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 Synclinoirum, 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
Figure 3. Eleven access options initially considered for Kimballton DUSEL. Option 11 is currently the preferred design.
### Table 1 – Relative Horizontal Distances

<table>
<thead>
<tr>
<th>Location</th>
<th>Mountain Lookout</th>
<th>Central Campus</th>
<th>Deep Campus</th>
<th>Kimballton Portal Campus</th>
<th>Kimballton Mine Campus</th>
<th>Hoges Chapel Portal Campus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mountain Lookout</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3672</td>
<td>2509</td>
<td>6551</td>
</tr>
<tr>
<td>Central Campus</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3672</td>
<td>2509</td>
<td>6551</td>
</tr>
<tr>
<td>Deep Campus</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3672</td>
<td>2509</td>
<td>6551</td>
</tr>
<tr>
<td>Kimballton Portal Campus</td>
<td>3672</td>
<td>3672</td>
<td>3672</td>
<td>0</td>
<td>1295</td>
<td>10115</td>
</tr>
<tr>
<td>Kimballton Mine Campus</td>
<td>2509</td>
<td>2509</td>
<td>2509</td>
<td>1295</td>
<td>0</td>
<td>9048</td>
</tr>
<tr>
<td>Hoges Chapel Portal Campus</td>
<td>6551</td>
<td>6551</td>
<td>6551</td>
<td>10115</td>
<td>9048</td>
<td>0</td>
</tr>
</tbody>
</table>

### Table 2 - Elevation Differences

<table>
<thead>
<tr>
<th>Location</th>
<th>Mountain Lookout</th>
<th>Central Campus</th>
<th>Deep Campus</th>
<th>Kimballton Portal Campus</th>
<th>Kimballton Mine Campus</th>
<th>Hoges Chapel Portal Campus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mountain Lookout</td>
<td>0</td>
<td>1280</td>
<td>2280</td>
<td>658</td>
<td>953</td>
<td>658</td>
</tr>
<tr>
<td>Central Campus</td>
<td>-1280</td>
<td>0</td>
<td>1000</td>
<td>-622</td>
<td>-327</td>
<td>-622</td>
</tr>
<tr>
<td>Deep Campus</td>
<td>-2280</td>
<td>-1000</td>
<td>0</td>
<td>-1622</td>
<td>-1327</td>
<td>-1622</td>
</tr>
<tr>
<td>Kimballton Portal Campus</td>
<td>-658</td>
<td>622</td>
<td>1622</td>
<td>0</td>
<td>295</td>
<td>0</td>
</tr>
<tr>
<td>Kimballton Mine Campus</td>
<td>-953</td>
<td>327</td>
<td>1327</td>
<td>-295</td>
<td>0</td>
<td>-295</td>
</tr>
<tr>
<td>Hoges Chapel Portal Campus</td>
<td>-658</td>
<td>622</td>
<td>1622</td>
<td>0</td>
<td>295</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 3 - Required Tunnel Length

<table>
<thead>
<tr>
<th>Location</th>
<th>Mountain Lookout</th>
<th>Central Campus</th>
<th>Deep Campus</th>
<th>Kimballton Portal Campus</th>
<th>Kimballton Mine Campus</th>
<th>Hoges Chapel Portal Campus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mountain Lookout</td>
<td>0</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Central Campus</td>
<td>NA</td>
<td>0</td>
<td>5556</td>
<td>3672</td>
<td>2509</td>
<td>6551</td>
</tr>
<tr>
<td>Deep Campus</td>
<td>NA</td>
<td>5556</td>
<td>0</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Kimballton Portal Campus</td>
<td>NA</td>
<td>3672</td>
<td>NA</td>
<td>0</td>
<td>1639</td>
<td>NA</td>
</tr>
<tr>
<td>Kimballton Mine Campus</td>
<td>NA</td>
<td>2509</td>
<td>NA</td>
<td>1639</td>
<td>0</td>
<td>NA</td>
</tr>
<tr>
<td>Hoges Chapel Portal Campus</td>
<td>NA</td>
<td>6551</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>0</td>
</tr>
</tbody>
</table>

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 $n$-$\overline{n}$bar 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)>
# Table of Contents

