hoist capacity

1. Weight capacity

2. Size capacity

3. Personnel capacity

Shaft size

1. Diameter

3.6   Schedule

1. Time to first science

2. Overall development schedule shall be???

3. Project layout shall be conducive to incremental expansion

3.7   Experiment Isolation

The laboratory layout shall provide isolation of experiment spaces.

1. Experiment spaces shall be separate from each other

2. Experiment spaces shall be separate from ancillary and support spaces

4 Subsurface Construction Conditions

Assess subsurface construction conditions based on existing data provided by the Kimballton Team. (See the Kimballton Team tasks described in following section.)

5 Project Access Alternatives

5.1 Surface Access Locations

5.1.1 General

The project is located in Giles County, a rural area of west-central Virginia. The selection of the ideal surface access locations requires consideration of the following factors:

1. Proximity to existing infrastructure (e.g. transportation, lodging, utilities, etc.)
2. Horizontal Distance and relative elevation difference to Central Campus
3. Geology
4. Current land use

5.1.2 Hoges Chapel

The Hoges Chapel portal, located at 37.319 degrees north longitude and 80.584 degrees west longitude was selected by the Kimballton team. The site is located roughly 1.5 km due east of the city of Hoges Chapel, Va. The area is currently undeveloped and is located roughly 0.5 km from US Highway 460. The use of this site may require construction or upgrading of 0.5 – 1 km of access roads. Similar lengths of utilities would need to be extended to the site.

5.1.3 Kimballton

The Kimballton portal, located at 37.391 degrees north longitude and 80.654 degrees west longitude was selected by the Kimballton team. The site is located 0.5 km east of the town of Olean, VA. The site is currently undeveloped and is located roughly 0.5 km from Giles County Road 635. The use of this site would require construction or upgrading of 0.5 – 1 km of access roads. Similar lengths of utilities may need to be extended to the site.

5.1.4 Mountain Lookout

The mountain lookout facility is located at 37.369 degrees north latitude and 80.623 degrees west longitude atop Butt Mountain. The site is located adjacent to Rock Mountain Road. The road would likely require some upgrading to be used as an access route.

5.2 Project Access Components

5.2.1 General

The project access components include the following: access tunnels, access shafts, and ventilation shafts. All ventilation is accomplished vertically through shafts rather than horizontally through the tunnels. The typical tunnel and shaft cross sections are shown in figures X.X and X.X respectively.

While the calculation of shaft height is very straight forward, the required length of tunnel between facilities depends on several factors: relative horizontal distance, elevation difference, and maximum tolerable tunnel grade. Table 1 lists relative distances and table 2 lists the elevation differences between the facilities.

Table 1 - Relative Horizontal Distances

Location	Mountain Lookout	Central Campus	Deep Campus	Kimballton Portal Campus	Kimballton Mine Campus	Hoges Chapel Portal Campus
Mountain Lookout	0	0	0	3672	2509	6551
Central Campus	0	0	0	3672	2509	6551
Deep Campus	0	0	0	3672	2509	6551
Kimballton Portal Campus	3672	3672	3672	0	1295	10115
Kimballton Mine Campus	2509	2509	2509	1295	0	9048
Hoges Chapel Portal Campus	6551	6551	6551	10115	9048	0

Table 2 - Elevation Differences

Location	Mountain Lookout	Central Campus	Deep Campus	Kimballton Portal Campus	Kimballton Mine Campus	Hoges Chapel Portal Campus
Mountain Lookout	0	1280	2280	658	953	658
Central Campus	-1280	0	1000	-622	-327	-622
Deep Campus	-2280	-1000	0	-1622	-1327	-1622
Kimballton Portal Campus	-658	622	1622	0	295	0
Kimballton Mine Campus	-953	327	1327	-295	0	-295
Hoges Chapel Portal Campus	-658	622	1622	0	295	0

To generate required tunnel lengths, the lengths based on horizontal distances were compared to the lengths, based on required change in elevations. As a simplification, the lengths based on horizontal distance between facilities, were assumed to be equal to the horizontal distances rather than slope distances. This approximation results in a negligible 1.6 % error for the 18 % tunnel grade. Further, the length based on required change in elevation was calculated as simply the required change in elevation divided by the maximum tolerable tunnel grade. Table 3 was generated as a composite of these two values and is shown below. Numbers shown in blue font are controlled by the required change in elevation the black font indicates the length was controlled by horizontal distance between facilities.

Table 3 - Required Tunnel Length

Location	Mountain Lookout	Central Campus	Deep Campus	Kimballton Portal Campus	Kimballton Mine Campus	Hoges Chapel Portal Campus
Mountain Lookout	0	NA	NA	NA	NA	NA
Central Campus	NA	0	5556	3672	2509	6551
Deep Campus	NA	5556	0	NA	NA	NA
Kimballton Portal Campus	NA	3672	NA	0	1639	NA
Kimballton Mine Campus	NA	2509	NA	1639	0	NA
Hoges Chapel Portal Campus	NA	6551	NA	NA	NA	0

5.2.2 Kimballton Mine Connection Tunnel

The connecting tunnel to the Kimballton Mine is located on the main inbound access tunnel to the Kimballton Mine at a distance of 1200 meters from the portal. The connection point is approximately 500 m to the northeast of the tunnels and is located at mine drift 12 East #5 (elevation = 327 m). The resulting tunnel grade (assuming an 18 percent main tunnel grade) would be 16 percent.

5.2.3 Kimballton Portal to Central Campus Tunnel

The Kimballton Portal to Central Campus tunnel is an 8.23 meter diameter tunnel excavated by Tunnel Boring Machine (TBM). The tunnel connects the Kimballton Portal to the Central Campus and provides large vehicle primary access to the lower levels.

5.2.4 Central Campus Personnel Shafts

The Central Campus personnel access shaft is a 7.5 meter diameter concrete lined shaft excavated by drill and blast methods. The shaft connects the Mountain Lookout facility to the Central Campus and serves a primary access to the lower levels.

5.2.5 Hoges Chapel Portal to Central Campus Tunnels

The Hoges Chapel Portal to Central Campus tunnel is an 8.23 meter diameter tunnel excavated by TBM. The tunnel connects the Hoges Chapel Portal to the Central Campus and provides large vehicle primary access to the lower levels.

5.2.6 Central Campus to Deep Campus Personnel Shafts

The Deep Campus personnel access shaft is a 7.5 meter diameter concrete lined shaft excavated by drill and blast methods. The shaft connects the Central Campus to the Deep Campus and serves as primary access to the Deep Campus.

5.2.7 Central Campus to Deep Campus Tunnels

The Central Campus to Deep Campus tunnel is an 8.23 meter diameter tunnel excavated by TBM. The tunnel provides large vehicle primary access to the Deep Campus.

5.2.8 Ventilation Shafts

The ventilation shafts are 3-meter diameter vertical concrete lined shafts. Two such shafts connect the deep campus to the Central Campus and another two connect the Central Campus to the Mountain Lookout facilities. Two shafts are required to provide separation of the exhaust and the supply airflows.

5.3   Access Options

5.3.1 General

The following access options consist of various combinations of the previously described access components. Options 1 through 10 utilize tunnels with an 8 percent maximum tunnel grade, whereas option 11 utilizes an 18% maximum tunnel grade. See table x.x for a detailed tabular summary of the options.

5.3.2 Means of Underground Transport

The primary means of underground transport for the options which include tunnel access from the surface would be by rubber tired vehicles. The traditional cog-rail system was considered, but deemed inappropriate for the necessary functions of the facilities.

The 8 percent grade tunnels can accommodate standard highway vehicles with minimal accommodations. These options have the benefit that vehicles can carry their load directly into the underground facilities without offloading and reloading onto separate vehicles. There would be security concerns associated with allowing the public access to the underground facilities that would necessitate guarded entrance at the surface facility. There would also need to be safety provisions such as turn-outs and crash barricades to accommodate the long steep grades.

The 18% grade tunnels require the use of special off-road vehicles. One vehicle selected as a feasible option was Kiruna electric trucks (models K635E & K1050E). They are described by the Manufacturer as "low profile, articulated, compact heavy duty mining vehicles." The vehicle is capable of ascending and descending at grades up to 20 percent with hauling capacities of 35 and 50 metric tones of cargo respectively.

Several advantages to using these vehicles over the traditional cog-rail system are:

1. Lower capital cost

2. Reduction of ventilation cost due to electric versus diesel power

3. Eliminate need for sidings and switchgear

4. Trucks have greater freedom of movement (i.e. trucks not confined to a track)

Possible disadvantages of using Kiruna Trucks

1. Require trained drivers

2. Overhead power lines when traveling long distances

5.3.3 Options 1 through 10

Options 1 through 10 consist of various combinations of the following project access components.

1. Kimballton Mine Connection

2. Kimballton Portal to Central Campus Tunnel

3. Central Campus to Deep Campus Tunnel

4. Central Campus Personnel Shaft

5. Deep Campus Personnel Shaft

6. Central Campus Ventilation Shaft

7. Deep Campus Ventilation Shaft

5.3.4 Option 11

Option 11 consists of the following project access components.

1. One Kimballton Mine Connection

2. Two Kimballton Portal to Central Campus Tunnels

3. Two Central Campus to Deep Campus Tunnels

4. One Central Campus Ventilation Shaft

5. One Deep Campus Ventilation Shaft

5.4 Option Advantages and Disadvantages

Option	Advantages	Disadvantages
1	Ease of ventilating the Central campus with two 4300 ft supply and exhaust ducts. Ease of ventilating the Deep campus with two 3300 ft supply and exhaust ducts. Reduced operating cost of ventilating the central campus and deep campus with short shaft ducts.	Construction and operating cost to ventilate 87,000 ft of tunnels. Construction and operating cost to light 87,000 ft of tunnels. Construction cost to provide fire protection for 87,000 ft of tunnels.

	Fast egress through shafts to the surface.	
2	Parallel tunnels to the Central campus permit crossover egress compartmentalization. Ease of ventilating the Deep campus with two 3300 ft supply ducts and two 3300 ft exhaust ducts.	Construction and operating cost to ventilate 118,000 ft of tunnels. Construction and operating cost to light 118,000 ft of tunnels. Construction cost to provide fire protection for 118,000 ft of tunnels. Slower egress through exit tunnels from the Central campus (6 miles from central campus). More areas of refuge required due to additional tunnel length (every 2000 ft of tunnel). Increased campus ventilation construction and operating cost due to 64,000 ft of supply ductwork and 64,000 ft of exhaust ductwork to the central campus.
3	Ease of ventilating the Central campus with two 4300 ft supply and exhaust ducts. Ease of ventilating the Deep campus with two 3300 ft supply and exhaust ducts. Reduced operating cost of ventilating the central campus and deep campus with short shaft ducts. Fast egress through shafts to the surface.	Construction and operating cost to ventilate 90,000 ft of tunnels. Construction and operating cost to light 90,000 ft of tunnels. Construction cost to provide fire protection for 90,000 ft of tunnels.
4	Parallel tunnels to the Central campus permit crossover egress compartmentalization. Ease of ventilating the Deep campus with two 3300 ft supply ducts and two 3300 ft exhaust ducts.	Construction and operating cost to ventilate 124,000 ft of tunnels. Construction and operating cost to light 124,000 ft of tunnels. Construction cost to provide fire protection for 124,000 ft of tunnels. Slower egress through exit tunnels from the Central campus (6.5 miles from central campus). More areas of refuge required due to additional tunnel length (every 2000 ft of tunnel). Increased campus ventilation construction and operating cost due to 70,000 ft of supply ductwork and 70,000 ft of exhaust ductwork to the central campus.
5	Ease of ventilating the Central campus with two 4300 ft supply and exhaust ducts. Ease of ventilating the Deep campus with two 3300 ft supply and exhaust ducts. Reduced operating cost of ventilating the central campus and deep campus with short shaft ducts. Fast egress through shafts to the surface. Shortest walk out egress of 6 miles from the Central campus. Lowest construction and operating cost to ventilate 32,000 ft of tunnels. Lowest construction and operating cost to light 32,000 ft of tunnels Lowest construction cost to provide fire protection for 32,000 ft of tunnels	None identified.
6	Parallel tunnels to the Central campus permit crossover egress compartmentalization. Ease of ventilating the Deep campus with two 3300 ft supply ducts and two 3300 ft exhaust ducts	Construction and operating cost to ventilate 64,000 ft of tunnels Construction and operating cost to light 64,000 ft of tunnels Construction cost to provide fire protection for 64,000 ft of tunnels

		Slower egress through exit tunnels from the Central campus (6 miles from central campus)
		More areas of refuge required due to additional tunnel length (every 2000 ft of tunnel)
		Increased campus ventilation construction and operating cost due to 64,000 ft of supply ductwork and 64,000 ft of exhaust ductwork to the central campus.
7	Ease of ventilating the Central campus with two 4300 ft supply and exhaust ducts Ease of ventilating the Deep campus with two 3300 ft supply and exhaust ducts Reduced operating cost of ventilating the central campus and deep campus with short shaft ducts. Fast egress through shafts to the surface Walk out egress of 6.5 miles from the Central campus. Low construction and operating cost to ventilate 35,000 ft of tunnels Low construction and operating cost to light 35,000 ft of tunnels Low construction cost to provide fire protection for 35,000 ft of tunnels	None identified
8	Parallel tunnels to the Central campus permit crossover egress compartmentalization. Ease of ventilating the Deep campus with two 3300 ft supply ducts and two 3300 ft exhaust ducts	Construction and operating cost to ventilate 70,000 ft of tunnels Construction and operating cost to light 70,000 ft of tunnels Construction cost to provide fire protection for 70,000 ft of tunnels Slower egress through exit tunnels from the Central campus (6.5 miles from central campus) More areas of refuge required due to additional tunnel length (every 2000 ft of tunnel) Increased campus general ventilation construction and operating cost due to 70,000 ft of supply ductwork and 70,000 ft of exhaust ductwork to the central campus.
9	Ease of ventilating the Deep campus with two 3300 ft supply ducts and two 3300 ft exhaust ducts	Most expensive construction and operating cost to ventilate 122,000 ft of tunnels Most expensive construction and operating cost to light 122,000 ft of tunnels Most expensive construction cost to provide fire protection for 122,000 ft of tunnels Slower egress through exit tunnels from the Central campus (6 miles from central campus) More areas of refuge required due to additional tunnel length (every 2000 ft of tunnel) Increased campus ventilation construction and operating cost due to 64,000 ft of supply ductwork and 64,000 ft of exhaust ductwork to the central campus.
10	Ease of ventilating the Deep campus with two 3300 ft supply ducts and two 3300 ft exhaust ducts	Construction and operating cost to ventilate 67,000 ft of tunnels Construction and operating cost to light 67,000 ft of tunnels Construction cost to provide fire protection for 67,000 ft of tunnels Slower egress through exit tunnels from the Central campus (6 miles from central campus)

		More areas of refuge required due to additional tunnel length (every 2000 ft of tunnel)
		Increased campus ventilation construction and operating cost due to 64,000 ft of supply ductwork and 64,000 ft of exhaust ductwork to the central campus.
11	Steep 18% grade allows for shorter tunnel lengths	Steep 18% tunnel grade requires special vehicles for access

5.5   Selection of Access Option

5.5.1 Selection procedure

The selection of the access option involved analysis various factors including: overall cost, functionality, surface and subsurface geology, and available technologies. . . . .

5.5.2 Selected Option

Option 11 was selected by the Kimballton Team as the preferred access option. The main factors that contributed to this decision were the desire for a connection to Kimballton Mine, reduction of access costs for tunneling versus large shafts, and reduction of tunneling costs due to increased tunnel grade.

6 Underground Layouts

Develop underground layouts based on input from the DUSEL research community (e.g. including S1) and the Kimballton Team. One or more cavern complexes, at different depths, will be necessary to accommodate the science requirements. Under this task, CNA will prepare cavern layouts appropriate for needed functionality and taking into account geological and construction factors. The layouts will accommodate the access alternatives resulting from the two-stage process in item 6.

6.1   Kimballton Mine Science Campus

6.2   Central Campus

The preferred layout of the central campus is shown in figure x.x.

6.3   Deep Campus

The preferred layout of the central campus is shown in figure x.x.

7 Conceptual Design of Tunnels and Caverns

7.1   Mainline Tunnels

Insert info from matt on inclined tunnels

7.2   Crossover and Connecting Tunnels, and Caverns

7.2.1 Excavation

The cost estimate assumes that all caverns are excavated by drill and blast methods, using smoothwall blasting procedures to maintain the integrity of the rock. All caverns are assumed

to be excavated using one 6-meter top heading, and zero or more benches depending upon total cavern height. The top headings are drilled horizontally and require longer cycle times due to the installation of roof rockbolts and shotcrete. Cavern benches are drilled vertically and have shorter cycle times, due to less rock support.

7.2.2 Primary Support Requirements Based On Empirical Methods

The primary support requirements have been assessed using the method developed by the Norwegian Geotechnical Institute (NGI, 1984; Barton and Grimstad, 1993). The method, developed from a large number of case histories, relates the required primary support to the rock mass quality, Q. The Q value is determined from the frequency, orientation, roughness and infilling of the discontinuities, the groundwater, and in situ stress conditions. The Q rating is computed from:

$$Q = \frac{RQD}{Jn} \, x \, \frac{Jr}{Ja} \, x \, \frac{Jw}{SRF}$$

where:

RQD = Rock Quality Designation
Jn = Joint set number
Jr = Joint roughness number
Ja = Joint alteration number
Jw = Joint water reduction factor
SRF = Stress Reduction Factor

Assumed Q ratings for each of the major rock formations are described in Section 4.

(See appendix C for values.)

These Q values are used to determine rockbolt spacing and shotcrete thickness, while other methods are be used to estimate the rockbolt length. Cavern rockbolt length is based on one of Lang's (1961) rules of thumb. The minimum rockbolt length is:

1.   one-half the span for spans less than 6 meters, and
2.   One-fourth the span for spans of 18 meters to 30 meters.

Figure 3.1 and Figure 3.2 show the Q rating relationships for rockbolt spacing and shotcrete thickness, respectively. The numerical values for rockbolt spacing and shotcrete thickness are:

Q Rating	Rockbolt Spacing (m)	Shotcrete Thickness (mm)
0.33	1.54	220
0.44	1.61	211
2.63	2.01	154

4.82	2.15	135
7.01	2.23	123
10.63	2.32	110
11.14	2.34	108
22.28	2.49	86
33.75	2.58	73

Table 4—Rockbolt Spacing & Shotcrete Thickness vs. Rock Quality.

The estimate assumes that the cavern sidewalls and endwalls require rock support equal to 40 percent of the roof support cost.

7.2.3 Groundwater Control

Groundwater entering the caverns and drill & blast tunnels must be controlled to maintain the tunnels in a dry condition. Some combination of grouting, waterproofing, and drainage will be used depending on the conditions encountered. The estimate includes costs for groundwater control during construction and completing permanent groundwater control.

8 Conceptual Design of Infrastructure Systems

This section describes the mechanical and electrical infrastructure necessary to support the egress tunnels, support caverns and experimental caverns. Mechanical and electrical services will serve the various elements of the laboratory consisting of the egress tunnels, the central campus chamber interconnection tunnels, lower campus chamber interconnection tunnels, the service and support caverns and the experiment caverns. Descriptions of these elements are as follows:

1. Basic services will be provided to occupied areas including power, air, potable water, fiber communications, lighting, emergency safety systems and selected drainage.
2. Ventilation systems will provide basic normal and emergency ventilation as well as distribution systems for inner caverns.
3. Central services of fresh air, chilled water, power, process piping, communications, and safety systems will terminate at the interconnection tunnels to experiment caverns for tenant connections.

8.1 Ventilation

The following design criteria were used as a basis for the conceptual design of the ventilation systems:

Outdoor Design Conditions at the site were obtained from the 2001 ASHRAE Fundamentals Handbook, which is an industry standard for heating, ventilating and air conditioning design.

Summer: 89°F dry bulb, 72°F wet bulb (Roanoke, VA)

Winter: 12°F dry bulb

Tunnel & Cavern Rock Walls

Assume a rock surface temperature of 86°F at 7000 ft depth based upon a mean annual surface temperature of 50°F and a thermal gradient of 9°C/km.

Assume an overall heat transfer coefficient: 0.125 Btu / hr-ft^2 -°F after 100 days w/o test data Assuming shotcrete and insulation applied to walls for an R value of 8

8.1.1 Egress Tunnel Ventilation System

Normal ventilation inside tunnels could be provided using a push-pull ventilation system. The systems would be served from the Central Ventilation Shaft (8.1.3) and the Central Exhaust Shaft (8.2.1). The system would consist of two sets of variable speed inline axial supply and exhaust fans. One set will be located at central campus and serve the tunnels from the portal to the central campus and from the central campus half way to the deep campus. A second set of fans will serve the tunnels from the deep campus half way to the central campus. All of the central and deep campus fans will draw from a central fresh airshaft and discharge to a central exhaust airshaft both of which terminate on the top of Butt Mountain.

