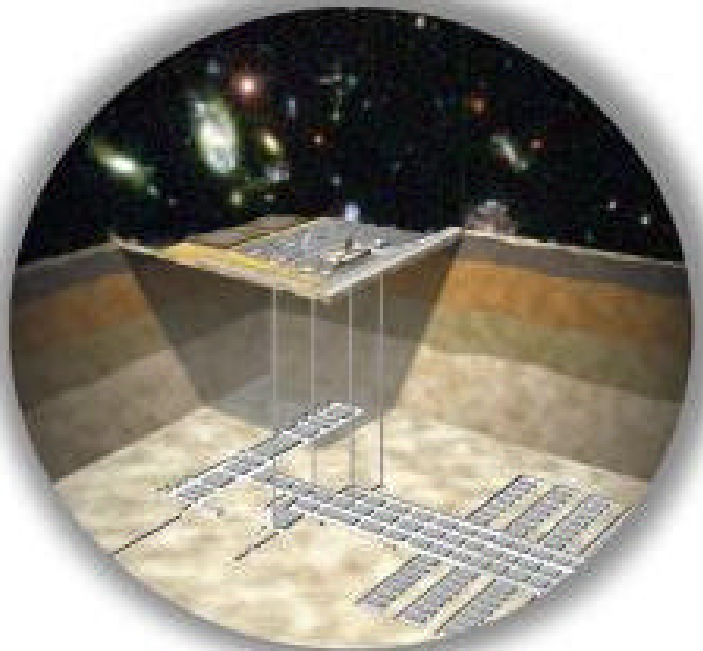


# Prospects for an Underground Laboratory in Carlsbad, NM

Report to the Underground Laboratory Committee  
February 28, 2001



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## I. INTRODUCTION

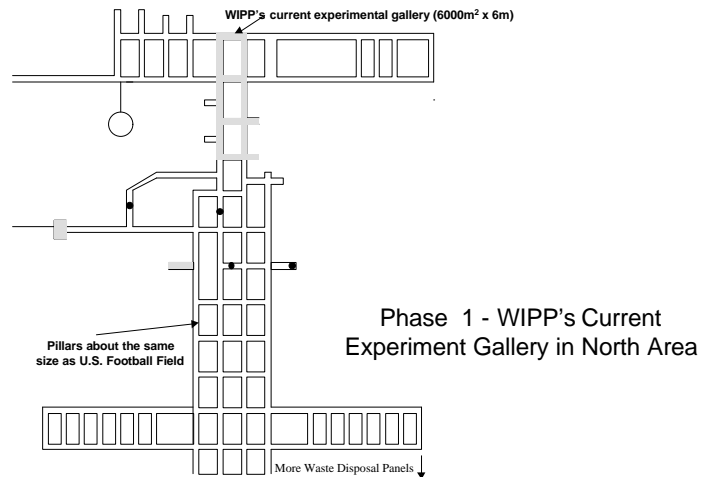
A half-million tourists visit Carlsbad Caverns National Park each year to view the natural wonders nearly 1,000' under the surface in the Guadalupe Mountains in southeastern New Mexico. A large reef beneath an ancient ocean formed those mountains. Evaporation of this ocean during the Permian produced a thickly bedded evaporite deposit of nearly pure salt, called the Salado formation. With a thickness of 2,000' and buried 1,000' below the Chihuahuan Desert east of the Caverns, this formation is home to the 2,150 foot deep Waste Isolation Pilot Plant (WIPP), the first underground repository for disposal of transuranic material. This dry and geologically inactive site on a 16 sq. mile tract is permanently withdrawn and owned by the U.S. Department of Energy (DOE).

It is a unique facility in another way — arguably the best and most cost effective location in the US to develop an underground laboratory dedicated to experiments to probe the nature of the cosmos, to study the fundamental particles and their interactions, and to search for ethereal particles that are thought to pervade our universe. WIPP offers very low background radiation and excellent shielding from the cosmic radiation. We call the facilities and infrastructure needed to support a strong and vigorous science program underground the Carlsbad Underground National Laboratory, or CUNL. In the autumn of 2000, the Secretary of Energy decided to make the underground reaches of the mine available for scientific research. Space is soon to be available underground for many new projects. By capitalizing on the investment by the government in extensive infrastructure that will operate for at least 35 years, and subsequently placed under active institutional control for an additional 100 years, this site can become home to many planned US projects. We believe that it will become the center of the burgeoning field of particle astrophysics in the US.