List of Tables ........................................................................................................ iv  
List of Figures ......................................................................................................... iv  
1 Introduction ........................................................................................................... 1  
2 Project Work Breakdown Structure (WBS) ......................................................... 1  
  2.1 WBS Section 1.0 Land Acquisition, Easements, Usage Fees & Insurance .... 1  
  2.2 WBS Section 2.0 Surface Facilities ............................................................ 1  
    2.2.1 Surface Site Work ........................................................................... 1  
    2.2.2 Surface Infrastructure .................................................................... 1  
    2.2.3 Science, Physics and Administration buildings ........................... 1  
    2.2.4 Rock Disposal ............................................................................. 1  
  2.3 WBS Section 3.0 Underground Access ....................................................... 2  
    2.3.1 Portals .......................................................................................... 2  
    2.3.2 Tunnels ....................................................................................... 2  
    2.3.3 Shafts ........................................................................................ 2  
  2.4 WBS Section 4.0 Underground Facilities ................................................... 2  
    2.4.1 Cavern Excavation by Drill and Blast ........................................... 2  
    2.4.2 Primary Support Requirements Based On Empirical Methods ....... 2  
  2.5 WBS Section 5.0 Systems ......................................................................... 2  
  2.6 WBS Section 6.0 Permits, Fees and Professional Services ....................... 2  
3 Preliminary Design Criteria .................................................................................. 3  
  3.1 Major Project Features ................................................................................ 3  
  3.2 Science Design Criteria ............................................................................ 3  
    3.2.1 General ...................................................................................... 3  
    3.2.2 Physics ....................................................................................... 3  
    3.2.3 Earth Science ............................................................................. 3  
    3.2.4 Public Access ............................................................................. 3  
  3.3 Occupancy ..................................................................................................... 3  
    3.3.1 Background .................................................................................. 3  
    3.3.2 Occupancy Assumptions ............................................................... 4  
    3.3.3 Occupancy ................................................................................... 4  
  3.4 Codes & Standards ....................................................................................... 4  
    3.4.1 Structural Codes .......................................................................... 4  
    3.4.2 Fire & Life Safety ......................................................................... 4  
  3.5 General Access .............................................................................................. 5  
    3.5.1 Access Availability ....................................................................... 5  
    3.5.2 Tunnel Access ............................................................................. 5  
    3.5.3 Shaft Access ................................................................................ 5  
  3.6 Schedule ......................................................................................................... 5  
  3.7 Experiment Isolation ..................................................................................... 5  
4 Subsurface Construction Conditions ................................................................... 5  
5 Project Access Alternatives .................................................................................. 6  
  5.1 Surface Access Locations ............................................................................. 6  
    5.1.1 General ...................................................................................... 6  
    5.1.2 Hoges Chapel ............................................................................. 6  
    5.1.3 Kimballton ................................................................................... 6  
    5.1.4 Mountain Lookout ....................................................................... 6
8.8 Safety Ventilation Systems .......................................................... 18
  8.8.1 Compartmentalization Smoke Ventilation ............................... 18
  8.8.2 Smothering Gas Ventilation ................................................ 18
8.9 Fire Protection Systems ............................................................. 19
  8.9.1 Laboratory ......................................................................... 19
  8.9.2 Portal Tunnels Standpipe Systems ......................................... 19
  8.9.3 Fire Protection Water Storage Tank ..................................... 19
8.10 Electrical ............................................................................. 19
  8.10.1 Distribution Systems .......................................................... 19
  8.10.2 Lighting ........................................................................ 22
  8.10.3 Lighting Control .............................................................. 23
  8.10.4 Motors, Appliances and Equipment .................................... 23
  8.10.5 Fire Alarm System .......................................................... 23
8.11 Security ................................................................................ 23
  8.11.1 Surveillance Camera System ............................................. 23
  8.11.2 Access Control System ..................................................... 24
  8.11.3 Security System .............................................................. 24
  8.11.4 Duress Alarm System ....................................................... 24
  8.11.5 Asset Locator ............................................................... 24
8.12 Communications......................................................................... 24
  8.12.1 Backbone Cabling System ................................................ 25
  8.12.2 Horizontal Cabling System ............................................. 25