Each portal will be provided with an air lock to the tunnel to maintain tunnel temperatures and reduce thermal stack effect. It is estimated that the tunnel ventilation fans under normal operation would deliver 60,000 CFM of ventilation air ventilating approximately 59,700 ft of egress tunnels at a rate of 0.05 CFM per Ft^2. Tunnel ventilation fans will also be used for smoke ventilation as described under Safety Ventilation Systems.

8.1.2 Cavern and Interconnection Tunnel Ventilation Systems

Normal ventilation inside chamber interconnection tunnels and common space caverns will be provided by dedicated air handling units providing temperature and humidity control as well as fresh air to all the occupied spaces. Each air handling system will draw fresh air from the common fresh airshaft and exhaust relief air to the common central exhaust shaft. Each air-handling unit will be provided with chilled water coils, electric heating coils to control humidity and filtration. Under normal operation the air-handling units will draw only a minimum average fresh air volume of 0.1 CFM per Ft^2 of fresh air for the caverns and connecting tunnels in the laboratory as are necessary for proper indoor air quality and to offset exhaust air volumes. Additional volumes of fresh air will be provided in clean room areas to provide proper pressurization.

Experimental caverns will be provided with a connection to the fresh air and exhaust air central shafts for connection to a dedicated air-handling unit provided when the experimental chamber is outfitted. Chilled water, electricity and drain will be provided to accommodate the future experimental air-handling unit.

Individual recirculating air handling units will be provided to serve the public spaces such as the clean tunnels, dirty tunnels, car wash, change, office and lunch/refuge spaces. Air-handling units and their associated relief/return air fans will also be used for smoke ventilation as described under Safety Ventilation Systems.

8.1.3 Central Ventilation Shaft Fresh Air Supply System

A pair of redundant variable speed inline axial supply fans, located on the top of Butt Mountain, will supply fresh air to the fresh air intake shaft serving the central and deep campus. The fan volume will be controlled to maintain positive air pressure at the base of the fresh airshaft serving the space ventilating fan systems. The fresh air fans will also be used for smoke control ventilation as described under Safety Ventilation Systems.

8.2 Exhaust Systems

8.2.1 Central Exhaust Shaft System

A pair of redundant variable speed inline axial exhaust fans, located on the top of Butt Mountain, will exhaust air from the central exhaust shaft serving the central and deep campus. The fan volume will be controlled to maintain negative air pressure at the base of the exhaust airshaft serving the space ventilating fan systems. The exhaust air fans will also be used for smoke control ventilation as described under Safety Ventilation Systems.

8.2.2 Special Exhaust systems

Two special exhaust systems, each at 10,000 CFM, will be provided for the caverns to exhaust special process, toilets, flammable liquid storage, low volume cryogenic liquid storage and other spaces with sources of contamination. This system will operate with variable volume control providing capacity as needed through sensing of duct pressure.

8.2.3 Large Volume Cryogenic Relief

Dedicated high pressure large volume cryogenic relief pipes will be run from the central and lower campus within the exhaust air shaft to the top of Butt Mountain where they will discharge away from the fresh air intake ductwork. Cryogenic chamber secondary containment vessels and airlocks, provided in the experiment fit-up, will be piped to the cryogenic relief pipes.

8.3 Cooling Systems

Cooling for the central and deep campuses will be provided by a central chilled water refrigeration system. The central chilled water system would consist of water-cooled chillers and evaporative fluid cooler towers at the tunnel portal with primary pumps to circulate the chillers. Evaporative fluid cooler towers will provide chilled water free cooling directly in the winter. Secondary duplex pumps will deliver chilled water to the central campus high-pressure heat exchanger. The central campus heat exchanger will provide chilled water to the central campus cooling coils and deep campus heat exchanger through duplex booster isolation pumps. The deep campus heat exchanger will deliver chilled water to the deep campus cooling coils through another set of duplex booster pumps   Additional booster pumps may be required at the caverns as required by the loads. The chilled water system is based upon the following load summary:

1. Laboratory Equipment Load   465 Tons

2. Lighting and People Load   260 Tons

3. Rock Heat, Ventilation Heat & Adiabatic Compression   455 Tons

4. Clean Room Fan Systems   285 Tons

Estimated Total Cooling Load: 1465 Tons of Refrigeration

The chilled water system would consist of three (3) 500-ton, air-cooled chillers, each with a primary chilled water pump sized for 750 gpm at 30 ft head (15 HP). The chilled water system would supply water utilizing a 16-degree temperature differential. Three (3) variable-speed secondary distribution system pumps, one serving as standby, would be located at the portal and sized to deliver 1125 gpm at 265 ft head (125 HP) each. Chilled water will be piped from the portal to the caverns through 16” insulated chilled water supply and return mains to the central campus heat exchanger. Two (2) variable-speed central campus distribution system pumps, one serving as standby, will be located at the central campus heat exchanger and will be sized to deliver 2500 gpm at 75HP each.

Chilled water from the secondary side of the central campus heat exchanger will be routed through 12” insulated chilled water supply and return mains to the central campus laboratory. Piping will be terminated at each common area air handling unit cooling coil, in valved connections at each cavern for tenant fit-up to tenant supplied air conditioning units and routed down the exhaust air shaft to the deep campus heat exchanger. An 85-ton sub-cooling

chiller in the deep campus will re-cool the chilled water to remove the heat of compression caused vertical head. The sub-cooling chiller heat will be removed from the condenser to the chilled water return through a 1000 gpm 10 HP condenser pump sub-loop pump. Two (2) variable-speed deep campus distribution system pumps, one serving as standby, will be located at the deep campus heat exchanger and will be sized to deliver 1030 gpm at 80 ft head (30 HP) each.

Sub-cooled chilled water from the secondary side of the deep campus heat exchanger will be routed through the deep campus laboratory and terminated at the cooling coils of each common area air handling unit as well as in valved connections at each cavern for tenant fit-up to tenant supplied air conditioning units. Tertiary booster pumps, if required due to pressure drop of detector cooling systems, will be provided by the tenant.

The facility will be provided with a direct digital control system with industry standard universal communication and bus systems for ease of future expansion. The base system will provide ample expandable points to add cavern control systems as the caverns are fitted with experiments. The DDC system will include sensors, control valves, controllers and equipment monitors for all pumps, chillers, and fans. All control devices will be networked to provide head end master control or Internet master control.

8.4   Plumbing

8.4.1 Domestic Water

Domestic water will be provided from a well near the portal or from a public potable water system. The domestic water will be stored in a 10,000-gallon water tank near the portal. Domestic water will be piped down the egress tunnels to the central and deep campus utilizing periodic pressure reducing stations to provide manageable water head pressures for domestic use. Electric water heaters will be provided at the central and deep campuses for domestic and emergency shower use.

8.4.2 Sanitary Waste

Each cavern will be provided with underground sanitary waste piping and a duplex sanitary lift station. Sanitary waste will be pumped to a central holding tank at the central campus and the deep campus. At each campus a transfer pump system will be provided for periodic removal to the surface by special waste handling vehicle. At the surface the waste will be disposed of in a privately owned sanitary waste disposal facility.

8.5   Utility Water Systems

8.5.1 Gray Water Waste

A central gray water system for rock seepage and area drainage will be provided in each cavern. Duplex sump pumps will pump gray water to a central storage sump. Transfer pumps will pump sump water through the tunnels to the portal where the water will be retained in a storage tank for evaluation before release. The gray water waste system will also be utilized to remove water from sprinkler discharge.

8.5.2 Deionized Water System

A central deionized reverse osmosis purified water system with recirculated PVDF loop will be provided for the central and deep campuses to provide experimental grade water to the entrances of each experimental cavern. The system will be sized for 10 gallons per hour and 1000 gallons storage at each level. Wastewater will be neutralized as required before releasing to the waste stream.

8.6 Process Utility Systems

8.6.1 Central Nitrogen Gas System

A central nitrogen gas system will be provided on the central and deep campus to provide clean nitrogen gas for experimental use. Nitrogen gas will be provided from a liquid nitrogen tank and evaporator with a 1" welded stainless steel loop distribution system piped to each experimental cavern.

8.6.2 Compressed Gas Systems

Compressed gas storage and piping used in experimental chambers will be evaluated for hazard and if required will be stored in ventilated gas vaults with double containment piping to maintain laboratory safety.

8.6.3 Clean Dry Compressed Air

A central oil free, dried and filtered compressed air system with distribution piping will be supplied to each experimental cavern for experimental use.

8.7 Clean Space Systems

Selected clean connecting tunnels, change rooms and other selected clean areas will be provided with individual air handling units to provide different levels of cleanliness and pressurization. The air handling units will include variable volume makeup air control, chilled water cooling coils, reheat coils and HEPA filtration to maintain the required clean room class. Corridors will be held at Class 100,000 with some adjoining and associated office areas considered unclassified clean spaces. Makeup air, chilled water and electrical power will be available to each experimental cavern to provide makeup and pressurization air for a tenant provided clean room system.

8.8 Safety Ventilation Systems

8.8.1 Compartmentalization Smoke Ventilation

An emergency compartmentalization smoke ventilation system in accordance with the International Building Code would utilize the tunnel and cavern ventilation fans in conjunction with the fresh air and exhaust air shaft fans. This system will provide makeup air and exhaust air at a rate of 6 air changes per hour to an alarm zone in the caverns and tunnels through a series of ducts and automatic dampers in the chambers and connecting tunnels. This system will provide an estimated airflow capacity for smoke control of approximately 150,000 CFM, which is approximately 6 air changes per hour in the largest segment of egress tunnel. The emergency smoke ventilating systems will be designed to ventilate the largest volume of underground space while providing pressurizing fresh air to adjoining spaces when the system is activated by automatic smoke detection or manual operation. The egress tunnels will be broken down into 20 segments through the use of automatic smoke doors, which will close thereby separating the segments in the event of smoke detection. Individual chambers and service tunnels will also be separated by smoke doors with HVAC units providing smoke control ventilation to the spaces through the fresh air and exhaust shafts when smoke is detected.

8.8.2 Smothering Gas Ventilation

Upon indication by gas sensors or manual activation, the compartmentalization smoke ventilation system may be activated to dilute and exhaust smothering gas releases from the

experimental spaces. Gas detectors connected to the central building control system will be provided to sense the hazardous and smothering gasses used in the laboratories.

8.9 Fire Protection Systems

8.9.1 Laboratory

The entire laboratory are including the caverns and connecting tunnels will be protected by a wet pipe sprinkler system fed from an on site fire water storage tank. The sprinkler system will be installed in accordance with NFPA 13 – Standard for Installation of Sprinkler systems and NFPA 22 – Standard for Fire Protection Storage Tanks. Cavern detectors containing large volumes of plastic or other combustible materials will dictate that the sprinkler system to be designed for Extra hazard group 1 which requires 910 gpm over 3500 square feet of floor area. An additional allowance of 500 gpm is also included for fire hose standpipes.

The sprinkler system will include supply piping with multiple pressure reducing stations through the tunnels to the laboratory. Sprinklers will be wet type upright heads in areas without ceilings and pendent heads with ceilings. The zones will include alarm valves, test connections, pressure reducing valves and shutoff valves. Each cavern will be zoned and supervised separately.

8.9.2 Portal Tunnels Standpipe Systems

The portal tunnels from the portals to the central and deep campuses will be provided with a Class 1 standpipe system in accordance with the provisions of NFPA 14 and NFPA 502 – Recommended Practice on Fire Protection for Limited Access Highways, Tunnels, Bridges, Elevated Roadways, and Air Tight Structures.

The systems will include fire department connections, distribution piping from the portal, supervised sectional shutoff valves, drain valves and hose connections. Hose connections will be located a maximum of 500 feet on center throughout the tunnels.

8.9.3 Fire Protection Water Storage Tank

Water for the wet pipe sprinkler fire protection system and the stand pipe system will be provided from an elevated water storage tank located outside the portal and sized to provide 1500 gpm at 150 psi. The system will also be provided with electric fill well pumps, and a fire department siamese connection.

The fire protection storage tank size is subject to the authority having jurisdiction due to the remote location of the site. Based upon preliminary information a minimum of 120 minutes of storage should be provides which indicates a 200,000-gallon firewater storage tank should be provided. The storage water tank will be insulated and heated as required by NFPA.

8.10 Electrical

8.10.1 Distribution Systems

A medium voltage electrical service will be required to serve the site. It is recommended that the service supply voltage be served at 13,800V. This service shall consist of multiple switches that will in turn serve the normal and emergency systems. Emergency and normal unit substations will be required at various locations in the tunnels as well as at each level of Campus. Electrical Vaults will be required at each of these locations for housing this equipment. Distribution at medium voltage to each substation will be accomplished via medium voltage cable encased in rigid metal conduit. Each substation will then provide

distribution at 277/480V for lighting and power supply to mechanical systems, with subsequent transformation to 120/208V for general receptacle services.

Redundant utility feeders from separate substations would be recommended. This combined with automatic medium voltage switching would provide an additional measure of reliability to the site.

The total facility electrical demand is calculated below:

Table 5 – Total Facility Electrical Demand

Occupancy		Load Type	Area (sq ft)	Volt-Amp./sq. ft. Or Load	Total Demand (VA)
Laboratory	Car Wash	Lighting	845	2 VA/ft^2	1690
		Gen. Power	845	3 kVA	2535
	Personnel	Lighting	845	2 VA/ft^2	1690
	Change	Gen. Power	845	1 VA/ft^2	845
	Offices,	Lighting	63375	2 VA/ft^2	126750
	Lunch, etc.	Gen. Power	63375	2 VA/ft^2	126750
	M & E/	Lighting	15316	1 VA/ft^2	15316
	Utilities	Gen. Power	15316	1 VA/ft^2	15316
	Refuge	Lighting	6338	1 VA/ft^2	6338
	Areas	Gen. Power	6338	2 VA/ft^2	12676
	Vehicle	Lighting	3380	1 VA/ft^2	3380
	Parking	Gen. Power	3380	3 kVA	10140
	Dirty/Clean	Lighting	8450	2 VA/ft^2	16900
	Machine	Gen. Power	8450	4 VA/ft^2	33800
	General Labs	Lighting	354000	2 VA/ft^2	708000
		Gen. Power	354000	2 VA/ft^2	708000
	MOON Solar Neutrino	Lab Eq.		80 kVA	80000
	LENS Solar Neutrino	Lab Eq.		250 kVA	250000
	HYBRID Solar Neutrino	Lab Eq.		20 kVA*	20000
	HERON solar Neutrino	Lab Eq.		125 kVA**	125000
	Clean Solar Neutrino	Lab Eq.		100 kVA **	100000
	TPC Solar Neutrino	Lab Eq.		70 kVA **	70000
	MAJORANA Double Beta Decay	Lab Eq.		25 kVA**	25000
	EXO Double Beta Decay	Lab Eq.		25 kVA**	25000
	MOON Double Beta Decay	Lab Eq.		25 kVA **	25000
	DRIFT-III Dark Matter	Lab Eq.		50 kVA **	50000

	ALNA Nuclear Astrophisics	Lab Eq.		150 kVA**	150000
	SuperCDMS Dark Matter	Lab Eq.		100 kVA **	100000
	XENON Dark Matter	Lab Eq.		110 kVA **	110000
	ZEPLIN IV Dark Matter	Lab Eq.		25 kVA **	25000
	CLEAN Solar Neut./Dark Matter	Lab Eq.		90 kVA **	90000
	EURECA Dark Matter	Lab Eq.		200 kVA **	200000
	Directional TPC	Lab Eq.		50 kVA ***	50000
	SIGN	Lab Eq.		10 kVA	10000
	HSD	Lab Eq.		50 kVA ***	50000
Miscellaneous	Peak Demand of Largest Load	Lab Eq.		475 kVA	475000
Tunnels	Lighting/Power	General Purpose Loads	600,000	0.5 VA/ft^2	300000
Electric Vehicle	Power	Emergency Power		250 kVA	250000
Mechanical					
	Cooling	General Purpose		1,930 kVA	1930000
	Ventilation	General Purpose and Emergency		3,000 kVA	3000000
	Gray Water Handling	General Purpose Power		6,500 kVA	6500000
Tenant Improvements	Miscellaneous Load	General Purpose Power		1,000 kVA	1000000
Total Demand	(Estimated)				16,800,126

Notes:

*   Estimated demand based on "modest" load

**   Average demand number used for this calculation. This load is based on file dusel_infractructure_Matrices_Rev 1.2.xls.

***   Estimated number. Final load to be verified.

Electrical service distribution feeders extending from the surface will include:

1. Two normal service feeders for double-ended substations. These would serve the facility loads as well as the mechanical systems not associated with smoke exhaust.

2. One life-safety feeder for egress lighting purposes, fire alarm, communication, etc.

3. One Emergency feeder serving mechanical equipment associated with the smoke exhaust system.

Electrical Substations:

1. One substation will be located at the on-grade entrance to the facility. The size of this will be dependant upon the surface facility demand.

2. Several substations will be distributed throughout the continuation of the tunnels. These services will be required for both the electrified truck system as well as the emergency lighting system. Thus, at various locations, there will be two independent substations.

3. Services will be located at each of the Central and Deep Campuses. The size and quantity of these services will be dependant upon the total load to be served in that area.

4. One substation will be located at the on-grade equipment at the top of the exhaust shaft of the mountain. The size of this will be dependant upon the surface facility demand.

Emergency Power

1. An emergency generation system will be necessary for the ventilation equipment related to smoke control, emergency lighting and communication systems. It is assumed that any critical experiments performed within the facility will have a dedicated UPS system, thus generation capacity is kept to a minimum.

2. The expected generation capacity is calculated to serve the egress vehicle, the smoke control fans and egress lighting. This system is expected to serve approximately 3.5 to 4 MW of load. Due to the critical nature of each system, N+1 redundancy is included, such that (3) 2 MW generators are included with the cost estimate portion of this submittal.

3. It is recommended that the owner/operator consider emergency power generation for the Gray Water pumps. This will more than double the amount of generators on site, however an evaluation of expected loss due to a power outage and the associated loss of the Gray Water pumping system may warrant the increase of the generation capacity.

8.10.2 Lighting

Both normal and emergency lighting will be required in this facility. Normal lighting levels will be as follows:

1. Caverns: Lighting shall be provided to meet 30fc at 2.5' above finished floor per IES recommendations. Additional lighting requirements shall be provided with each lab fit-up. General illumination shall be provided by the following methods: Caverns with ceiling heights higher than 12' shall be illuminated via metal halide sources. These sources shall be damp location rated. Caverns with ceiling heights lower than or equal to 12' shall be illuminated via damp location rated, surface ceiling mounted fluorescent fixtures.

2. Clean Modules: Lighting shall be provided to meet IES recommendations for Halls, or a minimum of 10fc average. The style of fixture will be commensurate with the nature of the use of the area.

3. Office, Lunch, and Shop areas: Lighting shall be provided to meet approximately 50fc at 2.5' above finished floor per IES recommendations. Additional task lighting will be included as coordinated with owner. The style of fixture will be commensurate with the nature of the use of the area.

4. Miscellaneous Areas: Lighting shall be provided to meet approximately 10fc at 2.5' above finished floor per IES recommendations. The style of fixture will be commensurate with the nature of the use of the area.

5. Emergency lighting levels will be as indicated above in this report.

6. Inbound and Outbound Tunnels: Lighting shall be 1fc minimum and served from emergency power such that each tunnel can be used as a route of egress in the event of an emergency. All light fixtures shall include a quartz re-strike function.

7. Areas of Egress: Lighting of Areas of Egress shall be 1fc minimum. This includes all occupied areas as well as electrical equipment rooms per code.

8.10.3 Lighting Control

1. Lighting control will be provided in each area as required by local codes and ordinances. In each case, Emergency and Egress lighting shall remain illuminated unless the specific nature of the lab work requires that all lighting shall be turned off. In such an instance, the emergency lighting shall automatically illuminate should there be a power outage to the site.

2. Caverns: Lighting control in each dedicated cavern will have switches located as coordinated with facility operations such that it is convenient but does not contribute to accidental loss of illumination. Lighting contactors may be utilized to control the larger caverns

3. Clean Modules: Lighting within each module will be locally controlled via wall switches.

4. Inbound and Outbound Tunnels: Lighting within the tunnels shall be controlled at the panelboard serving these areas.

8.10.4 Motors, Appliances and Equipment

Electrical distribution shall be provided to serve all motors, appliances and equipment. That portion of this equipment necessary for the evacuation of smoke or used for egress purposes shall be supplied via the emergency generation equipment and distribution. See schedules above for load calculations.