One clear advantage of exploiting an existing facility, especially one that is already operated by the government, is to make best use of taxpayer's investment with highest scientific return. The following are the principal reasons why establishing an underground laboratory in Carlsbad, utilizing the resources and infrastructure available at WIPP and nearby, is attractive to researchers:

- The 2000' of rock overlying the repository absorbs most of the cosmic rays that continuously bombard Earth
- The salt contains lower concentrations of naturally occurring radioactive elements than most rocks that compose the Earth's crust. The natural abundance of U/Th is typically 1/50 that found in rock. The abundance of airborne Rn is at the level of surface air, and because there are few fissures in salt it can be reduced by about a factor of 30 if it is removed from the input air stream. There is no water in the mine. Salt has other advantages, the most obvious being that it can be mined in nearly any cavity/drift configuration, and the cost of mining (approx. \$20/m<sup>3</sup> based upon current costs at the site) is quite low.
- The WIPP is a federal project with a sophisticated infrastructure and workforce, and will have a lifetime of at least 35 years. The scientific community will not have to bear the majority of the costs associated with maintenance and operation of the mine or available infrastructure; the science program will obviously have to cover its own expenses.
- Safety and mine rescue, training, ES&H, security, etc. already exist at the site.

There has already been a large investment to support underground science in this facility. As shown in the drawing, about 1.5 acres of space underground is now being refurbished with lighting and power installed throughout the area. This “north experimental area” is soon to be available to the science community. An Environmental Assessment concluded these projects can proceed without concern. There is also support for installation of some prototype projects that are described below. Underground areas involved in this work include the Room Q alcove, the alcove west of the W-170 drift at S-400, and the region circumscribed by the N-460 and N-1400 crosscuts and the E-0 and E-140 drifts identified as the Experimental Gallery. The roof beam in this latter area is being removed to enhance long-term stability.



## II. Current Projects

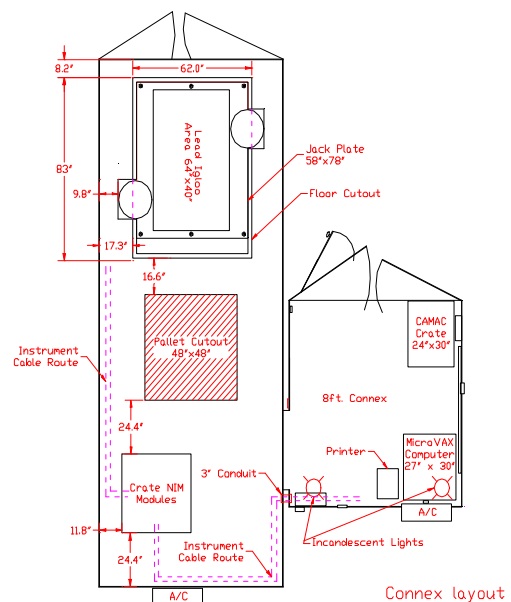
Currently, there are four projects going on underground that show the interest of the scientific community.

### 1. Los Alamos National Lab (LANL) Astrophysics Project

This project consists of two astrophysics experiments in the Q room alcove. The first experiment involves the testing of ultra-low background neutron proportional counters. The second experiment tests solid-state dark matter detectors in a low radioactive background environment. The ultra-low background neutron proportional counters in the first experiment are being used in the Sudbury Neutrino Observatory (SNO) experiment. Experiments with these detectors will be performed as needed throughout the SNO project lifetime. The second experiment will test a Si(Li) detector prototype to identify its quality limits. This project is ongoing and is expected to continue into the near future. It has benefited greatly from the low natural backgrounds and available infrastructure. Related to this work is a preliminary measurement of the muon flux that gave a flux within 50% of the expected overburden; these results are being further refined and prepared for publication.