9 Fire and Life Safety ................................................................. 25
  9.1 Jurisdiction ........................................................................ 25
  9.2 Building Code .................................................................... 26
  9.3 Access Tunnel Regulations ................................................... 26
  9.4 Drift/Unoccupied Safety Regulations ..................................... 27
  9.5 References ....................................................................... 27
10 Project Cost and Schedule ...................................................... 27
  10.1 Heavy Civil Costs ............................................................... 27
    10.1.1 Portals ....................................................................... 27
    10.1.2 Tunneling Costs .......................................................... 27
    10.1.3 Shaft Costs ................................................................. 28
    10.1.4 Cavern Construction ..................................................... 28
  10.2 Mechanical & Electrical Costs .............................................. 28
  10.3 Cavern Outfitting ............................................................... 28
  10.4 Schedule ......................................................................... 28
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
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 straightforward, 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 |
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 2 - Elevation Differences

<table>
<thead>
<tr>
<th>Location</th>
<th>Mountain Lookout</th>
<th>Central Campus</th>
<th>Deep Campus</th>
<th>Kimballton Portal Campus</th>
<th>Kimballton Mine Campus</th>
<th>Hoges Chapel Portal Campus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mountain Lookout</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3672</td>
<td>2509</td>
<td>6551</td>
</tr>
<tr>
<td>Central Campus</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3672</td>
<td>2509</td>
<td>6551</td>
</tr>
<tr>
<td>Deep Campus</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3672</td>
<td>2509</td>
<td>6551</td>
</tr>
<tr>
<td>Kimballton Portal Campus</td>
<td>3672</td>
<td>3672</td>
<td>3672</td>
<td>0</td>
<td>1295</td>
<td>10115</td>
</tr>
<tr>
<td>Kimballton Mine Campus</td>
<td>2509</td>
<td>2509</td>
<td>2509</td>
<td>1295</td>
<td>0</td>
<td>9048</td>
</tr>
<tr>
<td>Hoges Chapel Portal Campus</td>
<td>6551</td>
<td>6551</td>
<td>6551</td>
<td>10115</td>
<td>9048</td>
<td>0</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Option</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ease of ventilating the Central campus with two 4300 ft supply and exhaust ducts.</td>
<td>Construction and operating cost to ventilate 87,000 ft of tunnels.</td>
</tr>
<tr>
<td></td>
<td>Ease of ventilating the Deep campus with two 3300 ft supply and exhaust ducts.</td>
<td>Construction and operating cost to light 87,000 ft of tunnels.</td>
</tr>
<tr>
<td></td>
<td>Reduced operating cost of ventilating the central campus and deep campus with short shaft ducts.</td>
<td>Construction cost to provide fire protection for 87,000 ft of tunnels.</td>
</tr>
<tr>
<td></td>
<td><strong>Fast egress through shafts to the surface.</strong></td>
<td><strong>Construction and operating cost to ventilate 118,000 ft of tunnels.</strong></td>
</tr>
<tr>
<td>---</td>
<td>-----------------------------------------------</td>
<td>---------------------------------------------------------------------</td>
</tr>
<tr>
<td>2</td>
<td><strong>Parallel tunnels to the Central campus permit crossover egress compartmentalization.</strong>&lt;br&gt;<strong>Ease of ventilating the Deep campus with two 3300 ft supply ducts and two 3300 ft exhaust ducts.</strong></td>
<td><strong>Construction and operating cost to ventilate 118,000 ft of tunnels.</strong></td>
</tr>
<tr>
<td>3</td>
<td><strong>Ease of ventilating the Central campus with two 4300 ft supply and exhaust ducts.</strong>&lt;br&gt;<strong>Ease of ventilating the Deep campus with two 3300 ft supply and exhaust ducts.</strong>&lt;br&gt;<strong>Reduced operating cost of ventilating the central campus and deep campus with short shaft ducts.</strong>&lt;br&gt;<strong>Fast egress through shafts to the surface.</strong></td>
<td><strong>Construction and operating cost to ventilate 90,000 ft of tunnels.</strong></td>
</tr>
<tr>
<td>4</td>
<td><strong>Parallel tunnels to the Central campus permit crossover egress compartmentalization.</strong>&lt;br&gt;<strong>Ease of ventilating the Deep campus with two 3300 ft supply ducts and two 3300 ft exhaust ducts.</strong></td>
<td><strong>Construction and operating cost to ventilate 124,000 ft of tunnels.</strong></td>
</tr>
<tr>
<td>5</td>
<td><strong>Ease of ventilating the Central campus with two 4300 ft supply and exhaust ducts.</strong>&lt;br&gt;<strong>Ease of ventilating the Deep campus with two 3300 ft supply and exhaust ducts.</strong>&lt;br&gt;<strong>Reduced operating cost of ventilating the central campus and deep campus with short shaft ducts.</strong>&lt;br&gt;<strong>Fast egress through shafts to the surface.</strong>&lt;br&gt;<strong>Shortest walk out egress of 6 miles from the Central campus.</strong>&lt;br&gt;<strong>Lowest construction and operating cost to ventilate 32,000 ft of tunnels.</strong>&lt;br&gt;<strong>Lowest construction and operating cost to light 32,000 ft of tunnels</strong>&lt;br&gt;<strong>Lowest construction cost to provide fire protection for 32,000 ft of tunnels</strong></td>
<td>None identified.</td>
</tr>
<tr>
<td>6</td>
<td><strong>Parallel tunnels to the Central campus permit crossover egress compartmentalization.</strong>&lt;br&gt;<strong>Ease of ventilating the Deep campus with two 3300 ft supply ducts and two 3300 ft exhaust ducts</strong></td>
<td><strong>Construction and operating cost to ventilate 64,000 ft of tunnels</strong></td>
</tr>
<tr>
<td>7</td>
<td>Ease of ventilating the Central campus with two 4300 ft supply and exhaust ducts</td>
<td>None identified</td>
</tr>
<tr>
<td></td>
<td>Ease of ventilating the Deep campus with two 3300 ft supply and exhaust ducts</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reduced operating cost of ventilating the central campus and deep campus with short shaft ducts.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fast egress through shafts to the surface</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Walk out egress of 6.5 miles from the Central campus.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low construction and operating cost to ventilate 35,000 ft of tunnels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low construction and operating cost to light 35,000 ft of tunnels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low construction cost to provide fire protection for 35,000 ft of tunnels</td>
<td></td>
</tr>
</tbody>
</table>