8.10.5 Fire Alarm System

A code compliant fire alarm system will be required for this facility. Due to the length of the access tunnels, a portion of the fire alarm system will utilize fiber optic cabling, with main panelboards located both at the surface as well as at specified locations in the facility. The exact nature of the

8.11 Security

This section describes the security systems necessary to provide surveillance, monitoring, and security detection of the tunnels and laboratory areas. A main security checkpoint will be located in the Portal Building. This will be the main gathering point for all security related information and alarms. One security checkpoint will also be located in the Central Campus area as well as the Deep Campus area.

8.11.1 Surveillance Camera System

The Surveillance Camera system includes cameras and associates recording and monitoring equipment to provide surveillance of the entire premises. The cameras shall be digital color cameras with pan-tilt-zoom or fixed enclosures. All cameras shall be mounted in standard plexiglass domes. Cameras mounted in the tunnels or other hazardous areas shall be mounted in environmentally sealed and pressurized domes to prevent damage from fumes or debris. Wireless cameras will be installed in the tunnel vehicles with wireless antennas at various intervals along the tunnel. Fiber optic cabling will connect the wireless antennas to the central system. In addition fixed cameras will be mounted at various intervals inside the

tunnel. Cameras shall record at low frame rates until motion is detected when the frame rates will automatically increase for detailed viewing. Wired cameras shall utilized fiber optic cabling for video transmission and PTZ control due to the long distance between the cameras and the head-end equipment.

The Surveillance Camera system shall include a Digital Video Management (DVM) system. The DVM system utilizes hard disk drives for digital video storage and software for ease of monitoring, archiving, and retrieval of stored images.

A main security station will be designed for continuous monitoring of the video images and security related alarms. In addition, the DVM software shall be connected to the Local Area Network (LAN) so any workstation on the LAN can access the video images if the user has the rights to do so.

8.11.2 Access Control System

An Access Control system will restrict access to various areas throughout the facility. The system will consist of a single cardholder database, which will hold information on the cardholder as well as a digital picture of the cardholder. The database will allow up to (10) unique security levels. The Access Control system will integrate with the Surveillance Camera system such that when a card is being presented at a card reader the camera will focus on the reader and the name of the cardholder will appear on the video screen.

Card readers shall be proximity type and also include biometric identification at various access points. Access cards shall double as identification badges. Access cards shall utilize "smart card" technology and include 2 kilobytes of on-board memory that can hold biometric information or user account information.

8.11.3 Security System

The Security system will include door contacts and motion detectors to provide security of sensitive areas. Areas can be secured by local keypad or by time of day. When a door is opened or motion is detected within the secured area, alarms will be sounded at the Main Security station. The Security system will be integrated with the camera system so if an alarm sounds in an area, cameras in that area will activate.

8.11.4 Duress Alarm System

The duress Alarm system will include duress stations at various intervals in the tunnel system as well as some of the lab buildings. Mobile duress alarms may also be given to personnel that can be activated pressing a button located on an asset locator tag. See 8.11.5 for a description of the asset locator system.

8.11.5 Asset Locator

An Asset location system will utilize an array of wireless antennas throughout the facility. These antennas will monitor the location of any assets that require tracking. The items to be tracked will have an asset tag attached to them. If an asset must remain within a certain area, the system will alarm if that asset goes beyond the limits described for it. Asset tags may also be integrated with personal security badges so personnel can be tracked if necessary. Duress alarm buttons may also be integrated with this system.

8.12 Communications

This section describes the Communication systems necessary to provide voice and data services to the tunnels and laboratory areas.

8.12.1 Backbone Cabling System

All incoming communication utilities will enter the Portal Building into a Main Point of Presence (MPOP) room. Voice utilities and fiber utilities shall terminate in this room. The backbone communications link to the Central Campus and the Deep Campus will be via single-mode fiber optic cabling. This cabling can reach distances of up to 24 miles without a repeater for 10-gigabit Ethernet protocol communications. This fiber will also act as the voice backbone to the two campuses. The Portal Building will have a Main Distribution Frame (MDF) room to distribute the backbone cabling to the other areas. 192 strands of fiber will be routed to from the Portal to each campus. An additional 192 strands of fiber will be routed between the two campuses. This provides a redundant path for communications if a fiber is damaged. Adjacent to the MDF will be the Main Equipment Room (MER) to house network servers, voice switching equipment, and other communications equipment in an environmentally controlled and secured room.

The fiber will be routed in conduit from the Portal Building to the Central Campus in conduit routed along the tunnel. Air blown fiber with empty cells for future fiber may be used to minimize the initial investment of fiber and make the installation of future fiber more cost effective. The Central Campus will include an Intermediate Distribution Frame (IDF) that will terminate the backbone cabling from the MDF. From this IDF, multimode backbone fiber will be used to distribute to remote communications closets around the campus.

From the Central Campus IDF, additional single mode fiber cabling will be routed to the Deep Campus. The Deep Campus will also include an IDF for termination of the backbone cabling from the Central Campus and routing of multimode cabling to the communications closets around the campus.

8.12.2 Horizontal Cabling System

Category 6 unshielded twisted pair (UTP) horizontal cabling will be routed from the IDF rooms and communications closets to the workstations throughout the facility. Each workstation shall receive four (4) UTP cables per workstation as a minimum. Horizontal cabling will terminate in UTP patch panels mounted in 19" telecommunications racks in each closet. The UTP patch panels will include discreet monitoring of each port for security and troubleshooting purposes.

9 Fire and Life Safety

This section describes the fire and life safety strategies and concepts necessary to promote the sustained occupancy of subterranean laboratory and support spaces at Kimbalton DUSEL. This section establishes the type and level of safety requirements necessary for subterranean facility occupancy by permanent and transient laboratory staff, vendors/contractors, and escorted education and outreach visitors. This is a preliminary code review and addresses the broader issues of Occupancy Classification, Type of Construction, Allowable Area and Heights, Fire Resistive Requirements and Occupant Load.

9.1 Jurisdiction

Fire and Life Safety requirements for Kimbalton DUSEL are based on several different levels of jurisdictional codes and occupational safety requirements. These code differences are based on the authority having jurisdiction (AHJ) requirements and an authority's regulatory or technical ability to regulate a given portion of the facility. Establishing jurisdiction on such a unique facility will require discussion and coordination with the authorities and institutions associated with the project.

Three distinct levels of jurisdictional authority are currently identified for Kimbalton DUSEL. First, tunnel construction requirements for the Department of Transportation will be used for the main access tunnels. Second, building code requirements based on uniform model codes such as International Building Code with State and local amendments will be used for surface facilities, and the subterranean campuses. Third, mining and safety requirements from the Mine Safety Hazard Administration will be used for construction of the facility and low occupancy and temporary geo-science investigations in remote areas of the site. This report deals primarily with the requirements for long-term occupied laboratory and support spaces on the surface, central and deep campuses.

9.2   Building Code

Key Components of Kimbalton DUSEL building code includes:

1. All construction shall be non-combustible.

2. Occupancies within the laboratory shall be classified and segregated based on potential hazard. Laboratory space with extraordinary hazards such as: combustibles, cryogens or corrosives shall require lower numbers of occupants, shorter exit distances, increased fire rated separation from adjacent spaces and additional detection and suppression systems based on specific hazards.

3. Occupied spaces shall be compartmentalization and have a minimum 1-hour fire rated separation. This is achieved by having either a single cavern that is compartmentalized or multiple caverns/space at each campus with 1 and 2-hour rated separations.

4. Two paths of egress from each compartment. Exit distance to smoke and fire rated separation and/or area of refuge shall be less than 300 feet.

5. Due to extreme distances from both the central and deep campuses to the surface, Areas of Refuge are created at each campus. Areas of Refuge are intended to provide a safe, non-hazard compartment where occupants can remain until rescued. Areas of Refuge are designed to have: smoke and fire separation, independent ventilation with positive pressurization and two-way communication. Area of Refuge is designed to be for short-term occupancy with access from two separate air zones. This area shall be viewed for code purposes as the public way.

6. Fire detection, alarm and suppression systems

9.3   Access Tunnel Regulations

Key Components of Kimbalton DUSEL access tunnel code includes:

1. Two separate access tunnel shall be constructed to allow two separate means of egress.

2. All construction shall be non-combustible.

3. Storage, laboratory or support space can not be located in access tunnels.

4. Access Tunnels will have smoke and fire compartmentalization at least every 2,000 feet by means of tunnel cross-over. Compartmentalization will be supported by ventilation and exhaust systems.

5. Fire detection, alarm and suppression systems.

9.4 Drift/Unoccupied Safety Regulations

Key Components of Kimbalton DUSEL drift/unoccupied safety regulations includes:

1. Safety requirements will be more based more on personnel protection. Advanced training requirements for laboratory and support staff.
2. Limited occupancy allowed.
3. Limited fire detection, alarm and suppression systems.
4. Restrictive use of hazardous materials and equipment.

9.5 References

Supplemental information included in this section includes:

1. Memorandum regarding Applicable Codes that outlines jurisdictional building codes.
2. Memorandum regarding Code Study that outlines major elements of underground building codes for the IBC, IMC, IFC and NFPA.
3. Preliminary Code Review for Kimbalton DUSEL.
4. Preliminary Code Review Diagrams for Central and Deep Campuses for Kimbalton DUSEL.

Supplemental information not included by referenced includes:

1. International Building Code
2. Virginia Uniform Statewide Building Code
3. National Fire Protection Agency – Subterranean Space Code and Life Safety Code.
4. Mine Safety and Health Administration

10 Project Cost and Schedule

All costs are assumed to be expended in the year 2005. The following costs are considered in this report: heavy civil, mechanical & electrical,

10.1 Heavy Civil Costs

10.1.1 Portals

10.1.2 Tunneling Costs

The development of appropriate tunneling costs involved comparison of several similar past projects or studies: VLHC (Chicago 2001), MSP Light-Rail Tunnel (Minnesota 2002), Cascades – DUSEL (Washington 2003), and San Jacinto – DUSEL (California 2003). Considerations were made for differences in size, location, and time. For the basis of costs the Project site was assumed to be Roanoke Virginia because this was the closest similar location for which data was available.

The change in cost for varying diameters can depend on many factors including: available technology, site geology and hydrology, and tunnel diameter. Size escalation for tunnels for the range of diameters considered in this report involves a very simple linear relationship between cost and size.

$$\mathrm{Pr}\,oject \cdot Cost = \left(\frac{\mathrm{Pr}\,oject \cdot \phi}{Model \cdot \phi} \right) \times Model \cdot Cost$$

ϕ = Tunnel outside Diameter

The change in cost with time and location was considered using factors published in RSMeans Building Construction Cost Data for the year 2003. The following relationship was used to determine project costs.

$$\mathrm{Pr}\,oject \cdot Cost = \left[\frac{\mathrm{Pr}\,oject \cdot Index \cdot (2005)}{Model \cdot Index \cdot (Base \cdot Year)} \right] \times Model \cdot Cost$$

10.1.3 Shaft Costs

Shaft costs were calculated rule of thumb relations between shaft costs and tunneling costs. An additional factor was used to account for size.

10.1.4 Cavern Construction

10.2 Mechanical & Electrical Costs

10.3 Cavern Outfitting

10.4 Schedule

1. Develop CNA project schedule with milestones

Attachment 3: Kiruna Haulage Trucks

KIRUNA ELECTRIC TRUCK SYSTEM K1050E

Technical Specification

Content:

This drawing may be subject to changes without notice

Denna ritning gäller utan förbindelse

2830

6276

10570

3250

3187

K1050E

R4900

3418

3418

R10299

Appendix
249

1   Electric Truck K1050E

1.1   General

The electrical truck is designed as a ramp haulage vehicle where all functions are electric.

The main data for the truck is:

Payload	50 tonnes
Tare weights	40 tonnes
Supply voltage	690 V, 3-phase AC (optional 1050 V with onboard transformer 1050/690 V))
Length	10,64 m
Width	3,55 m
Height	3,35 m
Available box capacity	17, 20, 24 or 28 cubic meters, heaped

(To be matched to density of ore)

Temperature range	0-40 deg C (derating if higher)
Altitude	0-1000 m asl (derating if higher)
Base speed	16 km/h full load up, max slope,, 30 min
Max speed	25 km/h empty down
Acceleration	0.5 m/s^2
Off line speed	5 km/h loaded, 2 % inclination

Note: Box capacity is based on theoretical S.A.E. 2:1 calculations. Long-term volumetric load capacity is a function of loading under actual mine operating conditions. Length of truck will vary slightly with different box capacity.

The power to the truck is supplied from a trolley line, which is erected in the roof of the tunnel.

The trolley line voltage is 690 V (optional 1050 V), 3-phase, AC. The voltage is fed through the trolley arm to the truck where the voltage is converted to a DC-bus intermediate power supply. The DC-voltage is then converted by frequency convertors and supplies the two traction motors. One of the motors is driving the two front wheels and the other the rear wheels. The motors are rated for 315 kW (50 Hz) continuous power each. For non-continuous use (which is the normal case) a considerable higher power can be utilised.

By means of the diesel generator on board, the truck can leave the trolley line for e.g. loading, dumping etc.

The truck has the same torque available when working on the diesel as when working on the trolley line.

In offline mode the drive is not speed limited but power limited. The implication of that is that the speed can be maintained only if the required propulsion power is lower than what the diesel-generator can provide.

The operator uses the throttle for speed control.

690 V AC 50/60 — Trolley line

Active rectifier

ABB Control System
and
Information System

DC-bus

Clutch

M — Service Motor/Generator

D — Diesel Motor

Inverter Units

Traction Motors

M   M
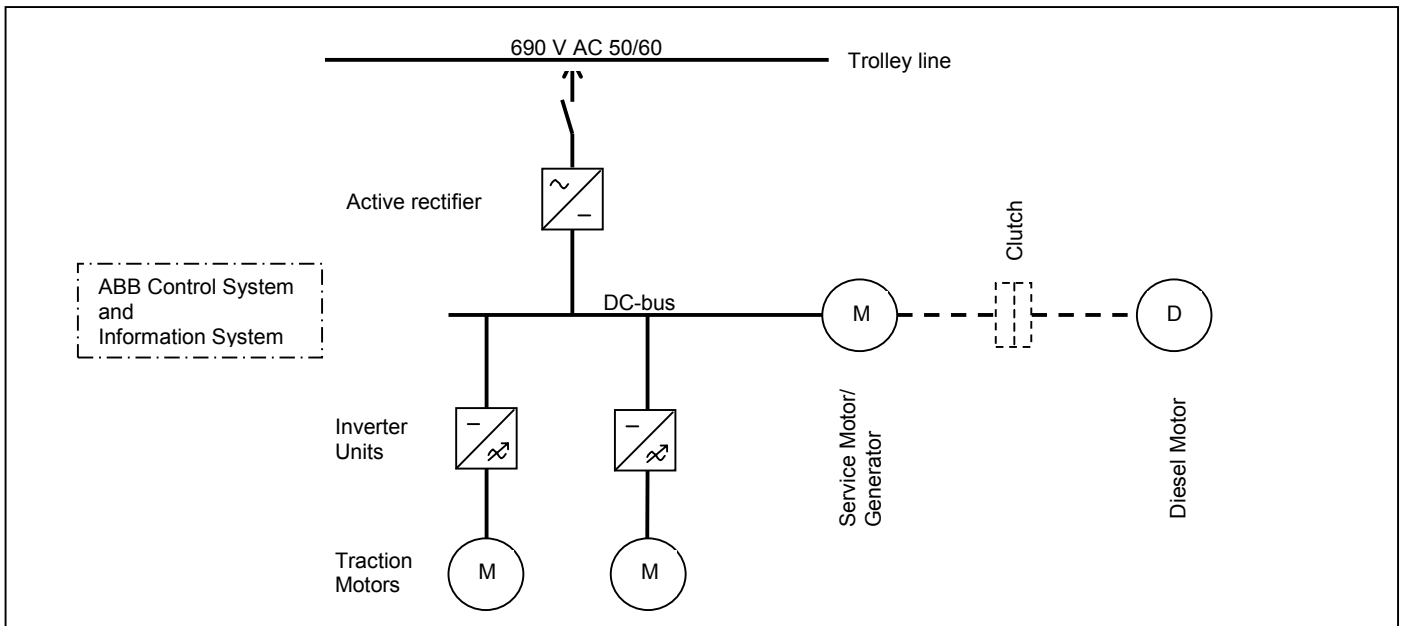
Single line diagram

1.2   Active rectifier

The active rectifier is a three-phase IGBT Supply Unit (ISU) with following main data:

Supply voltage	690 V, 3-phase AC
Rated input power	802 kW AC
Rated input current	695 A AC

1.3   Main frequency convertors

There is one frequency converter for each motor. The two main frequency convertors (Inverter Units, INU) have the following main data.

Supply voltage	690 V, 3-phase AC
Rated output power	490 kW AC
Rated output current	410 A AC

1.4   Main Motors

The two main motors are totally enclosed squirrel cage three phase induction motors.
The motors are each provided with a cooling fan supplied with 3-phase AC voltage.

Rated voltage	690 V DC
Rated current	315 A
Rated RMS output acc. To IEC	315 kW

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The motors are also provided with Pt 100 elements to measure the temperature and protect the motors against too high temperature.

Both motors have a built-on pulse transmitter used for the speed control.

1.5   24 V Battery

Truck electrical service system, 24 V for lighting and auxiliary systems

Type   lead acid traction batteries
Capacity   158 Ah
Voltage   2 x 12 V

1.6   Diesel generator set

The generator is mechanically connected to the diesel motor with a flexible coupling and a freewheel clutch. The generator is free to rotate when the diesel motor is at rest. When the diesel motor is started the clutch will engage when the diesel motor reaches the same speed as the generator. If the diesel motor then rotates slower than the generator the clutch will disengage.

On the other side of the generator there is belt drives driving auxiliary units. The auxiliary units are the hydraulic pump, the 24 V generator and the compressor for the air conditioning of the drivers cabin. The diesel motor, generator and the auxiliary units are mounted in a frame.

The diesel motor is an 81 kW Detroit 6-cylinder turbo charged model with direct fuel injection.

When the truck is disconnected from the trolley line the diesel motor is driving the service motor/generator and the auxiliary units.
The generator is supplying power to the frequency convertors DC-bus.

When the truck is connected to the trolley line the generator is working as a motor driving the auxiliary units.
The generator/motor is taking power from the frequency convertors DC-bus.

1.7   Power switching sequence between diesel supply and trolley supply.
The diesel motor is started and the generator is feeding the DC-supply with power.

The truck is driven to the trolley line and connected to the supply. The DC-supply is now fed from the trolley line. The diesel motor is automatically stopped.

The truck reaches the end of the trolley line. A proximity switch is indicating that the truck is close to the end and gives order to start the diesel motor. The truck is

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disconnected from the trolley line. If there is no proximity switch the diesel will start when the trolley is disconnected and there will be a small delay of some seconds before the full traction is available.

Passing from one trolley line section to another is done without starting the diesel motor.

1.8   Diesel Motor

Type	Detroit 706LT or similar
Power	81 kW continous at 1500 rpm
Fuel tank	80 l (equal 5-6 hour of continous duty)
Emission	EEC 77/537, EEC 72/306
	Stage 1 off – highway (C1–8 mode cycle, ISO 8178)

1.9   Service Motor/Generator

The service motor is a standard DC-motor. The motor will also be used as generator. See separate description.

Power	20 kW (short time 80 kW)
Rated voltage	930 V DC
Rated current	22 A DC

The motor is provided with a separate cooling fan with air filter. This fan is driven by an AC-motor.

1.10   Control and Regulation System

The central unit for control and regulation is an ABB type computer.

The computer takes care of the sequence and interlocking of the trolley arm, frequency convertors, dumping of the rock box weight measurements and fault indications.

The trolley arm is operated by means of a switch from the cabin.

When the truck comes to a branch or an intersection a proximity switch is energised by a flag at the trolley line and after a certain time the trolley car will be disconnected automatically. During this time an indication in form of flashing lamp and a sound will be given.

The driver can acknowledge the signal by a push-button in the cabin and then the trolley will continue to be connected.

The rock box is operated from the cabin and it can only be raised when the trolley arm is in down position and the truck stands still. However at connection to

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trolley line the rock box can be raised if the two proximity switches for intersection control are energised.

The driving of the truck is interlocked with rock box down and that the service motor is on.

The start of the truck proceeds in that way that the driver pushes down the throttle slowly, the frequency convertors will get reference.