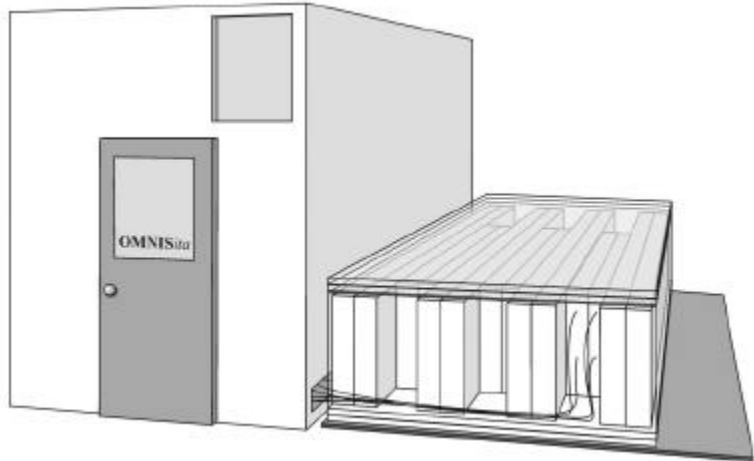
### 2. Majorana 2βdk Prototype

The purpose of this project is the development of a very precise double beta decay detector capitalizing on the very low natural background at the northern area. The experimental apparatus for the project consists of two high-purity germanium detectors. The installation of this equipment at the WIPP is expected to begin in March 2001 or April 2001, and the experiment will be conducted over the next two years. This project will be located in the south area of the Q room alcove and will be contained in two excess trailer units provided by the WIPP.



### 3. OMNISita Project

The purpose of OMNISita is the development of a small experiment as a prototype for the Observatory for Multi-flavor Neutrino Interactions from Supernovae (OMNIS) project. The collaboration will build a small-scale detector system consisting of twelve, four and a half meter scintillation tubes to be located in the former core storage alcove in W170 and S400. The Carlsbad site is ideal for this project because there is no need to shield



the detector from external backgrounds or radiation, and it is capitalizing upon the existing infrastructure for its success. The OMNISita project has the following objectives.

- Evaluate the construction of the detectors, especially the large metal segments, within the working environment of the mine.
- Evaluate the effects of the creep of the salt floor upon which the lead will be situated
- Evaluate the background events caused by high energy cosmic rays, gamma rays, and neutron emissions within the salt walls and the components of OMNISita itself
- Develop and prototype dedicated electronics and data acquisition systems to be ready to mass produce vastly cheaper electronics for the several thousand channels required in the future OMNIS project

An area 25' by 50' within the former core storage alcove is being prepared to house the experiment and for detector installation. The expected start date for the installation for this experiment is March 2001. The experiment is expected to run for three years and provide the basis for the development of a future larger OMNIS project likely to be housed in the north experimental area.

### 4. Portable Muon Flux Monitoring Device

The EXO Collaboration has completed an initial measurement of the flux of cosmic ray muons at the current mine depth. The purpose of this experiment is to measure the muon flux to determine if the current depth is a suitable location for this future double beta decay experiment. The portable muon flux monitoring device was used for three data collection sets were taken on January 29<sup>th</sup>, 30<sup>th</sup>, and 31<sup>st</sup>, 2001 collecting 4.8 million events. At present, the data sets are being reduced to determine the muon flux.

### Development of the North Experimental Gallery

The final undertaking started in fiscal year 2001 is the development of the Experimental Gallery. The purpose of this project is to provide a unique location separated from the waste disposal areas for more science experiments. This will allow ground control, power and telecommunications to be provided at one location resulting in a savings of resources. The Experimental Gallery is the region circumscribed by the N-460 and N-1400 crosscuts and the E-0 and E-140 drifts. This will provide about 6,000 m<sup>2</sup> of space to house one or perhaps two modest projects over the relatively short-term.

The first step is to raise the roof to approximately 6m in the area to enhance long-term stability. This has begun. A separate power station will be provided to support future electronics and HVAC

requirements in the area. A new network with separate fiber optics, routers, switches, file server and firewall software is also planned. This is to meet the flexibility needs of scientists and international collaborators when connecting to the Internet while protecting the DOE security requirements identified for WIPP project. It is expected that the refurbishment will take about a year and the work to provide the infrastructure enhancements will take about three additional months. This work is being conducted within existing budgets and with existing resources. No new funding is required.

### **III. Potential Future Projects**

The projects listed below have either expressed a very strong desire to be located in the WIPP underground or have chosen Carlsbad as their prime site. They are in some cases competing projects and, as such, most certainly all will not be funded. One or more of these projects is likely to be installed in the next several years.

#### **OMNIS — Observatory for Multi-flavor Neutrino Interactions from Supernovae**

This project would be the next step after the OMNISita project and would follow in about three to five years, pending funding. This project would include a 10,000-ton lead and iron detector system (20 modules of 500 tons each installed in phases) to detect the muon- and tau-neutrinos that are expected to come from a core collapse supernova. A possible site is the refurbished north experimental gallery. The site offers an environment with very low backgrounds, thus allowing the detector to be built without external shielding, and the site offers more than a 35-year lifetime for a supernova detector. WIPP has been identified as the site for this project.