| 8 | Parallel tunnels to the Central campus permit crossover egress compartmentalization. | Construction and operating cost to ventilate 70,000 ft of tunnels |
|   | Ease of ventilating the Deep campus with two 3300 ft supply ducts and two 3300 ft exhaust ducts | 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 |
|   | Construction and operating cost to light 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 | 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) | 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) | 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. | 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 and operating cost to light 67,000 ft of tunnels |
|    | Construction cost to provide fire protection for 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) | Slower egress through exit tunnels from the Central campus (6 miles from central campus) |
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:

\[
Q = \frac{RQD}{Jn} \times \frac{Jr}{Ja} \times \frac{Jw}{SRF}
\]

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:

<table>
<thead>
<tr>
<th>Q Rating</th>
<th>Rockbolt Spacing (m)</th>
<th>Shotcrete Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.33</td>
<td>1.54</td>
<td>220</td>
</tr>
<tr>
<td>0.44</td>
<td>1.61</td>
<td>211</td>
</tr>
<tr>
<td>2.63</td>
<td>2.01</td>
<td>154</td>
</tr>
</tbody>
</table>
Table 4—Rockbolt Spacing & Shotcrete Thickness vs. Rock Quality.

<table>
<thead>
<tr>
<th>Rock Quality</th>
<th>Rockbolt Spacing</th>
<th>Shotcrete Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.82</td>
<td>2.15</td>
<td>135</td>
</tr>
<tr>
<td>7.01</td>
<td>2.23</td>
<td>123</td>
</tr>
<tr>
<td>10.63</td>
<td>2.32</td>
<td>110</td>
</tr>
<tr>
<td>11.14</td>
<td>2.34</td>
<td>108</td>
</tr>
<tr>
<td>22.28</td>
<td>2.49</td>
<td>86</td>
</tr>
<tr>
<td>33.75</td>
<td>2.58</td>
<td>73</td>
</tr>
</tbody>
</table>