The current reference to the frequency convertors comes from the speed regulator that has a P-characteristic. The reason to this is to be able to vary the torque by means of the throttle and also to have a regulation that when close to the set speed the torque will be decreasing.

The electrical braking is automatically engaged when the driver releases the throttle. The electrical braking is done by using the traction motors as generators. The braking energy is regenerated to the trolley line power supply. The electrical braking is therefore only working when the trolley is connected.

If the speed of the two motors diverges from each other too much a limitation of the motor current is performed by a regulator in order to avoid slip.

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1.11 Rock Box

Heavy duty, low profile constructed from high abrasion resistant steel with minimum hardness of 360 Brinell. Stiffeners on bottom, sides and front for impact resistance.

Single 5-stage telescopic hoist cylinder equipped with speed control.

Tripping angle 57 deg.
Box rise/lowering time   30 seconds

1.12 Front Chassis

Rigid box section built from high yield strength steel, 390 N/mm². Integrated hydraulic tank and battery compartment. Bumpers on front and sides.

Two rubber cushions and shock absorbers between axle and chassis.

Articulated hydraulic steering by double acting cylinders. Fully hydraulic closed centre system.

Steering angle   +/- 45 deg.

Oscillation between front chassis and rear frame   +/- 15 deg.

Emergency steering provision in the event of hydraulic pump or motor failure.

Electric motor and drive axle mounted in a frame, connected to chassis.

1.13 Rear Frame

Rectangular hollow box section from high yield strength steel, 390 N/mm².

Two rubber cushions and shock absorbers between rear axle and rear frame.

Electric motor and drive axle mounted in a frame, connected to rear frame.

1.14 Drive Axles

Two rigid axles with differential and final planetary reduction. Total reduction adapted to ramp inclination.
Type   Kiruna 5062 or Clark

1.15 Hydraulic System

Vane type pumps for steering, braking, hoisting and current collector, driven by auxiliary D.C. motor.

Working pressure   14.5 - 17.5 MPa
Tank capacity   450 dm^3 (l)

Pressure accumulator for braking, steering, dumping and current collector systems.

1.16 Braking Systems

Standard service brakes with dual circuits; hydraulic multi-disc brakes with oil cooling. In normal working condition the truck is connected to the trolley line and electrical braking is used, see Control and Regulation System.

Parking brake, spring applied oil released dry disc brake.

Service brakes also applied when loading brake activated.

Parking brake and rock box hoisting interlocked for safety.

Parking brake and 24 volt starting circuit interlocked for safety.

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1.17 Operator's Cab

Pressurised fully enclosed cab with filtered air intake. Sound insulation for maximum noise level in the cab should not exceeding 85 dBA with all windows closed and truck delivering full power.

Standard reinforced cab designed to meet FOPS specification. (No destructive test has or will be made for this cabin construction.)

- Front windshield wipers and washers

- Electrically adjustable rear view mirrors

- Operator controls, gauges and indicators for safe and easy operation

- Adequate handrails, steps and anti-slip surfaces for safe ingress and egress

- Emergency "kick out window"

- Two fire extinguishers

- Head lights, brake lights, back-up light and alarm, directional and tail lights, air horn

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2   Trolley line and pick-up system.

2.1   Pick-up system

The current pick-up system contains a trolley car, which rolls on the guide rails, and with 6 brushes to collect the current and an arm connecting the trolley car with the truck. The arm is suspended to keep pressure upwards to the trolley car and pivots horizontally as well as vertically.

When the trolley car is disconnected the trolley arm is lowered to a horizontal rest position. For reconnection to the trolley line, a precision of approx. ± 0.5 meters in respect to the trolley line is required. The driver pushes a button and connection is automatically made. The truck speed during connection can be up to 4 km/h. Disconnection can be made at any speed.

The trolley arm allows the truck to deviate approx. ± 2 meters from the centre of the trolley line when connected.

The trolley pick-up is allowed to rotate approx. $\pm 60°$ from it's central position and to tilt approx. $\pm 7°$ from it's horizontal axles.

2.2   Trolley line

The trolley line is sectioned electrically in 800-1000 m sections. Every such section of trolley line being powered by a single transformer sub-station.

The trolley line consists of rock bolts, steel supports and current conductors with insulators, holders and joints. At change over points, (going from a main ramp to a branch), the trolley line installation in the branch is started a distance from the trolley line in the main ramp.

There is a preference for intersections to be driven at "Drainage Grade". Intersections driven on Grade (plus 3 %) can be accommodated by extending the branch trolley line parallel to the main ramp trolley line for a short distance.

2.3   Mechanical switches

The Kiruna Electric does not require the use of mechanical trolley line switches.

2.4   Standard Trolley Line Layouts

The total trolley line is divided into numbered sections; straight and curved with different radii. The point where one type of section is followed by another type of

section (straight/curved) is used as a reference point for erection of the supports in the tunnel. Longer straight sections are sub-divided with reference points every 100 m. Curves have reference points at the beginning and the end of every 10 m curve section. The co-ordinates of the reference points are calculated and tabulated.

Straight steel supports are assembled in 10 m sections. Curved steel supports are manufactured with standard curve radii 15 m, 30 m, 50 m and 70 m and are assembled, by the mine, to arc lengths of about 10 m. When needed, they can be cut to 3/4, 1/2 or 1/4 of length.

The trolley line is secured to the back by two rock bolts every 5 meters. To accommodate back irregularities, if necessary, the distance maybe reduced to 2.5 meters. No additional support or reduction in support spacing is required on curved sections. When long rock bolts must be used due to back irregularities, it is recommended to cross brace the rock bolts to the back.

2.5   Rock Bolts

Rock bolt holes are drilled vertically, about 30 mm in diameter to a depth of approximately 300 mm; depending on rock quality. The rock bolts, normally supplied by the mine, must be of weldable material and 20 mm in diameter. The grouted rock bolt must be able to support a tensile stress of 5 tonne. Should the length of the exposed portion of rock bolt exceed 1.5 meters due to back irregularities, cross bracing to the back is recommended for stability.

2.6   Design

ABB consults with mine planning engineers to optimise trolley line layout and haulage efficiency. This includes loading and dumping layouts to minimise traction battery usage, installation of trolley line in existing excavations, ramp junctions and general trolley line layout.

2.7   Trolley Componentry Supply

The trolley line components are supplied to the mine site 3 to 5 months prior to arrival of the Kiruna Electric Truck. This permits trolley line assembly and installation to be completed in time to proceed with system commissioning and training.

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3   Transformer sub-stations

General

The transformer sub-station is supplied by ABB as an integral component of the Kiruna Electric System.

The standard 1600 kVA transformer is designed to provide power to approximately 800 - 1000 meters of trolley line on which up to two loaded K1050E trucks can be driven simultaneously up the ramp.

The actual length of trolley line to be powered by a transformer sub-station is subject to an engineering evaluation and consultation between the mine's and ABB's engineering staff.

Adjacent sections of trolley line, powered by individual transformer sub-stations, are electrically isolated by a trolley line "sectioning assembly".

A transformer sub-station is located approximately in the centre of the stretch of trolley line to which it is providing power, and physically located within 50 meters of the trolley line.

3.1   Dry type transformer with enclosure (T1)

Rated power (kVA)	1600
Primary voltage HV (kV)	4-10,5 $\pm$ 2 x 2.5 %
Secondary voltage LV (V)	690
Impedance at 75° C %	6
Protection class	IP 23
Insulation class	F
Coupling	Dyn 11
Standard	IEC 726
Enclosure	IP23

3.2   Switchgear

Factory assembled standard metal-clad type indoor switchgear for free standing erection. Designed for 40.0 kA short circuit current for 1s corresponding to 762 MVA at 11 kV. Basic insulation level 75 kV peak 1,2/50 and 50 Hz during 1 min. The switchgear conforms to applicable sections of the requirements of IEC Publication 298.

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4   Electric protection circuits

As the truck is a vehicle with rubber wheels the chassis of the truck has no contact to the ground and thus the chassis has a floating voltage against the ground.

On board the truck a synthetic zero point is build up with resistors and as long as the system is in balance i.e. when no phase difference, no connection phase to chassis, no ground faults, the earth fault current is zero. If now a lack of symmetry occurs and the earth fault current will be > 11 mA the earth fault protection unit trips within 300 msec and orders the main contactor to break the main circuit and then the trolley arm to go down to the rest position and thus disconnects the truck from the trolley line.

The earth fault protection unit is designed to maximise the earth fault current to 30 mA in order to prevent personal hazard.

5   Documentation

Three (3) sets of documentation in English language are included in the delivery.

The documentation consists of the following main items:

- Instruction book (mechanical) K1050E
- Spare parts book (mechanical) K1050E
- Functional Description
- Electrical Circuit Diagrams
- PC-diagrams
- Apparatus lists
- Product manuals

6   Options

6.1   Truck

Automatic lubrication system
Fire suppression system
Tire pressure warning
Cabin air conditioning
TV camera with monitor
Hydraulic jacks
Tailgate
Wear plates
Spare parts package

6.2   General

Erection and commissioning
Training program operators
Training program mechanics
Training program electricians

Appendix I-a: *Preliminary* Code Review

Date: **February 22, 2005**
Project: **Kimbalton DUSEL, Pre-S-2 Submittal**
CNA0402

Note: Shaded Sections not complete.

PRELIMINARY CODE REVIEW

Building Code: **International Building Code - 2003 Edition**
Virginia Uniform Statewide Building Code - 2000 Edition (Effective 10/1/03)
Virginia Americans with Disabilities Act - 2003 Edition
International Energy Conservation Code - 2000 Edition
Subterranean Code: **National Fire Protection Association - Subterranian Space Code (NFPA 520)**
National Fire Protection Association - Life Safety Code (NFPA 101)
IBC 2003 Edition - Section 405
Electrical Code: **National Electrical Code - 1999 Edition**
Plumbing Code: **International Plumbing Code - 2000 Edition**
Mechanical Code: **International Mechanical Code - 2000 Edition**
Fire Protection Code: **Virginia Statewide Fire Prevention Code - 2000 Edition**

A. OCCUPANCY CLASSIFICATION

[Section 302.1, Table 302.3.3]

GROUP	DESCRIPTION OF AREA
B	Offices and y & Meeting Rooms
H-2	Laboratories with a deflagration or accelerated burning hazard including Class I, II or III flammable or combustable liquids
H-3	Laboratories with a combustion or physical hazard including cryogen liquids
S-1	Storage
S-2	Enclosed Paaed Parking Garage

ACCESSORY USE AREA (IF ANY):   [Section 302.2]

Not Applicable

MIXED OCCUPANCY: [Section 302.3]

Group B to Group H-2 = 2-hour separation required

Group B to Group H-3 = 1-hour separation required

Group H-2 to Group H-3 = 1-hour separation required

Section 302.3.3 Separated Uses - Separation required with Group H Occupancy

INCIDENTAL USE AREAS (IF ANY):   [Table 302.1.1]

2-hour separation around Automotive Parking Garage

1-hour separation around storage room greater than 100 s.f.

B. TYPE OF CONSTRUCTION

[Table 601, Section 602]

Type I A

C. ALLOWABLE HEIGHTS AND BUILDING AREA

[Table 503]

HEIGHT MODIFICATIONS: [Section 504]

OCCUPANCY	ALLOW. HEIGHT	SPRINKLER INCREASE	ALLOW. STORIES	SPRINKLER INCREASE	ACTUAL HEIGHT	ACTUAL STORIES
B	UL	NA	UL	NA	TBD	TBD
H-2	UL	NA	UL	NA	TBD	TBD
H-3	UL	NA	UL	NA	TBD	TBD
S-1	UL	NA	UL	NA	TBD	TBD
S-2	UL	NA	UL	NA	TBD	TBD

AREA MODIFICATIONS: [Section 506, Equations 5-1 and 5-2]

Basic Allowable Area =	**Unlimited**
Sprinkler Increase =	**NA**
Frontage Increase =	**NA**
Total allowable Floor area =	**Unlimited**

UNLIMITED AREA ALLOWANCE APPLICABLE: [Section 507]   YES

BUILDING AREA:	OCCUPANCY		ALLOWABLE AREA	ESTIMATED AREA
Surface Facilites:	B	-	**UL**	**150,000**
Central Campus:	B, H & S	-	**UL**	**272,700**
Deep Campus:	B, H & S	-	**UL**	**163,100**
BUILDING TOTAL:			**UL**	**585,800**

Note:

1 Separated Uses (Section 302.3.3)

2 Estimated Area is Gross Square Footage and includes tunnels

D. FIRE RESISTIVE REQUIREMENTS BY TYPE OF CONSTRUCTION

[Table 601 and 602]

CONSTRUCTION TYPE: I-A

CONDITION	REQUIREMENT	NOTES
1. STRUCTURAL FRAME	3	
2. BEARING WALLS-EXTERIOR	3	
3. BEARING WALLS-INTERIOR	3	
4. NONBEARING WALLS-EXTERIOR	0	Separation Distance >/=30'-0"
5. NONBEARING WALLS-INTERIOR	-	
6. FLOOR CONSTRUCTION	2	
7. ROOF CONSTRUCTION	1 1/2	

FIRE RESISTIVE SUBSTITUTION (IF APPLICABLE):   NA

E. EXTERIOR WALL AND OPENING PROTECTION --- (TO BE DETERIMINED)

[Table 602, Section 704.12 table 704.8]

FIRE RESISTANCE REQUIREMENTS FOR EXTERIOR WALLS BASED ON FIRE SEPARATION DISTANCE

Separation Distance (ft.):	>5-10	>10-30	>30
Fire Resistance Rating	1 hour	1 hour	1 hour

MAXIMUM AREA OF EXTERIOR WALL OPENINGS - UNPROTECTED

Separation Distance (ft.):	>5-10	>10-15	>15-20	>20-25
Maximum Window Area	-	-	-	-
Actual Window Area	-		-	
			-	
			-	

Note:

1 Allowable areas for Protected Openings used due to Section 704.8.1 for Sprinkled Building

F. OCCUPANT LOAD AND NUMBER OF EXITS (TO BE FINALIZED)

[Table 1003.2.2.2, Section 1003.2.2, 1003.2.3, Table 1004.2.1]

OCCUPANCY CATEGORY	NO.	NAME/DESCRIPTION	AREA (sf)	LOAD FACTOR	OCCUP. LOAD	REQD. EXITS	PROV. EXITS	NOTES
SURFACE FACILITIES								
Business	-	Visitor Ctr & Admin.	25,000	100	250	-	-	-
Residence	-	Housing	25,000	200	125	-	-	-
Storage	-	Warehouse	50,000	300	167	-	-	-
Hazard	-	Laboratories	50,000	100	500	-	-	-
		SURFACE SUB-TOTALS	**150,000**		**500**			
CENTRAL CAMPUS								
Business	-	Common Facilities	44,400	100	444	-	-	-
Hazard	-	Module A	62,000	300	207	-	-	-
Hazard	-	Module B	17,600	300	59	-	-	-
Hazard	-	Module E	22,300	300	75	-	-	-
Hazard	-	Module F	1,600	300	6	-	-	-
Hazard	-	Module H-K	13,560	300	46	-	-	-
Storage	-	Car Parking	1,725	200	9	-	-	-
		CENTRAL CAMPUS SUB-TOTALS	**163,185**		**846**			
DEEP CAMPUS								
Business	-	Common Faciliites	37,000	100	370	-	-	-
Hazard	-	Module A	7,100	300	24	-	-	-
Hazard	-	Module D	33,900	300	113	-	-	-
Hazard	-	Module H-K	30,800	300	103	-	-	-
Storage	-	Car Parking	1,725	200	9	-	-	-
		DEEP CAMPUS SUBTOTALS	**110,525**		**619**			
		BUILDING TOTALS	**423,710**		**1,965**			

Note:

1 All Occupancies shall have minimum 2 exits per

2 Area used to determine occupant load will require modification for experiment mass

G. EXITING --- (TO BE DETERMINED)

EXIT WIDTH

[Table 1003.2.3]

LEVEL	OCC. LOAD FOR LEVEL	TRIB. OCC. LOAD	TOTAL OCC. LOAD	REQ'D. TOTAL EXIT WIDTH	ACTUAL TOTAL EXIT WIDTH	ACTUAL NO. OF EXITS	OCC. LOAD PER EXIT	REQ'D. EXIT WIDTH PER EXIT	NO. OF EXITS W/ STAIRS	OCC. LOAD AT STAIRS	REQ'D. STAIR WIDTH
				(0.15 inch/occ.)				(0.15 inch/occ.)			(.20 inch/occ.)
Surface Fac.	-	-	0	#VALUE!	-	-	#VALUE!	#VALUE!	-	#VALUE!	#VALUE!
Cen. Campus	-	-	0	#VALUE!	-	-	#VALUE!	#VALUE!	-	#VALUE!	#VALUE!
Deep Campus	-	-	0	#VALUE!	-	-	#VALUE!	#VALUE!	-	#VALUE!	#VALUE!

Note:

1 Exiting to further developed at the individual facility or campus level.

EXIT ACCESS TRAVEL DISTANCE: [Table 1004.2.4]

OCCUPANCY	ALLOWABLE **	ACTUAL *
B	300	TBD
H-2	100	TBD
H-3	150	TBD
H-4	175	TBD
S-1	250	TBD
S-2	400	TBD

Note:

*   (Actual travel distance to exit/area of refuge; not to public way.)

**   with sprinkler system

TRIBUTARY STAIR WIDTHS

	STAIR x
Surface Facilities	-
Central Campus	-
Deep Campus	-
Total Required Stair Width	0
Actual Stair Width	**TBD**

CORRIDOR CONSTRUCTION (w/ sprinkler system)

Occupancy	Req'd Rating
Business	0
Hazard	2
Storage	1

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H. PLUMBING FACILITIES --- TO BE DETERMINED

[Table 2902.1]

			Occupancy Category		
			Business	Hazard	Storage
		No. of Occupants	1,064	1,030	18
Water Closets	Male	Occupant Factor	50	100	0
		Req'd	0	#VALUE!	#DIV/0!
		Provided	TBD	TBD	TBD
	Female	Occupant Factor	50	100	0
		Req'd	0	#VALUE!	#DIV/0!
		Provided	TBD	TBD	TBD
Lavatories		Occupant Factor	80	100	0
		Req'd	0	#VALUE!	#DIV/0!
		Provided	TBD	TBD	TBD
Drinking Fountains		Occupant Factor	100	400	0
		Req'd	0	#VALUE!	#DIV/0!
		Provided	TBD	TBD	TBD
Service Sink		Req'd	1	1	0
		Provided	TBD	TBD	TBD

Note:

Note: These calculations do not apply to buildings with unlimimted area.

Date: **2/18/2005**
Project: **Kimbalton DUSEL**
CNA0402

IBC Area Increase Calculation - Section 506

Enter project specific information in shaded cells

Frontage Increase		
	Notation	Value
Building perimeter fronting on public way or open space with 20 ft. minimum width (LF)	F	312
Perimeter of entire building (LF)	P	703
Minimum width of public way or open space (LF)		50
Minimum width of public way or open space (LF) divided by 30 </=1	W	1.00

Area increase due to frontage (%)	If	**19**

Automatic Sprinkler System Increase	
Number of stories	3
Does the building contain Occupancy Group H-1, H-2, or H-3? If the answer is yes, enter a "1"	0

Area increase due to sprinkler protection (%)	Is	**200**

Allowable Floor Area		
	Notation	Enter Value
Allowable area per floor in from Table 503 (SF)	At	9500

Allowable area per floor (SF)	Aa	**30,341**

Note: These calculations do not apply to buildings with unlimimted area.

Date: **2/18/2005**
Project: **Kimbalton DUSEL**
                 CNA0402

Plubming Systems

MINIMUM NUMBER OF PLUMBING FACILITIES

[Table 2902.1]			Occupancy Category		
			Assembly*/**	Business***	Storage
		No. of Occupants	1,078	40	25
Water Closets	Male	Occupant Factor	125	50	100
		Req'd	5	1	1
		Provided	6	3 in unisex	
	Female	Occupant Factor	65	50	100
		Req'd	9	1	1
		Provided	9****	included in above	
Lavatories		Occupant Factor	200	50	100
		Req'd	6	1	1
		Provided		3 in unisex	
Drinking Fountains		Occupant Factor	500	100	1,000
		Req'd	3	1	1
		Provided	5		
Service Sink		Req'd	1		
		Provided	2		

* Using subcategory for "Theaters, halls, museums, etc."
** Full occupant load for Terrace included, although this occupancy would not coincide with full use of meeting room.
*** Business category served by 3 accessible unisex restrooms.
**** Includes family unisex restroom in Children's area.