#### **EXO - Enriched Xenon-136 Observatory**

This project is a world-wide collaboration to build a 10-ton Xenon-filled gas detector to measure neutrino-less double beta decay. EXO is considering the WIPP location because of the very low-backgrounds there—while an experiment can be shielded against such backgrounds, it is much easier to not have to do this. This project depends on availability of enriched Xenon-136 that must be made in Russia. The optimistic timeframe for any detector installation would be no sooner than FY 2004. The full detector would be assembled in pieces in the underground and would likely require some new excavation and require some air filtering equipment. Backgrounds are now being evaluated for the project.

#### **The Majorana Project - A 500kg Double Beta Decay Experiment**

A collaboration is proposing an enriched Ge-76 experiment to the DOE's Office of Science to build a detector to measure double beta decay events. This project is the next step after the prototype detector project located in the Q room area, assuming these tests show the site is viable. While similar to EXO in the physics explored, the detection system is much different, using solid-state detectors (cooled to liquid nitrogen temperatures). If funded in FY 2003, detection and equipment assembly would begin in the new Experiment Gallery. Majorana also would benefit from the very low natural backgrounds.

#### **Low Background Counting Facility and Advanced Detector Preparation Laboratory**

There is currently a need in the US nuclear and particle physics communities for a user facility especially dedicated to surveying modest sized samples of materials for radioimpurities at unprecedented sensitivity. The design concept for such a facility is now under study. It would involve a purified water shield to further reduce natural radioactive backgrounds; this shield can

also be instrumented as an active cosmic ray veto. Several very sensitive detectors would be placed inside the water shield with portal access for sample insertion.

There is also a growing need for a facility to prepare detectors in an underground setting to avoid cosmogenic production of impurities. This would include a clean area for storage of detector or shielding materials needed later at the CUNL or another location. Other concepts include a complete detector production laboratory. A related need is dedicated computing facilities needed to simulate and design the next generation of experiments in underground physics.

### **Neutrino Factory Detector**

A collaboration of universities and national laboratories may propose a major accelerator project for the coming decade. The so-called neutrino factory is a complex of accelerators including a muon accelerator to be built at either Fermi National Laboratory or Brookhaven National Laboratory. A separate collaboration is proposing that a neutrino detector be built at the present WIPP depth to study neutrino oscillation along long baselines. This neutrino detector would most likely be a large (4-5 meters in diameter) iron or lead segmented calorimeter using magnets to deflect daughter products from neutrino interactions in the detector nucleons. The detector would be perhaps 300—500 meters long, and the axis would have to point down towards either FNAL (Illinois) or BNL (New York). This neutrino factory is several years away from being constructed.

The steering committee of this project has selected WIPP as the prime site based primarily on its location with respect to the potential sites of the accelerator (BNL or FNAL). Other benefits of the site for this project would be issued related to detector deployment in the underground utilizing existing infrastructure. It also benefits from the very low mining costs.

### **NNN — The Next Generation Nucleon Decay and Neutrino Experiment**

There have been several workshops that have explored the scientific potential of a next generation nucleon decay and neutrino experiment, a detector with capabilities much better than the current SuperKamiokande. Different groups are now exploring at least three different detection techniques. One is a straightforward extension of the water-Cherenkov method in a 450-kiloton detector that is sometimes known as UNO. LANDD would be a 70-kiloton fine-grained detector built from a liquid Argon TPC. The third concept is for a 100-kiloton detector known as Hybrid because it exploits particle detection with both Cherenkov and scintillation light using a dilute liquid scintillator. The latter two ideas are aimed at avoiding some of the pitfalls of the more conventional water-Cherenkov technique.

These concepts all have one thing in common: their preferred location in the US is in the salt just below the current WIPP depth. This is for several reasons, including the low cost mining. The fact that the salt is relatively radiopure and the air is radon free means that the background singles rates in these detectors may be much lower, possibly resulting in lower energy thresholds. Deployment of such a large detector in salt or rock anywhere presents considerable technical challenges that must be overcome.

### **Neutrino Detection by Radio Antennas**

A very-high-energy astrophysical neutrino detection experiment under consideration includes an array of radio antennas. The antennas will be 100m long and spaced 100m apart in a one-cubic-kilometer block of salt. Japanese and US researchers are investigating the feasibility of such

detection schemes. This can only be performed in a relatively heterogeneous material like salt or ice; a preliminary study of the feasibility of this project at WIPP is underway.