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, the 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·ft²·°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 Ft². 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 Ft² 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
cased 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>
<thead>
<tr>
<th>Table 5 – Total Facility Electrical Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupancy</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>Laboratory</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Personnel</td>
</tr>
<tr>
<td>Change</td>
</tr>
<tr>
<td>Offices,</td>
</tr>
<tr>
<td>Lunch, etc.</td>
</tr>
<tr>
<td>M &amp; E/</td>
</tr>
<tr>
<td>Utilities</td>
</tr>
<tr>
<td>Refuge</td>
</tr>
<tr>
<td>Areas</td>
</tr>
<tr>
<td>Vehicle</td>
</tr>
<tr>
<td>Parking</td>
</tr>
<tr>
<td>Dirty/Clean</td>
</tr>
<tr>
<td>Machine</td>
</tr>
<tr>
<td>General Labs</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>MOON Solar Neutrino</td>
</tr>
<tr>
<td>LENS Solar Neutrino</td>
</tr>
<tr>
<td>HYBRID Solar Neutrino</td>
</tr>
<tr>
<td>HERON solar Neutrino</td>
</tr>
<tr>
<td>Clean Solar Neutrino</td>
</tr>
<tr>
<td>TPC Solar Neutrino</td>
</tr>
<tr>
<td>MAJORANA Double Beta Decay</td>
</tr>
<tr>
<td>EXO Double Beta Decay</td>
</tr>
<tr>
<td>MOON Double Beta Decay</td>
</tr>
<tr>
<td>DRIFT-III Dark Matter</td>
</tr>
<tr>
<td>Lab</td>
</tr>
<tr>
<td>-------------------------</td>
</tr>
<tr>
<td>ALNA Nuclear Astrophysics</td>
</tr>
<tr>
<td>SuperCDMS Dark Matter</td>
</tr>
<tr>
<td>XENON Dark Matter</td>
</tr>
<tr>
<td>ZEPLIN IV Dark Matter</td>
</tr>
<tr>
<td>CLEAN Solar Neut./Dark Matter</td>
</tr>
<tr>
<td>EURECA Dark Matter</td>
</tr>
<tr>
<td>Directional TPC</td>
</tr>
<tr>
<td>SIGN</td>
</tr>
<tr>
<td>HSD</td>
</tr>
<tr>
<td>Miscellaneous Peak Demand of Largest Load</td>
</tr>
<tr>
<td>Tunnels</td>
</tr>
<tr>
<td>Electric Vehicle</td>
</tr>
<tr>
<td>Mechanical</td>
</tr>
<tr>
<td>Cooling</td>
</tr>
<tr>
<td>Ventilation</td>
</tr>
<tr>
<td>Gray Water Handling</td>
</tr>
<tr>
<td>Tenant Improvements</td>
</tr>
<tr>
<td>Total Demand</td>
</tr>
</tbody>
</table>

Notes:

* Estimated demand based on “modest” load
** Average demand number used for this calculation. This load is based on file duseL_infrastructructure_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 utilize 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.

Supplemental information not included by referenced includes:

1. International Building Code
2. Virginia Uniform Statewide Building 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.
\[
\text{Project} \cdot \text{Cost} = \left( \frac{\text{Project} \cdot \phi}{\text{Model} \cdot \phi} \right) \times \text{Model} \cdot \text{Cost}
\]

\[\phi = \text{Tunnel outside Diameter}\]

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.

\[
\text{Project} \cdot \text{Cost} = \left[ \frac{\text{Project} \cdot \text{Index} \cdot (2005)}{\text{Model} \cdot \text{Index} \cdot (\text{Base} \cdot \text{Year})} \right] \times \text{Model} \cdot \text{Cost}
\]

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:

1 Electric Truck K1050E .............................................................................................................................................. 2
  1.1 General ............................................................................................................................................................... 2
  1.2 Active rectifier .................................................................................................................................................... 3
  1.3 Main frequency convertors .................................................................................................................................. 3
  1.4 Main Motors ......................................................................................................................................................... 3
  1.5 24 V Battery ......................................................................................................................................................... 4
  1.6 Diesel generator set ............................................................................................................................................. 4
  1.7 Power switching sequence between diesel supply and trolley supply ................................................................. 4
  1.8 Diesel Motor ......................................................................................................................................................... 5
  1.9 Service Motor/Generator ..................................................................................................................................... 5
  1.10 Control and Regulation System ...................................................................................................................... 5
  1.11 Rock Box ........................................................................................................................................................... 7
  1.12 Front Chassis ..................................................................................................................................................... 7
  1.13 Rear Frame ......................................................................................................................................................... 7
  1.14 Drive Axles ......................................................................................................................................................... 7
  1.15 Hydraulic System ............................................................................................................................................... 7
  1.16 Braking Systems ............................................................................................................................................... 8
  1.17 Operator's Cab .................................................................................................................................................... 9
  2 Trolley line and pick-up system .............................................................................................................................. 10
    2.1 Pick-up system .................................................................................................................................................... 10
    2.2 Trolley line ........................................................................................................................................................ 10
    2.3 Mechanical switches ......................................................................................................................................... 10
    2.4 Standard Trolley Line Layouts ......................................................................................................................... 10
    2.5 Rock Bolts ........................................................................................................................................................ 12
    2.6 Design ............................................................................................................................................................... 12
    2.7 Trolley Componentry Supply ............................................................................................................................ 12
  3 Transformer sub-stations ........................................................................................................................................... 13
    3.1 Dry type transformer with enclosure (T1) ........................................................................................................... 13
    3.2 Switchgear ........................................................................................................................................................ 13
  4 Electric protection circuits ...................................................................................................................................... 14
  5 Documentation ......................................................................................................................................................... 15
  6 Options ................................................................................................................................................................... 15
    6.1 Truck ................................................................................................................................................................. 15
    6.2 General ............................................................................................................................................................... 15

ABB Industries AB
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/s²
- **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.

ABB Industries AB
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

ABB Industries AB
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

<table>
<thead>
<tr>
<th>Type</th>
<th>lead acid traction batteries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>158 Ah</td>
</tr>
<tr>
<td>Voltage</td>
<td>2 x 12 V</td>
</tr>
</tbody>
</table>

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

ABB Industries AB
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

<table>
<thead>
<tr>
<th>Type</th>
<th>Detroit 706LT or similar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>81 kW continuous at 1500 rpm</td>
</tr>
<tr>
<td>Fuel tank</td>
<td>80 l (equal 5-6 hour of continuous duty)</td>
</tr>
<tr>
<td>Emission</td>
<td>EEC 77/537, EEC 72/306</td>
</tr>
<tr>
<td></td>
<td>Stage 1 off – highway (C1–8 mode cycle, ISO 8178)</td>
</tr>
</tbody>
</table>

1.9 Service Motor/Generator

The service motor is a standard DC-motor. The motor will also be used as generator. See separate description.

<table>
<thead>
<tr>
<th>Power</th>
<th>20 kW (short time 80 kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage</td>
<td>930 V DC</td>
</tr>
<tr>
<td>Rated current</td>
<td>22 A DC</td>
</tr>
</tbody>
</table>

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
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.
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

ABB Industries AB
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.
1.17 Operator's Cab

Pressurised fully enclosed cab with filtered air intake. Sound insulation for maximum noise level in the cab should not exceed 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
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. ± 60° from it's central position and to tilt approx. ± 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.
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)

<table>
<thead>
<tr>
<th>Specification</th>
<th>T1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated power (kVA)</td>
<td>1600</td>
</tr>
<tr>
<td>Primary voltage HV (kV)</td>
<td>4-10.5 + 2 x 2.5 %</td>
</tr>
<tr>
<td>Secondary voltage LV (V)</td>
<td>690</td>
</tr>
<tr>
<td>Impedance at 75°C (%)</td>
<td>6</td>
</tr>
<tr>
<td>Protection class</td>
<td>IP 23</td>
</tr>
<tr>
<td>Insulation class</td>
<td>F</td>
</tr>
<tr>
<td>Coupling</td>
<td>Dyn 11</td>
</tr>
<tr>
<td>Standard</td>
<td>IEC 726</td>
</tr>
<tr>
<td>Enclosure</td>
<td>IP23</td>
</tr>
</tbody>
</table>

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.
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