Code Study
Kimbalton DUSEL Solicitation 2 proposal
Comm. No.:   0404075
December 21, 2004

Definition of an Underground Building

- IBC Section 405.1 – (Underground Buildings) General. "The provisions of this section apply to building spaces having a floor level used for human occupancy more than 30 ft below the lowest level of exit discharge."
- NFPA 101 – Life Safety Code Section 101.3.3.217.11 Underground Structure "A structure or portions of a structure in which the floor level is below the level of exit discharge."

Construction Requirements

- IBC Section 405.2 – (Underground Buildings) "The underground portion of the building shall be of Type I construction."

Egress Requirements

- IBC Section 405.8 – (Underground Buildings) Means of egress. "Means of egress shall be in accordance with Sections 405.8.1 and 405.8.2."
  - o IBC Section 405.8.1 – Number of Exits. "Each floor level shall be provided with a minimum of two exits. Where compartmentation is required by Section 405.4, each compartment shall have a minimum of one exit and shall also have an exit access doorway into the adjoining compartment."
  - o IBC Section 405.8.2 – Smokeproof Enclosure. "Every required stairway serving floor levels more than 30 feet (9144 mm) below its level of exit discharge shall comply with the requirements for a smokeproof enclosure as provided in Section 1019.1.8."
- IBC/IFC Section 1019.1.8 – Smokeproof Enclosures. "In buildings required to comply with Section 405 or 405, each of the exits of a building that serves stories where the floor surface is located more than 75 feet (22,860 mm) above the lowest level of fire department vehicle access or more than 30 feet (9144 mm) below the level of exit discharge serving such floor levels shall be a smokeproof enclosure or pressurized stairway in accordance with Section 909.20 of the International Building Code."
  - o IBC/IFC Section 1019.1.8.1 – Enclosure exit. "A smoke proof enclosure or pressurized stairway shall exit to a public way or into an exit passageway, yard or open space having direct access to a public way. The exit passageway shall be without other openings and shall be separated from the remainder of the building by 2-hour fire-resistance-rated construction. Exceptions: 1) Openings in the exit passageway serving a smokeproof enclosure are permitted where the exit passageway is protected and pressurized in the same manner as the smokeproof enclosure, and opening s are protected as required for access from other floors. 2) Openings in the exit passageway serving a pressurized stairway are permitted where the exit passageway is protected and pressurized in the same manner as the pressurized stairway."
  - o IBC/IFC Section 1019.1.8.2 – Enclosure access. "Access to the stairway within a smokeproof enclosure shall be by way of a vestibule or an open exterior balcony. Exception: Access is not required by way of a vestibule or exterior balcony for stairways using the pressurization alternative complying with Section 909.20.5.

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- IBC Section 909.20 – Smokeproof enclosures. "Where required by section 1019.1.8, a smokeproof enclosure shall be constructed in accordance with this section. A smokeproof enclosure shall be consist of an enclosed interior exit stairway that conforms to Section 1019.1 and an outside balcony or ventilated vestibule meeting the requirements of this section. Where access to the roof is required by the International Fire Code, such access shall be from the smokeproof enclosure where a smokeproof enclosure is required.
    - o IBC Section 909.20.1 – Access. "Access to the stair shall be by way of a vestibule or an open exterior balcony. The minimum dimension of the vestibule shall not be less than the required width of the corridor leading to the vestibule but shall not have a width of less than 44 inches (1118 mm) and shall not have a length of less than 72 inches (1829 mm) in the direction of egress travel."
    - o IBC Section 909.20.2 – Construction. "The smokeproof enclosure shall be separated from the remainder of the building by not less than a 2-hour fire fire-resistance-rated fire barrier without openings other than the required means of egress doors. The vestibule shall be separated from the stairway by not less than a 2-hour fire-resistance-rated barrier. The open exterior balcony shall be constructed in accordance with the fire-resistance-rating requirements for floor construction."
    - o IBC Section 909.20.2.1 – Door Closers. "Doors in a smokeproof enclosure shall be self-closing or automatic closing by actuation of a smoke detector in accordance with Section 715.3.7. The actuation of the smoke detector on any door shall activate the closing devices on all doors in the smokeproof enclosure at all levels. Smoke detectors shall be installed in accordance with Section 907.10." *907.10 included under smoke detection section of this document.*
- IBC Section 1019.1 – Enclosures required. "Interior exit stairways and interior exit ramps shall be enclosed with fire barriers. Exit enclosures shall have a fire-resistance rating of not less than 2 hours where connecting four stories or more and not less than 1 hour where connecting less than four stories. The number of stories connected by the shaft enclosure shall include any basements but not any mezzanines. An exit enclosure shall not be sued for any purpose other than means of egress. Enclosures shall be constructed as fire barriers in accordance with Section 706." *There is a list of 9 exceptions. DUSEL does not appear to meet any of them.*
- IBC Section 715.3.7 – Door Closing. "Fire doors shall be self-closing or automat-closing in accordance with this section. Exception: Fire doors located in common walls separating sleeping units in Group R-1 shall be permitted without automatic-closing or self-closing deices."
    - o IBC Section 715.3.7.1 – Latch Required. "Unless otherwise specifically permitted, single fire doors and both leaves of pairs of side-hinged swinging fire doors shall be provided with an active latch bolt that will secure the door when it sis closed."
    - o IBC Section 715.3.7.2 – Automatic-closing fire door assemblies. "Automatic-closing fire door assemblies shall be self-closing in accordance with NFPA 80."
    - o IBC Section 715.3.7.3 – Smoke-activated doors. "Automatic-closing fire doors installed in the following locations shall be automatic-closing by the actuation of smoke detectors installed in accordance with Section 907.10 or by loss of power to the smoke detector or hold-open device. Fire door that are automatic-closing by smoke detection shall not have more than a 10-second delay before the door starts to close after the smoke detector is actuated.
    - o IBC Section 715.3.7.4 – Doors in pedestrian ways. "Vertical sliding or vertical rolling steel fire doors in openings through which pedestrians travel shall be heat activated or activated by smoke detectors with alarm verification."
- IBC Section 706 – Included as attachment.
- IBC Section 1006 – Means of Egress Illumination
    - o IBC Section 1006.1 – Illumination required. "The means of egress, including the exit discharge, shall be illuminated at all times the building space served by the means of egress is occupied."
    - o IBC Section 1006.2 – Illumination level. "The means of egress illumination level shall not be less than 1 foot-candle (11 lux) at the floor level.

o   IBC Section 1006.3 – Illumination emergency power – *See emergency power section of this document.*

- IMC Section 401.4 – (Ventilation) Exits. "Equipment and ductwork for exit enclosure ventilation shall comply with one of the following items:
  1. Such equipment and ductwork shall be located exterior to the building and shall be directly connected to the exit enclosure by ductwork enclosed in construction as required by the International Building Code for shafts.
  2. Where such equipment and ductwork is located within the exit enclosure, the intake air shall be taken directly from the outdoors and the exhaust air shall be discharged directly to the outdoors, or such air shall be conveyed through ducts enclosed in construction as required by the International Building Code for shafts.
  3. Where located within the building, such equipment and ductwork shall be separated from the remainder of the building, including other mechanical equipment, with construction as required by the International Building Code for Shafts.

  In each case, openings into fire-resistance-rated construction shall be limited to those needed for maintenance and operation and shall be protected by self-closing fire-resistance-rated devices in accordance with the International Building Code for enclosure wall opening protectives. Exit enclosure ventilation systems shall be independent of other building ventilation systems."

- IFC Section 1003.7 – (General Means of Egress) Elevators, escalators, and moving walks. "Elevators, escalators and moving walks shall not be used as a component of a required means of egress from any other part of the building. Exception: Elevators used as an accessible means of egress in accordance with Section 1007.4.

- IFC Section 1007.4 – (Accessible Means of Egress) Elevators. "An elevator to be considered part of an accessible means of egress shall comply with the emergency operation and signaling device requirements of Section 2.27 of ASME A17.1. Standby power shall be provided in accordance with Section 2702 and 3003 of the International Building Code. The elevator shall be assessed from either an area of refuge complying with Section 1007.6 or a horizontal exit. Exceptions: 1) Elevators are not required to be accessed from an area of refuge or horizontal exit in open parking garages. 2) Elevators are not required to be accessed from an area of refuge or horizontal exit in buildings and facilities equipped throughout with an automatic sprinkler system installed in accordance with Section 909.3.1.1 or 909.3.1.2."

Areas of Refuge

- IFC Section 1007.6 – (Accessible Means of Egress) Areas of refuge. "Every required area of refuge shall be accessible from the space it serves by an accessible means of egress. The maximum travel distance from any accessible space to an area of refuge shall not exceed the travel distance permitted for the occupancy in accordance with Section 1015.1. Every required area of refuge shall have direct access to an enclosed stairway complying with Section 1007.3 and 1019.1 or an elevator complying with Section 1007.4. Where an elevator lobby is used as an area of refuge, the shaft and lobby shall comply with Section 1019.1.8 for smokeproof enclosures except where the elevators are in an area of refuge formed by a horizontal exit or smoke barrier."
  o   IFC Section 1007.6.1 – Size. "Each area of refuge shall be sized to accommodate one wheelchair space of 30 inches by 48 inches (762 mm by 1219 mm) for each 200 occupants or portion thereof based on the occupant load of the area of refuge and areas served by the area of refuge. Such wheelchair spaces shall not reduce the required means of egress width. Access to any of the required wheelchair spaces in an area of refuge shall not be obstructed by more than one adjoining wheelchair space.
  o   IFC Section 1007.6.2 – Separation. "Each area of refuge shall be separated from the remainder of the story by a smoke barrier complying with Section 709 of the International Building Code. Each area of refuge shall be designed to minimize the intrusion of smoke. Exceptions: 1) Areas

of refuge located within a stairway enclosure. 2) Areas of refuge where the area of refuge and areas served by the area of refuge are equipped throughout with an automatic sprinkler system installed in accordance with Section 903.3.1.1 or 903.3.1.2.

- o IFC Section 1007.6.3 – Two Way Communication. "Areas of refuge shall be provided with a two-way communication system between the area of refuge and a central control point. If the central control point is not constantly attended the area of refuge shall also have controlled access to a public telephone system. Location of the central point shall be approved by the fire department. The two-way communication system shall include both audible and visible signals."

Compartmentation and Smoke Venting of Chambers

- IBC Section 405.4 – (Underground Buildings) Compartmentation. "Compartmentation shall be in accordance with Sections 405.4.1 through 405.4.3.
  - o IBC Section 405.4.1 – Number of Compartments. "A building having a floor level more than 60 feet below the lowest level of exit discharge shall be divided into a minimum of two compartments of approximately equal size. Such Compartmentation shall extend through the highest level of exit discharge serving the underground portions of the building and all levels below. (Exception: the lowest story need not be compartmented where the area does not exceed 1500 square feet and has an occupant load of less than 10.
  - o IBC Section 405.4.2 – Smoke Barrier Penetration. The separation between the two compartments shall be of minimum 1-hour fire barrier wall construction that shall extend from floor slab to floor deck above. Openings between the two compartments shall be limited to plumbing and electrical piping and conduit penetrations firestopped in accordance with Section 712. Doorways shall be protected by fire door assemblies that are automatic-closing by smoke detection in accordance with Section 715.3 and shall be provided with gasketing and a drop sill to minimize smoke leakage. Where provided, each compartment shall have an air supply and an exhaust system independent of the other compartments."
  - o IBC Section 405.4.3 – Where elevators are provided, each compartment shall have direct access to an elevator. Where an elevator serves more than one compartment, an elevator lobby shall be provided and shall be separated from each compartment by a 1-hour fire barrier wall. Doors shall be gasketeted, have a drop sill, and be automatic-closing by smoke detection installed in accordance with Section 907.10"
- IBC Section 712 – Penetrations. 712.1 Scope. "The provisions of this section shall govern the materials and methods of construction used to protect through penetrations and membrane penetrations." *There are no specific additional considerations that need to be made for underground buildings or compartmented buildings.*
- IBC Section 715.3 – Fire door and shutter assemblies. "Approved fire door and fire shutter assemblies shall be constructed of an material or assembly of component materials that conforms to the test requirements of Section 715.3.1, 715.3.2, or 715.3.3 and the fire protection rating indicated in Table 715.3. Fire door assemblies and shutters shall be installed in accordance with the provisions of this section and NFPA 80." *There are no specific additional considerations that need to be made for underground buildings or compartmented buildings.*
- IBC Section 715.3. – Smoke and draft control door labeling requirements. Smoke and draft control doors complying with UL 1784 shall be labeled in accordance with Section 175.3.5.1 and shall show the letter "S" on the fire rating label of the door. This marking shall indicate that the door and frame assembly are in compliance when listed or labeled gasketing is also installed.
- IMC Section 607.5.2 – (Duct Systems) Fire barriers. "Duct penetrations and air transfer openings in fire barriers shall be protected with approved fire dampers installed in accordance with their listing." *For DUSEL, Exception 2 appears to apply*. "Ducts are used as part of an approved smoke control system in accordance with Section 513."

Related to several requirements of size with requirements for multiple independent systems

Smoke Control System
- IBC Section 405.5 – Smoke Control System. "A smoke control system shall be provided in accordance with Sections 405.5.1 and 405.5.2.
- IBC Section 405.5.1 – Control System. "A smoke control system is required to control the migration of products of combustion in accordance with Section 909 and the provisions of this section. Smoke control shall restrict movement of smoke to the general area of fire origin and maintain means of egress in a usable condition.
- IBC Section 909 – Included as attachment.
- IBC Section 405.5.2 – Smoke Exhaust System. "Where compartmentation is required, each compartment shall have an independent smoke control system. The system shall be automatically activated and capable of manual operation in accordance with Section 907.2.18."
- IBC Section 907.2.18 – Underground Buildings with Smoke Exhaust System. "Where a smoke exhaust system is installed in an underground building in accordance with this code, automatic fire detectors shall be provided in accordance with this section."
- IBC Section 907.2.18.1 – Smoke Detectors. "A minimum of one smoke detector listed for the intended purpose shall be installed in the following areas: 1) Mechanical equipment, electrical, transformer, telephone equipment, elevator machine or similar rooms. 2) Elevator lobbies. 3) The main return and exhaust air plenum of each air-conditioning system serving more than one story and located in a serviceable area downstream of the last duct inlet. 4) Each connection to a vertical duct or riser serving two or more floors from return air ducts or plenum of heating, ventilating, and air conditioning systems, except that in Group R occupancies, a listed smoke detector is allowed to be used in each air riser carrying not more than 5,000 cfm (2.4 m^3/s) and serving not more than 10 air inlet openings."
- IBC Section 907.2.18.2 – Alarm Required. "Activation of the smoke exhaust system shall activate an audible alarm at a constantly attended location.
- IFC Section 909.20 – (Smoke Control Systems) Underground building smoke exhaust system. "Where required by the International Building Code for underground buildings, a smoke exhaust system shall be provided in accordance with this section."
  o IFC Section 909.20.1 – Exhaust capability. "Where compartmentation is required, each compartment shall have an independent, automatically activated smoke exhaust system capable of manual operation. The system shall have an air supply and smoke exhaust capability that will provide a minimum of six air changes per hour.
  o IFC Section 909.20.2 – Operation. "The smoke exhaust system shall be operated in accordance with the International Fire Code."
  o IFC Section 909.20.3 – Alarm required. "Activation of the smoke exhaust system shall activate an audible alarm at a constantly attended location in accordance with the International Fire Code."
- IFC Section 909.1 – (Smoke Control Systems) Scope and purpose. " This section applies to mechanical and passive smoke control systems that are required by the International Building Code. The purpose of this section is to establish minimum requirements for the design, installation and acceptance testing of smoke control systems that are intended to provide a tenable environment for the evacuation or relocation of occupants. These provisions are not intended for the preservation of contents, the timely restoration of operations, or for assistance in fire suppression or overhaul activities. Smoke control systems regulated by this section serve a different purpose than the smoke and heat venting provisions found in Section 910 of the International Building Code. Mechanical smoke control systems shall not be considered exhaust systems under Chapter 5 of the International Mechanical Code."

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- IFC Section 909.2 – (Smoke Control Systems) General Design Requirements. "Buildings, structures, or parts thereof required by this code to have a some control system or systems shall have such systems designed in accordance with the applicable requirements of Section 909 and the generally accepted and well-established principles of engineering relevant to the design. The construction documents shall include sufficient information and detail to describe adequately the elements of the design necessary for the proper implementation of the smoke control systems. These documents shall be accompanied with sufficient information and analysis to demonstrate compliance with these provisions."
- IFC Section 909.3 – (Smoke Control Systems) Special inspection and test requirements. "In addition to the ordinary inspection and test requirements which buildings, structures, and parts thereof are required to undergo, smoke control systems subject to the provisions of Section 909 shall undergo special inspections and tests sufficient to verify the proper commissioning of the smoke control design in its final installed condition. The design submission accompanying the construction document shall clearly detail procedures and methods to be used and the items subject to such inspections and tests. Such commissioning shall be in accordance with generally accepted engineering practice and, where possible, based on published standards for the particular testing involved. The special inspections and tests required by this section shall be conducted under the same terms as found in International Building Code.
- IFC Section 909.5 – (Smoke Control Systems) Smoke Barrier Construction. "Smoke barriers shall comply with the International Building Code. Smoke barriers shall be constructed and sealed to limit leakage areas exclusive of protected openings." *(This is a partial quotation of this section. For max allowable leakage areas see full version of section 909.5.)*
- IFC Section 909.5.2.1 – (Smoke Control Systems) Duct and air transfer openings. "Ducts and air transfer openings are required to be protected with a minimum Class II, 250°F (121°C) smoke damper complying with the International Building Code."
- IFC Section 909.10 – (Smoke Control Systems) Equipment. "Equipment such as, but not limited to, fans, ducts, automatic dampers and balance dampers shall be suitable for their intended use, suitable for the probable exposure temperatures and that the rational analysis indicates, and as approved by the code official."
  o IFC Section 909.10.1 – Exhaust Fans. "Components of exhaust fans shall be rated and certified by the manufacturer for the probable temperature rise to which components will be exposed." *(Equation for T_s provided in 513.10.1, but not included here.)*
  o IFC Section 909.10.2 – Ducts. "Duct materials and joints shall be capable of withstanding the probable temperatures and pressures to which they are exposed as determined in accordance with Section 513.10.1. Ducts shall be constructed and supported in accordance with Chapter 6. Ducts shall be leak tested to 1.5 the maximum design pressure in accordance with nationally accepted practices. Measured leakage shall not exceed 5 percent of design flow. Results of such testing shall be part of the documentation procedure. Ducts shall be supported directly from fire-resistance-rated structural elements of building by substantial, noncombustible supports."
  o IFC Section 909.10.5 – Fans. "In addition to other requirements, belt-driven fans shall have 1.5 times the number of belts required for the design duty with the minimum number of belts being two. Fans shall be selected for stable performance based on normal temperature and, where applicable, elevated temperature. Calculations and manufacturer's fan curves shall be part of the documentation procedures. Fans shall be supported and restrained by noncombustible devices in accordance with the structural design requirements of the International Building Code. Motors driving fans shall not be operating beyond their nameplate horsepower (kilowatts) as determined from measurement of actual current draw. Motors driving fans shall have a minimum service factor of 1.15."
- IFC Section 909.11 – (Smoke Control Systems) Power systems. "The smoke control system shall be supplied with two sources of power. Primary power shall be the normal building power systems.

Secondary power shall be from an approved standby source complying with the ICC Electrical Code. The standby power source and its transfer switches shall be in a separate room from the normal power transformers and switch gear and shall be enclosed in a room constructed of not less than 1-hour fire-resistance-rated fire barriers, ventilated directly to and from the exterior. Power distribution from the two sources shall be by independent routes. Transfer to full standby power shall be automatic and within 60 seconds of failure of the primary power. The systems shall comply with the ICC Electrical Code.

- IFC Section 909.12 – (Smoke Control Systems) Detection and control systems. "Fire detection systems providing control input or output signals to mechanical smoke control systems or elements thereof shall comply with the requirements of Chapter 9 of the International Building Code and NFPA 72. Such systems shall be equipped with a control unit complying with UL 864 and listed as smoke control equipment. Control systems for mechanical smoke control systems shall include provisions for verification. Verification shall include positive confirmation of actuation, testing, manual override, the presence of power downstream of all disconnects and, through a preprogrammed weekly test sequence report, abnormal conditions audibly, visually and by printed report.

Standpipe Systems
- IBC Section 405.11 – Standpipe System. "The underground building shall be equipped throughout with a standpipe system in accordance with Section 905."
- IBC Section 905.3.5 – Underground buildings. "Underground buildings shall be equipped throughout with a Class I automatic wet or manual wet standpipe system."
- IFC Section 905.3.5 – (Standpipe systems) Underground buildings. "Underground buildings shall be equipped throughout with a Class I automatic wet or manual wet standpipe system."

Fire Protection - Sprinklers
- NFPA 101.7.3.1 – (Underground and Limited Access Structures) "A structure or portion of a structure that does not have openings in compliance with 11.7.3.1 (A) and 11.7.3.1 (B) shall be designed as a limited access structure and shall comply with 11.7.3.4 and 11.7.3.5." *DUSEL does not comply with 11.7.3.1(A) or 11.7.3.1(B).*
- NFPA 101.7.3.4 – (Underground and Limited Access Structures) "Underground and limited access structures, and all areas and floor levels traversed in traveling to the exit discharge, shall be protected by an approved, supervised, automatic sprinkler system in accordance with Section 9.7…"
- IBC Section 405.3 – Automatic Sprinkler System. "The highest level of exit discharge serving the underground portions of the building and all levels below shall be equipped with an automatic sprinkler system installed in accordance with Section 903.3.1.1. Water-flow switches and control valves shall be supervised in accordance with Section 903.4
- IBC Section 903.3.1.1 – NFPA 13 Sprinkler Systems. "Where the provisions of this code require that a building or portion thereof be equipped throughout with an automatic sprinkler system in accordance with Section 903.3.1.1, sprinklers shall be installed in accordance with NFPA 13 except as provided in Section 903.1.1.1
  o IBC Section 903.3.1.1.1 – Exempt Locations. "Automatic sprinklers shall not be required in the following rooms or areas where such rooms or areas are protected with an approved automatic fire detection system in accordance with Section 907.2 that will respond to visible or invisible particles of combustion. Sprinklers shall not be omitted from any room merely because it is damp, of fire-resistance-rated construction, or contains electrical equipment.
    1. "Any room where the application of water, or flame and water, constitutes a serious life or fire hazard.
    2. "Any room or space where sprinklers are considered undesirable because of the nature of the contents, when approved by the building official.

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3. "Generator and transformer rooms separated from the remainder of the building by walls and floor/ceiling or roof/ceiling assemblies having a fire-resistance rating of not less than 2 hours.

4. "In rooms or areas that are of noncombustible construction with wholly noncombustible contents."

- IMC Section 513.9.4 (Smoke Control Systems) Sprinkler effectiveness assumptions. "A documented engineering analysis shall be provided for conditions that assume fire growth is halted at the time of sprinkler activation."

- IFC Section 903.2.2 – (Automatic Sprinkler Systems, Where Required.) Group E. "An automatic sprinkler system shall be provided for Group E occupancies as follows:

1. Throughout all Group E fire areas greater than 20,000 square feet (1858 m^2) in area.

2. Throughout every portion of educational buildings below the level of exit discharge.

- IFC Section 903.2.10 – (Automatic Sprinkler Systems, Where Required.) All occupancies except Groups R-3 ad U. "An automatic sprinkler system shall be installed in the locations set forth in Sections903.2.10.1 through 903.2.10.1.3."

  o IFC Section 903.2.10.1 – Stories and basements without openings. "An automatic sprinkler system shall be installed in every story or basement of all buildings where the floor area exceeds 1,500 square feet (139.4 m^2) and where there is not provided at least one of the following types of exterior wall openings.

    1. Openings below grade that lead directly to ground level by an exterior stairway complying with Section 1009 or an outside ramp complying with Section 1010. Openings shall be located in each 50 linear feet (15240 mm), or fraction thereof, of exterior wall in the story on at least one side.

    2. Openings entirely above the adjoining ground level totaling at least 20 square feet (1.86 m^2) in each 50 linear feet (15240 mm), or fraction thereof, of exterior wall in the story on at least one side.

Smoke Detection

- IBC Section 907.10 – Fire Safety Functions. "Automatic fire detectors utilized for the purpose of performing fire safety functions shall be connected to the building's fire alarm control panel where a fire alarm system is required by Section 907.2. Detectors shall, upon action, perform the intended function and activate the alarm notification appliances or a visible and audible supervisory signal at a constantly attended location. In buildings not required to be equipped with a fire alarm system, the automatic fire detector shall be powered by normal electrical service and, upon actuation, perform the intended function. The detectors shall be located in accordance with NFPA 72.

Fire Alarm

- IBC Section 405.6 – Fire Alarm Systems. "A fire alarm system shall be provided where required by Section 907.2.19.

- IBC Section 907.2.19 – Underground Buildings. "Where the lowest level of a structure is more than 60 feet (18,288 mm) below the lowest level of exit discharge, the structure shall be equipped throughout with a manual fire alarm system, including an emergency voice/alarm communication system installed in accordance with Section 907.2.12.2.

- IBC Section 907.2.12.2 – Emergency voice/alarm communication system. "The operation of any automatic fire detector, sprinkler water-flow device or manual fire alarm box shall automatically sound an alert tone followed by voice instructions giving approved information and directions on a general or selective basis to the following terminal areas on a minimum of the alarming floor, the floor above and the floor below in accordance with the International Fire Code. 1) Elevator lobbies. 2) Corridors. 3) Rooms and tenant spaces exceeding 1,000 square feet (93 m^2) in area. 4) Dwelling

units or seeping units in Group R-2 occupancies. 5) Sleeping units in Group R-1 occupancies. 6) Areas of refuge as defined in Section 1002."

- IBC Section 1002 – Definition of Area of Refuge: "An area where persons unable to use stairways can remain temporarily to await instructions or assistance during emergency evacuation."
- IBC Section 907.2.12.2.1 – Manual Override. "A manual override for emergency voice communication shall be provided for all paging zones."
- IBC Section 907.2.12.2.2 – Live Voice Messages. "The emergency voice/alarm communication system shall also have the capability to be broadcast live voice messages through speakers located in elevators, exit stairways and throughout a selected floor or floors."
- IBC Section 907.2.12.2.3 – Standard. "The emergency voice/alarm communication system shall be designed and installed in accordance with NFPA 72."
- IBC Section 405.7 – Public Address. "A public address system shall be provided where required by Section 907.2.19.1"
- IBC Section 907.2.19.1 – Public Address System. "Where a fire alarm system is not required by Section 907.2 a public address system shall be provided that shall be capable of transmitting voice communications to the highest level of exit discharge serving the underground portions of the structure and all levels below."
- IBC Section 907.2 – Where Required. "An approved manual, automatic or manual and automatic fire alarm system shall be provided in accordance with Sections 907.2.1 through 907.2.23." (Those sections describe requirements based on occupancy and are not included in this document.) "Where automatic sprinkler protection, installed in accordance with Section 903.3.1.1 or 903.3.1.2, is provided and connected to the building fire alarm system, automatic heat detection required by this section shall not be required. An approved automatic fire detection system shall be installed in accordance with the provisions of this code and NFPA 72. Devices, combinations of devices, and appliances and equipment shall comply with Section 907.1.2. The automatic fire detectors shall be smoke detectors, except that an approved alternative type of detector shall be installed in spaces such as boiler rooms where, during normal operation, products of combustion are present in sufficient quantity to actuate a smoke detector."
- IBC Section 907.1.2 – Equipment. "Systems and their components shall be listed and approved for the purpose for which they are installed."
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Standby & Emergency Power and Emergency Lighting
- IBC Section 405.9 – Standby power. "A standby power system comply with Section 2702 shall be provided standby power loads specified in Section 405.9.1."
  - o IBC Section 405.9.1 – Standby power loads. "The following loads are classified as standby power loads. 1) Smoke control systems. 2) Ventilation and automatic fire detection equipment for smokeproof enclosures. 3) Fire pumps. Standby power shall be provided for elevators in accordance with Section 3003."
  - o IBC Section 905.9.2 – Pick-up time. "The standby power system shall pick up connected loads within 60 seconds of failure of the normal power supply."
- IBC Section 2702 – Included as attachment.
- IBC Section 405.10 – Emergency power. "An emergency power system comply with Section 2702 shall be provided for emergency power loads specified in Section 405.10.1."
  - o IBC Section 405.10.1 – Emergency power loads. "The following loads are classified as emergency power loads: 1) Emergency voice/alarm communications systems. 2) Fire alarm systems. 3) Automatic fire detection systems. 4) Elevator car lighting. 5) Means of egress and exit sign illumination as require by Chapter 10."
- IBC Section 1006.3 – Illumination emergency power. "The power supply for means of egress illumination shall normally be provided by the premise's electrical supply. In the event of power

supply failure, an emergency electrical system shall automatically illuminate the following areas: 1) Exit access corridors, passageways and aisles in rooms and spaces which require two or more means of egress. 2) Exit access corridors and exit stairways located n buildings required to have two or more exits. 3) Exterior egress components at other than the level of exit discharge until exit discharge is accomplished for buildings required to have two or more exits. 4) Interior exit discharge elements, as permitted in Section 1023.1, in buildings required to have two or more exits. 5) The portion of the exterior exit discharge immediately adjacent to exit discharge doorways in buildings required to have two or more exits. The emergency power system shall provide power for a duration of not less than 90 minutes and shall consist of storage batteries, unit equipment or an on-site generator. The installation of the emergency power system shall be in accordance with Section 2072."

- NFPA 101.7.3.1 – (Underground and Limited Access Structures) "A structure or portion of a structure that does not have openings in compliance with 11.7.3.1 (A) and 11.7.3.1 (B) shall be designed as a limited access structure and shall comply with 11.7.3.4 and 11.7.3.5." *DUSEL does not comply with 11.7.3.1(A) or 11.7.3.1(B).*

- NFPA 101.11.7.3.5 – (Underground and Limited Access Structures) "Underground or limited access portions of structures and all areas traversed in traveling to the exit discharge, other than in one and two family dwellings, shall be provided with emergency lighting in accordance with Section 7.9."

- NFPA 101.7.9 – (Emergency Lighting) Section 7.9.2.1 Performance of Systems. "Emergency illumination shall be provided for not less than 1½ hours in the event of failure of normal lighting. Emergency lighting facilities shall be arranged to provide initial illumination that is not less than an average of 10.8 lux (1 ft-candle) and, at any point, not less than 1.1 lux (0.1 ft-candle), measured along the path of egress at floor level. Illumination levels shall be permitted to decline to not less than an average of 6.5 lux (0.6 ft-candle) and, at any point, not less than 6.5 lux (0.06 ft-candle) at the end of the 1½ hours. A maximum to minimum illumination uniformity ratio of 40 to 1 shall not be exceeded.

- NFPA 101.7.9.2.2 – "The emergency lighting system shall be arranged to provide the required illumination automatically in the event of any interruption of normal lighting due to any of the following: 1) Failure of a public utility or other outside electrical power supply. 2) Opening of a circuit breaker or fuse. 3) Manual act(s), including accidental opening of a switch controlling normal lighting facilities."

- IFC Section 604.2.15 – (Emergency and Standby Power Systems) Underground Buildings. "Emergency and standby power systems in underground buildings covered in Chapter 4 of the International Building Code shall comply with Sections 6042.15.1 and 604.2.15.2.
    o IFC Section 604.2.15.1 – Standby Power. "A standby power system complying with the ICC Electrical Code shall be provided for standby power loads as specified in Section 604.2.15.1.1.
        ▪ IFC Section 604.2.15.1.1 – Standby power loads. "The following loads are classified as standby power loads: 1) Smoke control system, 2) Ventilation and automatic fire detection equipment for smokeproof enclosures, 3) Fire pumps, 4) Standby power shall be provided for elevators in accordance with Section 3003 of the International Building Code.
        ▪ IFC Section 604.2.15.1.2 – Pickup time. "The standby power system shall pick up its connected loads within 60 seconds of failure of the normal power supply.
    o IFC Section 604.2.15.2 – Emergency Power. "An emergency power system complying with the ICC Electrical Code shall be provided for emergency power loads as specified in Section 604.2.15.2.1.
        ▪ IFC Section 604.2.15.2.1 – Emergency power loads. "The following loads are classified as emergency power loads: 1) Emergency voice/alarm communication systems, 2) Fire alarm systems, 3) Automatic fire detection systems, 4) Elevator Car lighting, 5) Means of egress lighting and exit sign illumination as required by Chapter 10.

International Building Code 2003
International Mechanical Code 2003
International Fire Code 2003
NFPA 2003

705.8 Openings. Each opening through a fire wall shall be protected in accordance with Section 715.3 and shall not exceed 120 square feet (11 m²). The aggregate width of openings at any floor level shall not exceed 25 percent of the length of the wall.

Exceptions:

1. Openings are not permitted in party walls constructed in accordance with Section 503.2.

2. Openings shall not be limited to 120 square feet (11 m²) where both buildings are equipped throughout with an automatic sprinkler system installed in accordance with Section 903.3.1.1.

705.9 Penetrations. Penetrations through fire walls shall comply with Section 712.

705.10 Joints. Joints made in or between fire walls shall comply with Section 713.

705.11 Ducts and air transfer openings. Ducts and air transfer openings shall not penetrate fire walls.

Exception: Penetrations by ducts and air transfer openings of fire walls that are not on a lot line shall be allowed provided the penetrations comply with Sections 712 and 716. The size and aggregate width of all openings shall not exceed the limitations of Section 705.8.

SECTION 706
FIRE BARRIERS

706.1 General. Fire barriers used for separation of shafts, exits, exit passageways, horizontal exits or incidental use areas, to separate different occupancies, to separate a single occupancy into different fire areas, or to separate other areas where a fire barrier is required elsewhere in this code or the *International Fire Code*, shall comply with this section.

706.2 Materials. The walls and floor assemblies shall be of materials permitted by the building type of construction.

706.3 Fire-resistance rating. The fire-resistance rating of the walls and floor assemblies shall comply with this section.

706.3.1 Shaft enclosures. The fire-resistance rating of the fire barrier separating building areas from a shaft shall comply with Section 707.4.

706.3.2 Exit enclosures. The fire-resistance rating of the fire barrier separating building areas from an exit shall comply with Section 1019.1.

706.3.3 Exit passageway. The fire-resistance rating of the separation between building areas and an exit passageway shall comply with Section 1020.1.

706.3.4 Horizontal exit. The fire-resistance rating of the separation between building areas connected by a horizontal exit shall comply with Section 1021.1.

706.3.5 Incidental use areas. The fire barrier separating incidental use areas shall have a fire-resistance rating of not less than that indicated in Table 302.1.1.

706.3.6 Separation of mixed occupancies. Where the provisions of Section 302.3.2 are applicable, the fire barrier separating mixed occupancies shall have a fire-resistance rating of not less than that indicated in Section 302.3.2 based on the occupancies being separated.

706.3.7 Single-occupancy fire areas. The fire barrier separating a single occupancy into different fire areas shall have a fire-resistance rating of not less than that indicated in Table 706.3.7.

TABLE 706.3.7
FIRE-RESISTANCE RATING REQUIREMENTS FOR FIRE BARRIER ASSEMBLIES BETWEEN FIRE AREAS

OCCUPANCY GROUP	FIRE-RESISTANCE RATING (hours)
H-1, H-2	4
F-1, H-3, S-1	3
A, B, E, F-2, H-4, H-5, I, M, R, S-2	2
U	1

706.4 Continuity of fire barrier walls. Fire barrier walls shall extend from the top of the floor/ceiling assembly below to the underside of the floor or roof slab or deck above and shall be securely attached thereto. These walls shall be continuous through concealed spaces such as the space above a suspended ceiling. The supporting construction for fire barrier walls shall be protected to afford the required fire-resistance rating of the fire barrier supported except for 1-hour fire-resistance-rated incidental use area separations as required by Table 302.1.1 in buildings of Type IIB, IIIB and VB construction. Hollow vertical spaces within the fire barrier wall shall be firestopped at every floor level.

Exceptions:

1. The maximum required fire-resistance rating for assemblies supporting fire barriers separating tank storage as provided for in Section 415.7.2.1 shall be 2 hours, but not less than required by Table 601 for the building construction type.

2. Shaft enclosure shall be permitted to terminate at a top enclosure complying with Section 707.12.

706.5 Horizontal fire barriers. Horizontal fire barriers shall be constructed in accordance with Section 711.

706.6 Exterior walls. Where exterior walls serve as a part of a required fire-resistance-rated enclosure, such walls shall comply with the requirements of Section 704 for exterior walls and the fire-resistance-rated enclosure requirements shall not apply.

Exception: Exterior walls required to be fire-resistance rated in accordance with Section 1022.6.

706.7 Openings. Openings in a fire barrier wall shall be protected in accordance with Section 715. Openings shall be limited to a maximum aggregate width of 25 percent of the length of the wall, and the maximum area of any single opening shall not exceed 120 square feet (11 m²). Openings in exit enclosures shall also comply with Section 1019.1.1.

Exceptions:

1. Openings shall not be limited to 120 square feet (11 m²) where adjoining fire areas are equipped throughout with an automatic sprinkler system in accordance with Section 903.3.1.1.

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2. Fire doors serving an exit enclosure.

3. Openings shall not be limited to 120 square feet (11 m²) or an aggregate width of 25 percent of the length of the wall where the opening protective assembly has been tested in accordance with ASTM E 119 and has a minimum fire-resistance rating not less than the fire-resistance rating of the wall.

706.8 Penetrations. Penetrations through fire barriers shall comply with Section 712.

706.8.1 Prohibited penetrations. Penetrations into an exit enclosure shall only be allowed when permitted by Section 1019.1.2.

706.9 Joints. Joints made in or between fire barriers shall comply with Section 713.

706.10 Ducts and air transfer openings. Penetrations by ducts and air transfer openings shall comply with Sections 712 and 716.

SECTION 707
SHAFT ENCLOSURES

707.1 General. The provisions of this section shall apply to vertical shafts where such shafts are required to protect openings and penetrations through floor/ceiling and roof/ceiling assemblies.

707.2 Shaft enclosure required. Openings through a floor/ceiling assembly shall be protected by a shaft enclosure complying with this section.

Exceptions:

1. A shaft enclosure is not required for openings totally within an individual residential dwelling unit and connecting four stories or less.

2. A shaft enclosure is not required in a building equipped throughout with an automatic sprinkler system in accordance with Section 903.3.1.1 for an escalator opening or stairway which is not a portion of the means of egress protected according to Item 2.1 or 2.2:

   2.1. Where the area of the floor opening between stories does not exceed twice the horizontal projected area of the escalator or stairway and the opening is protected by a draft curtain and closely spaced sprinklers in accordance with NFPA 13. In other than Groups B and M, this application is limited to openings that do not connect more than four stories.

   2.2. Where the opening is protected by approved power-operated automatic shutters at every floor penetrated. The shutters shall be of noncombustible construction and have a fire-resistance rating of not less than 1.5 hours. The shutter shall be so constructed as to close immediately upon the actuation of a smoke detector installed in accordance with Section 907.10 and shall completely shut off the well opening. Escalators shall cease oper-

ation when the shutter begins to close. The shutter shall operate at a speed of not more than 30 feet per minute (152.4 mm/s) and shall be equipped with a sensitive leading edge to arrest its progress where in contact with any obstacle, and to continue its progress on release therefrom.

3. A shaft enclosure is not required for penetrations by pipe, tube, conduit, wire, cable, and vents protected in accordance with Section 712.4.

4. A shaft enclosure is not required for penetrations by ducts protected in accordance with Section 712.4. Grease ducts shall be protected in accordance with the *International Mechanical Code.*

5. A shaft enclosure is not required for floor openings complying with the provisions for covered malls or atriums.

6. A shaft enclosure is not required for approved masonry chimneys, where annular space protection is provided at each floor level in accordance with Section 717.2.5.

7. In other than Groups I-2 and I-3, a shaft enclosure is not required for a floor opening that complies with the following:

   7.1. Does not connect more than two stories.

   7.2. Is not part of the required means of egress system except as permitted in Section 1019.1.

   7.3. Is not concealed within the building construction.

   7.4. Is not open to a corridor in Group I and R occupancies.

   7.5. Is not open to a corridor on nonsprinklered floors in any occupancy.

   7.6. Is separated from floor openings serving other floors by construction conforming to required shaft enclosures.

8. A shaft enclosure is not required for automobile ramps in open parking garages and enclosed parking garages constructed in accordance with Sections 406.3 and 406.4, respectively.

9. A shaft enclosure is not required for floor openings between a mezzanine and the floor below.

10. A shaft enclosure is not required for joints protected by a fire-resistant joint system in accordance with Section 713.

11. Where permitted by other sections of this code.

707.3 Materials. The shaft enclosure shall be of materials permitted by the building type of construction.

707.4 Fire-resistance rating. Shaft enclosures shall have a fire-resistance rating of not less than 2 hours where connecting four stories or more and not less than 1 hour where connecting less than four stories. The number of stories connected by the shaft enclosure shall include any basements but not any mezzanines. Shaft enclosures shall be constructed as fire barriers in accordance with Section 706. Shaft enclosures

straight line between exit doors or exit access doorways. Interlocking or scissor stairs shall be counted as one exit stairway.

Exceptions:

1. Where exit enclosures are provided as a portion of the required exit and are interconnected by a 1-hour fire-resistance-rated corridor conforming to the requirements of Section 1016, the required exit separation shall be measured along the shortest direct line of travel within the corridor.

2. Where a building is equipped throughout with an automatic sprinkler system in accordance with Section 903.3.1.1 or 903.3.1.2, the separation distance of the exit doors or exit access doorways shall not be less than one-third of the length of the maximum overall diagonal dimension of the area served.

1014.2.2 Three or more exits or exit access doorways. Where access to three or more exits is required, at least two exit doors or exit access doorways shall be placed a distance apart equal to not less than one-half of the length of the maximum overall diagonal dimension of the area served measured in a straight line between such exit doors or exit access doorways. Additional exits or exit access doorways shall be arranged a reasonable distance apart so that if one becomes blocked, the others will be available.

Exception: Where a building is equipped throughout with an automatic sprinkler system in accordance with Section 903.3.1.1 or 903.3.1.2, the separation distance of at least two of the exit doors or exit access doorways shall not be less than one-third of the length of the maximum overall diagonal dimension of the area served.

1014.3 Boiler, incinerator and furnace rooms. Two exit access doorways are required in boiler, incinerator and furnace rooms where the area is over 500 square feet (46 m²) and any fuel-fired equipment exceeds 400,000 British thermal units (Btu) (422 000 KJ) input capacity. Where two exit access doorways are required, one is permitted to be a fixed ladder or an alternating tread device. Exit access doorways shall be separated by a horizontal distance equal to one-half the maximum horizontal dimension of the room.

1014.4 Refrigeration machinery rooms. Machinery rooms larger than 1,000 square feet (93 m²) shall have not less than two exits or exit access doors. Where two exit access doorways are required, one such doorway is permitted to be served by a fixed ladder or an alternating tread device. Exit access doorways shall be separated by a horizontal distance equal to one-half the maximum horizontal dimension of room.

All portions of machinery rooms shall be within 150 feet (45 720 mm) of an exit or exit access doorway. An increase in travel distance is permitted in accordance with Section 1015.1.

Doors shall swing in the direction of egress travel, regardless of the occupant load served. Doors shall be tight fitting and self-closing.

1014.5 Refrigerated rooms or spaces. Rooms or spaces having a floor area of 1,000 square feet (93 m²) or more, containing a refrigerant evaporator and maintained at a temperature below 68°F (20°C), shall have access to not less than two exits or exit access doors.

Travel distance shall be determined as specified in Section 1015.1, but all portions of a refrigerated room or space shall be within 150 feet (45 720 mm) of an exit or exit access door where such rooms are not protected by an approved automatic sprinkler system. Egress is allowed through adjoining refrigerated rooms or spaces.

Exception: Where using refrigerants in quantities limited to the amounts based on the volume set forth in the *International Mechanical Code*.

1014.6 Stage means of egress. Where two means of egress are required, based on the stage size or occupant load, one means of egress shall be provided on each side of the stage.

1014.6.1 Gallery, gridiron and catwalk means of egress. The means of egress from lighting and access catwalks, galleries and gridirons shall meet the requirements for occupancies in Group F-2.

Exceptions:

1. A minimum width of 22 inches (559 mm) is permitted for lighting and access catwalks.
2. Spiral stairs are permitted in the means of egress.
3. Stairways required by this subsection need not be enclosed.
4. Stairways with a minimum width of 22 inches (559 mm), ladders, or spiral stairs are permitted in the means of egress.
5. A second means of egress is not required from these areas where a means of escape to a floor or to a roof is provided. Ladders, alternating tread devices or spiral stairs are permitted in the means of escape.
6. Ladders are permitted in the means of egress.

SECTION 1015
EXIT ACCESS TRAVEL DISTANCE

1015.1 Travel distance limitations. Exits shall be so located on each story such that the maximum length of exit access travel, measured from the most remote point within a story to the entrance to an exit along the natural and unobstructed path of egress travel, shall not exceed the distances given in Table 1015.1.

Where the path of exit access includes unenclosed stairways or ramps within the exit access or includes unenclosed exit ramps or stairways as permitted in Section 1019.1, the distance of travel on such means of egress components shall also be included in the travel distance measurement. The measurement along stairways shall be made on a plane parallel and tangent to the stair tread nosings in the center of the stairway.

Exceptions:

1. Travel distance in open parking garages is permitted to be measured to the closest riser of open stairs.

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2. In outdoor facilities with open exit access components and open exterior stairs or ramps, travel distance is permitted to be measured to the closest riser of a stair or the closest slope of the ramp.

3. Where an exit stair is permitted to be unenclosed in accordance with Exception 8 or 9 of Section 1019.1, the travel distance shall be measured from the most remote point within a building to an exit discharge.

TABLE 1015.1
EXIT ACCESS TRAVEL DISTANCE[a]

OCCUPANCY	WITHOUT SPRINKLER SYSTEM (feet)	WITH SPRINKLER SYSTEM (feet)
A, E, F-1, I-1, M, R, S-1	200	250[b]
B	200	300[c]
F-2, S-2, U	300	400[b]
H-1	Not Permitted	75[c]
H-2	Not Permitted	100[c]
H-3	Not Permitted	150[c]
H-4	Not Permitted	175[c]
H-5	Not Permitted	200[c]
I-2, I-3, I-4	150	200[c]

For SI: 1 foot = 304.8 mm.

a. See the following sections for modifications to exit access travel distance requirements:
   Section 402: For the distance limitation in malls.
   Section 404: For the distance limitation through an atrium space.
   Section 1015.2: For increased limitation in Groups F-1 and S-1.
   Section 1024.7: For increased limitation in assembly seating.
   Section 1024.7: For increased limitation for assembly open-air seating.
   Section 1018.2: For buildings with one exit.
   Chapter 31: For the limitation in temporary structures.

b. Buildings equipped throughout with an automatic sprinkler system in accordance with Section 903.3.1.1 or 903.3.1.2. See Section 903 for occupancies where sprinkler systems according to Section 903.3.1.2 are permitted.

c. Buildings equipped throughout with an automatic sprinkler system in accordance with Section 903.3.1.1.

1015.2 Roof vent increase. In buildings which are one story in height, equipped with automatic heat and smoke roof vents complying with Section 910 and equipped throughout with an automatic sprinkler system in accordance with Section 903.3.1.1, the maximum exit access travel distance shall be 400 feet (122 m) for occupancies in Group F-1 or S.

1015.3 Exterior egress balcony increase. Travel distances specified in Section 1015.1 shall be increased up to an additional 100 feet (30 480 mm) provided the last portion of the exit access leading to the exit occurs on an exterior egress balcony constructed in accordance with Section 1013.5. The length of such balcony shall not be less than the amount of the increase taken.

SECTION 1016
CORRIDORS

1016.1 Construction. Corridors shall be fire-resistance rated in accordance with Table 1016.1. The corridor walls required to be fire-resistance rated shall comply with Section 708 for fire partitions.

Exceptions:

1. A fire-resistance rating is not required for corridors in an occupancy in Group E where each room that is used for instruction has at least one door directly to the exterior and rooms for assembly purposes have at least one-half of the required means of egress doors opening directly to the exterior. Exterior doors specified in this exception are required to be at ground level.

2. A fire-resistance rating is not required for corridors contained within a dwelling or sleeping unit in an occupancy in Group R.

3. A fire-resistance rating is not required for corridors in open parking garages.

4. A fire-resistance rating is not required for corridors in an occupancy in Group B which is a space requiring only a single means of egress complying with Section 1014.1.

TABLE 1016.1
CORRIDOR FIRE-RESISTANCE RATING

OCCUPANCY	OCCUPANT LOAD SERVED BY CORRIDOR	REQUIRED FIRE-RESISTANCE RATING (hours)	
		Without sprinkler system	With sprinkler system[c]
H-1, H-2, H-3	All	Not Permitted	1
H-4, H-5	Greater than 30	Not Permitted	1
A, B, E, F, M, S, U	Greater than 30	1	0
R	Greater than 10	1	0.5
I-2[a], I-4	All	Not Permitted	0
I-1, I-3	All	Not Permitted	1[b]

a. For requirements for occupancies in Group I-2, see Section 407.3.

b. For a reduction in the fire-resistance rating for occupancies in Group I-3, see Section 408.7.

c. Buildings equipped throughout with an automatic sprinkler system in accordance with Section 903.3.1.1 or 903.3.1.2 where allowed.

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smokeproof enclosure by ductwork enclosed by 2-hour fire-resistance-rated fire barriers.

2. Equipment and ductwork shall be located within the smokeproof enclosure with intake or exhaust directly from and to the outside or through ductwork enclosed by 2-hour fire-resistance-rated fire barriers.

3. Equipment and ductwork shall be located within the building if separated from the remainder of the building, including other mechanical equipment, by 2-hour fire-resistance-rated fire barriers.

909.20.6.2 Standby power. Mechanical vestibule and stair shaft ventilation systems and automatic fire detection systems shall be powered by an approved standby power system conforming to Section 403.10.1 and Chapter 27.

909.20.6.3 Acceptance and testing. Before the mechanical equipment is approved, the system shall be tested in the presence of the building official to confirm that the system is operating in compliance with these requirements.

909.21 Underground building smoke exhaust system. Where required in accordance with Section 405.5 for underground buildings, a smoke exhaust system shall be provided in accordance with this section.

909.21.1 Exhaust capability. Where compartmentation is required, each compartment shall have an independent, automatically activated smoke exhaust system capable of manual operation. The system shall have an air supply and smoke exhaust capability that will provide a minimum of six air changes per hour.

[F] 909.21.2 Operation. The smoke exhaust system shall be operated in the compartment of origin by the following, independently of each other:

1. Two cross-zoned smoke detectors within a single protected area of a single smoke detector monitored by an alarm verification zone or an approved equivalent method.

2. The automatic sprinkler system.

3. Manual controls that are readily accessible to the fire department.

[F] 909.21.3 Alarm required. Activation of the smoke exhaust system shall activate an audible alarm at a constantly attended location.

SECTION 910
SMOKE AND HEAT VENTS

[F] 910.1 General. Where required by this code or otherwise installed, smoke and heat vents or mechanical smoke exhaust systems and draft curtains shall conform to the requirements of this section.

Exception: Frozen-food warehouses used solely for storage of Class I and II commodities where protected by an approved automatic sprinkler system.

[F] 910.2 Where required. Approved smoke and heat vents shall be installed in the roofs of one-story buildings or portions thereof occupied for the uses set forth in Sections 910.2.1 through 910.2.4.

[F] 910.2.1 Groups F-1 and S-1. Buildings and portions thereof used as a Group F-1 or S-1 occupancy having more than 50,000 square feet (4645 m²) in undivided area.

Exception: Group S-1 aircraft repair hangars.

[F] 910.2.2 Group H. Buildings and portions thereof used as a Group H occupancy as shown:

1. In occupancies classified as Group H-2 or H-3, any of which are over 15,000 square feet (1394 m²) in single floor area.

   Exception: Buildings of noncombustible construction containing only noncombustible materials.

2. In areas of buildings in Group H used for storing Class 2, 3, and 4 liquid and solid oxidizers, Class 1 and unclassified detonable organic peroxides, Class 3 and 4 unstable (reactive) materials, or Class 2 or 3 water-reactive materials as required for a high-hazard commodity classification.

   Exception: Buildings of noncombustible construction containing only noncombustible materials.

[F] 910.2.3 High-piled combustible storage. Buildings and portions thereof containing high-piled combustible stock or rack storage in any occupancy group in accordance with Section 413 and the *International Fire Code*.

[F] 910.2.4 Exit access travel distance increase. Buildings and portions thereof used as a Group F-1 or S-1 occupancy where the maximum exit access travel distance is increased in accordance with Section 1015.2.

[F] 910.3 Design and installation. The design and installation of smoke and heat vents and draft curtains shall be as specified in this section and Table 910.3.

[F] 910.3.1 Vent operation. Smoke and heat vents shall be approved and labeled and shall be capable of being operated by approved automatic and manual means. Automatic operation of smoke and heat vents shall conform to the provisions of this section.

[F] 910.3.1.1 Gravity-operated drop-out vents. Automatic smoke and heat vents containing heat-sensitive glazing designed to shrink and drop out of the vent opening when exposed to fire shall fully open within 5 minutes after the vent cavity is exposed to a simulated fire, represented by a time-temperature gradient that reaches an air temperature of 500°F (260°C) within 5 minutes.

[F] 910.3.1.2 Sprinklered buildings. Where installed in buildings provided with an approved automatic sprinkler system, smoke and heat vents shall be designed to operate automatically.

[F] 910.3.1.3 Nonsprinklered buildings. Where installed in buildings not provided with an approved automatic sprinkler system, smoke and heat vents shall operate automatically by actuation of a

CHAPTER 27

ELECTRICAL

SECTION 2701
GENERAL

2701.1 Scope. This chapter governs the electrical components, equipment and systems used in buildings and structures covered by this code. Electrical components, equipment and systems shall be designed and constructed in accordance with the provisions of the ICC *Electrical Code.*

[F] SECTION 2702
EMERGENCY AND STANDBY POWER SYSTEMS

2702.1 Installation. Emergency and standby power systems shall be installed in accordance with the ICC *Electrical Code,* NFPA 110 and NFPA 111.

2702.1.1 Stationary generators. Emergency and standby power generators shall be listed in accordance with UL 2200.

2702.2 Where required. Emergency and standby power systems shall be provided where required by Sections 2702.2.1 through 2702.2.19.

2702.2.1 Group A occupancies. Emergency power shall be provided for voice communication systems in Group A occupancies in accordance with Section 907.2.1.2.

2702.2.2 Smoke control systems. Standby power shall be provided for smoke control systems in accordance with Section 909.11.

2702.2.3 Exit signs. Emergency power shall be provided for exit signs in accordance with Section 1011.5.3.

2702.2.4 Means of egress illumination. Emergency power shall be provided for means of egress illumination in accordance with Section 1006.3.

2702.2.5 Accessible means of egress elevators. Standby power shall be provided for elevators that are part of an accessible means of egress in accordance with Section 1007.4.

2702.2.6 Horizontal sliding doors. Standby power shall be provided for horizontal sliding doors in accordance with Section 1008.1.3.3.

2702.2.7 Semiconductor fabrication facilities. Emergency power shall be provided for semiconductor fabrication facilities in accordance with Section 415.9.10.

2702.2.8 Membrane structures. Standby power shall be provided for auxiliary inflation systems in accordance with Section 3102.8.2. Emergency power shall be provided for exit signs in temporary tents and membrane structures in accordance with the *International Fire Code.*

2702.2.9 Hazardous materials. Emergency or standby power shall be provided in occupancies with hazardous materials in accordance with Section 414.5.4.

2702.2.10 Highly toxic and toxic materials. Emergency power shall be provided for occupancies with highly toxic or toxic materials in accordance with the *International Fire Code.*

2702.2.11 Organic peroxides. Standby power shall be provided for occupancies with silane gas in accordance with the *International Fire Code.*

2702.2.12 Pyrophoric materials. Emergency power shall be provided for occupancies with silane gas in accordance with the *International Fire Code.*

2702.2.13 Covered mall buildings. Standby power shall be provided for voice/alarm communication systems in covered mall buildings in accordance with Section 402.12.

2702.2.14 High-rise buildings. Emergency and standby power shall be provided in high-rise buildings in accordance with Sections 403.10 and 403.11.

2702.2.15 Underground buildings. Emergency and standby power shall be provided in underground buildings in accordance with Sections 405.9 and 405.10.

2702.2.16 Group I-3 occupancies. Emergency power shall be provided for doors in Group I-3 occupancies in accordance with Section 408.4.2.

2702.2.17 Airport traffic control towers. Standby power shall be provided in airport traffic control towers in accordance with Section 412.1.5.

2702.2.18 Elevators. Standby power for elevators shall be provided as set forth in Section 3003.1.

2702.2.19 Smokeproof enclosures. Standby power shall be provided for smokeproof enclosures as required by Section 909.20.

2702.3 Maintenance. Emergency and standby power systems shall be maintained and tested in accordance with the *International Fire Code.*

Appendix J: Education and Outreach

**Broader Impacts at the Kimballton DUSEL: Education and Outreach (E&O)
Preliminary Plan**

Rationale

"If America is to sustain its international competitiveness, its national security, and the quality of life for its citizens, then it must move quickly to achieve significant improvements in the participation of all students in mathematics and science," begins a report issued on February 16, 2005 by the Business-Higher Education Forum titled *A Commitment to America's Future: Responding to the Crisis in Mathematics and Science Education*. The report calls for business, higher education, and policy leaders to organize and implement a nationwide plan that addresses the quality of the mathematics and science education provided to all students, "in collaboration with classroom teachers and school administrators and taking advantage of the promising work they have already initiated." From <http://science.nsta.org/nstaexpress/nstaexpress_2005_02_22_bhef.htm>

NSF and other national science organizations concur, identifying Science, Technology, Engineering, and Math (STEM) education as a critical need in our nation (NSB 2004). Programs at local, state, national and international levels seek to develop skills in these [STEM] areas. Our target audiences include students, teachers, scientists, practicing professionals, officials, legislators and the public. To meet the science and engineering workforce needs and future regional economic development, Appalachia must become a source of future scientists and technical personnel. Inclusion of this diversity would be a deliberate focus of E&O from this project.

Several reports have presented detailed plans for E&O that could be applied to an underground laboratory (EarthScope 2002, EarthLab 2003, NeSS 2002, NUSL 2001). These highlight opportunities to appreciate basic science alongside practical applications of multidisciplinary learning and technology. The Kimballton DUSEL will leverage and build collaborative projects with established local networks from VT-STEM (a university-wide outreach initiative) and with E&O programs such as NASA Astrobiology Institutes, EarthScope, GLOBE, and others. Partnerships targeting E&O activities will be developed with informal education venues, schools, community, and professional organizations.

An advantage of the Kimballton location is that it is within a day's drive for 50% of the U.S. population (New River Valley Planning District Commission Regional Data Book, 2004) making site visitation a possibility for many and offering the potential for distance education combined with onsite learning. Unique to this location is the potential for partnership with USFS Jefferson National Forest Blacksburg Ranger District in building a joint visitor center on Butt Mountain, availability of VT's Mobile Lab enhanced for off-site visits exploring DUSEL science questions, and eager participants who have not had access to this kind of "big science" before.

A major, but not inherently obvious, opportunity for E&O lies with the international

nature of the lab. In addition to STEM literacy, much concern also goes into preparing our society to better participate in a global economy. We can anticipate far more opportunities for interaction between people from different cultures as a result of this project. This will cut both ways: we need to be prepared to do E&O for international visitors and researchers, as well as providing E&O for local and national groups. These efforts will be both formal and informal. Locally, the Southern Appalachians have limited opportunities for these kinds of rich international interactions. This project will definitely increase global awareness in this location, as well as increasing STEM literacy.

Virginia Tech is the senior Virginia land-grant institution, and has a long history of community education and outreach to improve economic and social well-being. The University has recently renewed its commitment to outreach and extension: the Division of Outreach and International Affairs has programs across Virginia, the United States, and in countries around the world, as well as here in Appalachia. <http://www.outreach.vt.edu/about.html/>. The Cooperative Extension Division alone engaged over 40,000 volunteers in support of its programs throughout the Commonwealth <http://www.ext.vt.edu>.

One group that will certainly be active with the Kimballton DUSEL E&O programs is VT-STEM, the Virginia Tech Science Technology Engineering and Mathematics K-12 Outreach Initiative <http://www.stem.vt.edu>. This is an interdisciplinary group of people and programs that share research and resources among the university community, K-12 education, and other partners to contribute to Virginia's leadership in K-12 science, technology, engineering, and mathematics education.

VT Geosciences is a founding member of VT-STEM. Geosciences direct service outreach programs reached over 6800 people in Fall 2004, including teacher workshops, public programs, visitors and school visits to the Museum of Geosciences, and materials loaned through the Education Resource Center. Many more people were served through the Geosciences websites developed by departmental research groups and projects, and by faculty responses to public inquiries.

Beyond science and engineering, a variety of research projects in STEM educational theories and methods will be possible through evaluation of informal and formal programs and products emanating from the Kimballton DUSEL. Assessment and evaluation will be part of the instructional design for all our E&O projects. Wide sharing of results is an important role for the project as a model of integrated research and education.

Goals
E&O goals for the Kimballton DUSEL will be developed in consultation with scientists, formal and informal educators, regional partners, and other collaborators and colleagues from large-scale education and outreach projects. A major intent is the enhancement of science, technology, engineering, and math (STEM) education achievements and literacy on the ground, as well as exploring innovative STEM education methods and research.

°Increase the broad recognition of Southern Appalachia as a place engaged in Big Science, building on NASA's Marshall Space Flight Center, Huntsville, AL, DOE's Oak Ridge National Labs, Oak Ridge, TN, the University of Tennessee-Knoxville, Virginia Tech, NSF's National Radio Astronomy Observatory at Green Bank, WV, etc. This is a sea change from the now waning extractive industries historically associated with the region, and offers a new global economic base for the region.

°Share the questions, methods, and results emanating from Kimballton DUSEL projects to encourage the broader community to embrace and support research as well as to attract additional projects and funding.

°Inspire male *and* female students and citizens in the Southern Appalachians to pursue the learning needed in science and technology careers. Increase opportunities for students and citizens from all economic backgrounds to become thus engaged.

°Energize K-12 and college faculty through access to state-of-the-art research, teaching, and learning facilities in a real-world, international, multidisciplinary lab setting.

° Evaluate and disseminate E&O efforts to continue improvements in effectiveness. E&O of the Kimballton DUSEL will help create a national model for increasing the participation of male and female students and citizens of rural America in science and technology. This diversity will strengthen future economies based on science and technology for those rural areas.

Partners
There are many large collaborative projects that are underway in the sciences that will be at the Kimballton DUSEL They will be powerful partners. We will research these and access them as appropriate to inform our work and to re-use wheels that are already invented and rolling out there. They can also quickly lend national and international scope to our E&O. Ones we are already working with include EarthScope, GLOBE, NASA Astrobiology, East Tennessee Science Partnership (ETnSP), and Appalachian Mathematics and Science Partnership (AMSP).

Local school systems in both Virginia and West Virginia and regional undergraduate and community colleges will be important partners.

Informal educational venues not only will be educational partners, but will also be part of regional tourism marketing. Collaboration for tourism marketing has just begun in the region. This project could be a keystone to help smaller venues, and highlight education as a value-added for tourism. The Visitor and Education Center would become a tourism "destination" drawing visitors deeper into this area of Appalachia.

We will be working with the Community Engagement-Public Relations group to coordinate community input meetings and workshops. In garnering initial input, Education and Outreach and Community Engagement will likely use similar strategies.

Features, Facilities Planning: Kimballton DUSEL E&O Infrastructure

Modularity and flexibility, as stated in S-1, is key. (S-1 supplemental materials, p. 24)

E&O will encourage the use of Universal Design Principles (UDP) throughout to provide accessibility for the maximum number of people, keeping in mind international audiences.

Dedicated E&O staff is essential in a facility with this mission.

Some separate, safe, noise-limited spaces (outdoor, indoor, and possibly underground) will need to be committed to E&O needs. Lab and classroom spaces intended only for E&O will deepen the educational experiences possible for K-12, college, professional, and public visitors. In research labs, providing additional space beyond the research need and enhancing the visibility of operations will increase E&O possibilities.
As stated in S-1 this facility presents many educational opportunities in STEM (Science, Technology, Engineering, and Math) as well as other disciplines, and will provide outreach and interpretation for diverse audiences. Valuing the ideal of education and outreach happening side-by-side with international research leads to additional resources and infrastructure, and incorporation of universal design principles. These will enhance the facility for researchers also.

Interpreted design and construction makes lab elements and facilities into educational platforms. The facilities could also be demonstration grounds for the remarkable challenge of Leadership in Energy and Environmental Design (LEED) construction at a major research laboratory. This consideration will be even more appropriate by the time construction is completed. There will be many opportunities for E&O around the facility and its construction and operation.

Our E&O should encourage the use of Universal Design Principles to provide accessibility to the maximum number of people, keeping in mind international audiences.

Above-ground site interpretation and E&O design elements should also be incorporated as design proceeds. Locations for outdoor interpretive signage can be planned to work with overall site design.

Time Lines:
Short term: (year 1)
Web page
Community forum and education for local citizens and decision-makers
Posters/flyers, bookmarks
Investigate VT Mobile lab expanding to DUSEL science
Leveraging with other programs for K-12 activities, i.e. K-12 in-services, scientists visiting schools, SHADES, GLOBE, tours
Build partnerships
Facility design involvement
Evaluation and assessment

Mid term: (year 2-4)
On-site and satellite exhibits
REU
teacher workshops
Coordinating DUSEL research with education and outreach
Developing K-12 curricular products, outreach products
Foster partnerships and expand networks
Facility design
Evaluation and assessment

Long term: (year 4+)
K-12 curricula product dissemination
Product dev./dissemination: video, remote access/experimentation, interactive exhibits
Expanding DUSEL research with education and outreach activities
Building partnerships Facility design
Evaluation and assessment

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Appendix K: S2 Costs and Timeline

This appendix describes the major components for the proposed scope of work to develop the conceptual design for Kimballton DUSEL. These activities are now moving forward and will continue through the six-month S2 funding period, which we have assumed here to be August 2005 through January 2006.

The scope of work for S2 includes 13 major tasks each with a series of subtasks. The total cost of these tasks is estimated to be $2.665 million. Virginia Tech will provide the difference between this cost and funding provided by NSF. Costs and timelines of the activity categories are summarized in Table A-1. Some items were completed by Virginia Tech faculty, students and consultants during preparation for this proposal as described below. Other line item costs shown are amounts to be spent during S2 studies.

1.0   Subsurface characterization studies were initiated in March 2004 and are continuing. A seismic survey, lineament study, and mapping in adjacent quarries were completed in August 2004. Detailed results of these studies are available in Appendix B and C.

Major subsurface characterization activities proposed for S2 include drilling and logging of boreholes and in-situ testing. Preliminary rock characterization, geomechanical modeling and local hydrological studies will be conducted using the results of the drilling, in-situ tests and previous characterization studies. A deep core hole will be advanced from the top of Butt Mountain to the lowest campus depth. Scheduling of a drilling subcontractor and completing permit applications with the US Forest Service are underway now. The cost of $1.885 million for this task will be borne by Virginia Tech.

2.0   Underground Laboratory Planning and Design studies began in March 2004, and a budget of $100,000 is allocated for continuing studies in S2. Initial studies conducted between March 2004 and January 2005 included development of a series of conceptual laboratory layouts, determining infrastructure requirements and visualization of alternatives. CNA Consultants, Inc. of Minneapolis, Minnesota was retained for those studies (Appendix I). This work will continue in S2 and will lead to the preliminary design level layout, preliminary engineering and a preliminary construction cost estimation.

3.0   Surface Campus and Laboratory Facility Planning and Design will begin during S2. Kimballton's close proximity to Virginia Tech and the support facilities available on campus reduce the surface campus requirements. For instance, extensive machine shops, fabrication areas, electronics shop, glass shops, chemistry stores are available on campus. The surface facility will consist of chemistry facilities (including wet chemistry); cryogenics infrastructure; computing and data acquisition facility; water, sewer and power infrastructure; research project staff offices; staging areas for the underground laboratories; classrooms and meeting rooms for education and outreach; and, other facilities identified by the research community. An experienced architectural and engineering firm will be retained to design the facility. It is envisioned that the surface campus and surface portion of the portal will be constructed using sustainable construction materials and methods, and could serve as a test bed for studies incorporating new building technologies.

4.0   Environmental Assessments began in May 2004 and the NEPA checklist study of Appendix D was completed prior to this proposal. A full NEPA assessment will be initiated during S2, which includes public meetings and comment. Should a full Environmental Impact Statement be required, it will be initiated as soon as possible.

5.0   Permitting. The results of a preliminary permitting study are presented in Appendix G. During S2, this study will be continued focusing on the application process and the time line for approval.

6.0   Risk Analysis and Uncertainty. A discussion of risk and uncertainty is provided in Appendix H. The Kimballton team recognizes the inherent risks and uncertainties in developing a large project. The

team consists of recognized experts in a broad range of fields and has access to external expertise in private firms required to successfully construct and operate the DUSEL.

7.0   Public Relations activities have been underway since the beginning of the DUSEL@Kimballton effort and will continue during S2. A web site is hosted at Virginia Tech that will have a public question and answer section, which links a citizen with a DUSEL scientist. This will provide prompt, direct response to any question or concern. Public meetings with local government officials, local community groups and the university community were held in the months leading to this proposal.

8.0   Administration. The Kimballton team will work with private firms with experience in managing facilities, such as national laboratories or other large multidisciplinary research enterprises, to develop an administrative structure for S2 and beyond. It is envisioned that a board consisting of representatives from science; engineering; finance; environmental safety and health; NSF and other funding agencies be formed. This board will select a director and an interdisciplinary advisory board developed so that all research areas are represented. The central philosophy of the Kimballton Team is that DUSEL Kimballton should remain at its core the most attractive research location for leading research both the sciences and engineering.

9.0   Personnel. This budget includes salary for university faculty, staff and students working during the S2 phase.

10.0   First Science. Starting in S2, each research community will develop detailed plans and schedules for the first suite of experiments to be conducted in Kimballton DUSEL. These experiments will match those in the S1 Modules. Opportunities for early research at Kimballton DUSEL include S2 studies (e.g., subsurface characterization, environmental, hydrogeology), S3 studies, tunnel construction, and laboratory operation.

11.0   Science and Engineering Integration. The Kimballton team consists of an interdisciplinary group of scientists and engineers. However, it is important that the vision and research goals that each discipline brings to the site can be addressed and that important opportunities for research are not missed. This task will form the Science and Engineering Integration (SEI) committee consisting of experienced researchers from physics, geosciences, biosciences, and geoengineering. This committee will oversee proposed site research beginning with S2 to facilitate and promote multi-use, multi-group interaction and coordination during site activities. An early assignment for the SEI committee will be to determine how the maximum research value from the deep borehole to be advanced from the top of Butt Mountain can be obtained. This borehole could be important to the bioscience community and steps should be taken to coordinate drilling and sampling protocols such that cross contamination is minimized.

12.0   Outreach and Education. Outreach and education will begin in S2 as described in Appendix J.

13.0   Economic Impact. An economic impact assessment of Kimballton DUSEL on the local and regional economy will be made during S2.

Table A-1. Budget and Timeline for S2 Preliminary Engineering

Task	Cost 1,000's	2004				2005				2006				2007				
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1
1.0 Subsurface Characterization	**$1,885.0**																	
Seismic Survey	-																	
Lineament Study	-																	
Field Survey and Modeling	40.0																	
Resistivity Study	20.0																	
Bore Holes	1,575.0																	
Kimballton portal	30.0																	
Hoges Chapel	45.0																	
Butt Mountain	1,500.0																	
Bore Hole Studies	70.0																	
Thermal Gradient	10.0																	
Anelastic Strain Recovery	10.0																	
Hydrological Properties	50.0																	
Rock Characterization	70.0																	
Quarry Study	-																	
In-Mine Study	20.0																	
Core Studies	50.0																	
Geomechanical Modeling	70.0																	
Local Hydrological Study	40.0																	
2.0 Underground Lab Planning/Design	**$100.0**																	
3-D Visualization	5.0																	
Layout/Lab Infrastructure																		
Conceptual & Preliminary	60.0																	
Pre-Final	25.0																	
Cost Estimation/Value Engineering	10.0																	
3.0 Surface Lab Planning/Design	**$80.0**																	
Architectural/Civil	40.0																	
Site Civil	20.0																	
Cost Estimation/Value Engineering	20.0																	
4.0 Environmental Assessment	**$70.0**																	
Checklist	-																	
Full Assessment	70.0																	
EIS (if required)																		
5.0 Permitting	**$40.0**																	
Access																		
Construction																		
Air Quality																		
Water Quality																		
Rock Disposal																		
Soil Erosion & Sediment Control																		
Reclamation and Closure																		

Task	Cost 1,000's	Year and Quarter																	
		2004				2005				2006				2007				
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1
6.0 Risk Analysis & Uncertainties	**$40.0**																	
Subsurface																		
Surface																		
Environmental																		
Permitting																		
Finance																		
7.0 Public Relations	**$30.0**																	
Web Site																		
Media																		
Public Meetings																		
8.0 Administration	**$50.0**																	
Administrative Structure																		
Integrate NSF, other Stakeholders																		
Risk/Liability/Insurance																		
9.0 Personnel	**$190.0**																	
Faculty																		
Graduate Students																		
Staff																		
10.0 First Science	**$80.0**																	
Physics																		
Biosciences																		
Geosciences																		
Engineering																		
11.0 Science & Engineering Integration	**$10.0**																	
12.0 Outreach & Education	**$60.0**																	
13.0 Economic Impact	**$30.0**																	
Total Cost of S-2 Activities	**$2,665.0**																	

Appendix L: NRL-VT Kimballton Low Background Counting Facility

- joint program of the Naval Research Laboratory and Virginia Tech

- open to new collaborators and experiments (see Appendix E)

The Naval Research Laboratory has long history of developing gamma- and X-ray radiation detector technology and applications. This investment in technology has produced a rich variety of scientific and technical advances.   Much of our work over the last several decades has focused on detectors which function in a high radiation environment as is typical in Earth orbit.   This investment has led to the successful completion of astrophysics instrumentation on major NASA missions such as the Compton Gamma Ray Observatory and the Solar Maximum Mission, as well as opportunities provided by the military Space Test Program such as the recent Unconventional Stellar Aspect experiment.

A natural direction that our detector technology and expertise is applied is in the area of environmental remediation, homeland security, nuclear medicine, and nuclear nonproliferation. Another current area of interest is in cosmic dust, man made orbital debris, and atmospheric science. A requirement in many of these applications is the need for a variety of detector systems that are sensitive to the radioactive signature (i.e. spectra) exhibited by extremely small quantities of radioactive isotopes. An equally rich area of interest is in the development ultra-low background counting technology itself. Much of this technology has been developed and advanced for studies in neutrino physics, and for the detection of dark matter. Measurements are typically performed deep underground where detectors are shielded from cosmic rays and the secondary particles that they create. This technology provides a new capability: the ability to detect trace amounts of radioactivity contained in small samples of material.   These counting techniques are already being applied to screen materials that will be used in order to construct ultra-low background detection systems.

In a broader sense, the ultra-low background counting technology is also useful in the field of trace nuclear characterization. This includes such things as nuclear fingerprinting, and the unraveling the history of a sample based on detection of trace radioactivity.   A niche for these detector systems in the detection of extremely small quantities of radioactive material, where they can be significantly more sensitive than conventional mass spectroscopy. This niche is bounded by those isotopes with half-lives between a few hours and about 100 years. This boundary is depends on details such as sample size, sample impurities, decay signature, as well as the sample preparation. Under the right conditions, detection thresholds on the order of a few decays over a period of weeks can be achieved. Another application is for larger samples with an extremely dilute isotope of interest.   Large samples do not lend themselves to mass spectroscopy, but in some instances may be well suited for low background counting.

Key applications of interest to which this detection capability can be applied include improved radio-dating capabilities, the study of the radiation environment of cosmic dust and atmospheric samples, and environmental monitoring. Dust samples may be collected in space for return to Earth, or directly from the atmosphere. Analysis of

these samples provides direct measurements of transport and mixing phenomena in the atmosphere. Alternately, ^{7}Be and other isotopes produced by cosmic ray interactions in the atmosphere may be used to study transport phenomena in the exo-atmospheric region above the Earth. Short lived isotopes are expected to provide an indication of whether the dust originates from outside or inside the Earth's magnetosphere.

We are also interested in developing applications in the field of nuclear non-proliferation. The ability to detect underground testing of small-yield nuclear weapons is particularly important in the world today. Inevitably, small quantities of gasses and radioactive dust are produced in any nuclear test. Atmospheric samples and dust collected from these test sites can provide important evidence as to the nature of the test.

This spring marks the completion of two new detector systems that we have invested in. One system is an ultra-low background germanium detector, modeled after the GEMPI-I detector, and the other a low background gas detector modeled after the GNO/GALLEX detectors, both developed by the Max Planck Institut für Kernphysik, Germany. Both systems are now located at Laboratori Nazionali del Gran Sasso (LNGS), Italy. We are also constructing a new low background counting facility closer to home in the Kimballton mine, called the Kimballton Low Background Facility (KLBF). This new facility will begin operations this year with a germanium detector provided by the National Institute of Standards, Maryland, and provide a local capability to make measurements and screen materials.

Studies are currently in progress to collect cosmic dust with sounding rockets and return the samples to Earth for rapid analysis. The first of these sounding rockets was launched in January, 2005, and the second is scheduled for March, 2005. These samples are immediately sent to LNGS for analysis.

NRL is working with Virginia Tech to construct the KLBF. This is a pre-DUSEL laboratory located away from active mining activity. It serves as both a path-finder laboratory, but also contributes directly to science. It will also provide essential services that will be fundamental to the DUSEL facility and many of the principle experiments. The key services include:

- Measurement of low background materials used for building experiments.
- Screening of materials brought into the laboratory.
- Study of background sources.
- Development of low background detectors and systems.

In addition, the KLBF will support science and applications:

- Measurements of samples, e.g. space, sedimentation, ocean, biologic.
- Host for visiting scientists and experiments
- National security.
- Nuclear nonproliferation.

The KLBF will establish an underground facility in an unused drift, known as XC-4 on the 14th level of the mine. XC-4 is far from the active mining activity at a depth of 1400 mwe. It will be operational in July 2005 (projected). It will serve two functions: (1) provide useful high-quality low-background laboratory space, and (2) provide an engineering model for the development of the primary DUSEL low background facility.

KLBF will be a building measuring 32' wide and 60' long, with a minimum clear ceiling height of 12'. It will be kept at a positive pressure over the ambient environment with filtered air to minimize contamination from mine dust, diesel fumes, or other particulates. The air quality shall be sufficient to maximize the efficiency of secondary air filtration that may be required around the various experimental stations. The environment will maintained warmer and dryer than the external environment, thus there will be no condensation either inside or outside the structure.

The building will be erected upon a concrete pad designed with fluid containment capacity. Concrete comes from local sources consisting primarily of local limestone sand, and aggregate, and screened for radioactivity. The preliminary design provides for containment of a minimum of 300 cubic feet liquid, consistent with a worst-case spill of the full volume of liquid scintillator in a LENS prototype module and a large safety margin (>2). Containment is achieved by a small concrete berm around the experiment area. The berm will have a gentle slope in critical access areas, enabling vehicles and carts to easily pass over it. The concrete pad for the building is designed to both contain fluids from inside the building, and exclude water from outside the building.

The building will be provided with 50 kW electrical service. Power is drawn from a 480 V line provided by the Chemical Lime Company. Sub-panels will distribute power to the various experimental areas. The building and immediate surroundings will be protected from falling rock by a steel mesh anchored to the mine ceiling. Interior and exterior lighting will provide a comfortable work-environment. Emergency lighting will be provided. Fire suppression will be developed to support the use of flammable materials, such as liquid scintillators.

The site plan is shown in figure L.1. The KLBF will provide infrastructure necessary to host laboratories NRL, VT, and others. Experimenters will initially be required to provide their own enclosures if they require secondary air filtration. Access is provided by a 14'x14' roll-up door on the end face of the building, and a loading dock on a platform to the side of the building.
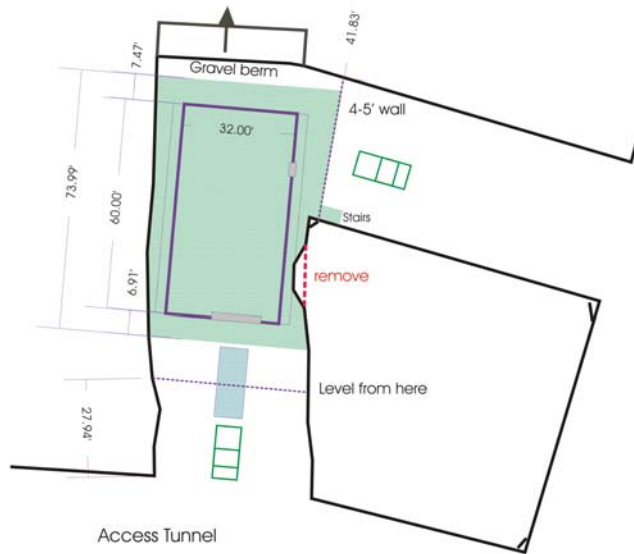
Figure L.1 – KLBF concrete pad, building placement and site plan.

Appendix M: Links to Documents Included by Reference

DUSEL S1 Homepage
---S1 Project Summary
---S1 Project Description
---S1 Supplementary Materials (Working Group Contributions)
S1 Requirement Matrices (xls)
Preliminary S1 Science Book (pdf)
Earth Lab Report (pdf)
NeSS 2002 Homepage