### **High Pressure Helium Time Projection Chamber**

One of the ideas for a next generation solar neutrino experiment now under consideration is a high-pressure (30 atmospheres) helium-filled time projection chamber (TPC). This project does not require very great depths because of its insensitivity to cosmic ray induced backgrounds, but it does require a low radiation environment. The TPC high pressure He tank would be about 17 meters in diameter and 25 meters long. The WIPP site is working with the project to develop a conceptual design for installation in WIPP.

### **Other Projects**

Research and development in other areas, such as geology and geophysics, electronics, and biology, would benefit from the infrastructure available at CUNL. While this proposal concentrates on particle, nuclear and astrophysics, the CUNL will actively solicit and support other areas of research.

## **IV. Concepts for the Underground Cavities in Carlsbad**

Various different concepts for an underground lab, expanded beyond the current north experimental area, that exploit the existing resources and infrastructure at WIPP have been studied. The underground options are considered for various scenarios of the physics program that may unfold at CUNL. Two *new* options are given here for new experimental areas, one at about the existing level in the Salado salt formation and another at the bottom most reaches of the Castile formation below the Salado. They are presented in order of the size of initial construction needed. These cases show the flexibility and adaptability of the site—it can support virtually any size facilities that are needed by the scientific community.

Note that Phase 1 already exists, using the space now being prepared in the northern areas. As part of this document, we are proposing new surface facilities and CUNL staff required to support the experimental program that might occur in the event that the scientific community needs no new underground facilities beyond the north experimental area.

### **Salt Mining and Cavity Stability**

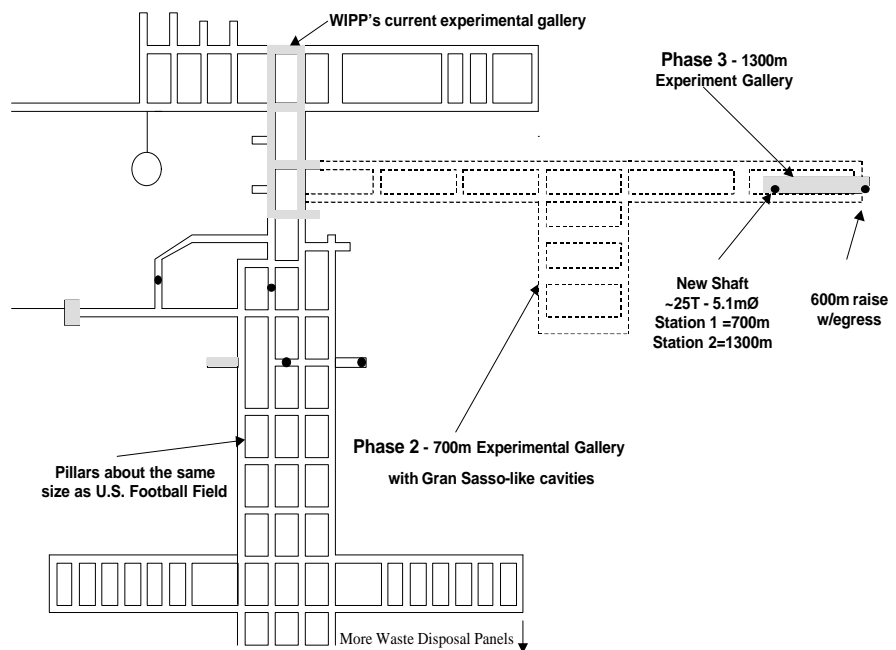
A short discussion of salt mining and cavity stability will be given before discussing each of the options so far evaluated. New experimental rooms would be mined either slightly below the WIPP horizon (700 m level) or in salt near the base of the Castile (1300 m level). At either of these levels the rooms will close over time due to salt creep. This closure means that the rooms either need to be oversized to account for the closure over a period of time, or need to be periodically maintained by trimming the walls, floor and roof. This creep closure is well understood and can be calculated with some precision: WIPP salt is probably one of the best understood rock materials due to the extensive research and laboratory and field measurement carried out in support of the waste disposal mission. The reliability of long-term prediction over the expected life of an underground experimental facility has been shown. The tendency of salt to creep also means that the rooms will be stable, with no unexpected failures (e.g. rock-bursting or movement on pervasive systems of discontinuities).

Non-uniform closure and rock fracture can sometimes be seen in openings in salt, often associated with the presence of partings, clay seams or anhydrite beds. Panel 1 in the existing waste repository, for example, shows fracturing in the floor associated with movement on the underlying anhydrite, and shows fractures at the ribs, influenced partly by an overlying clay seam. In noting these observations it needs to be clearly understood that Panel 1 now greatly exceeds its design life and any excavations intended for long-term use would be designed to avoid or minimize these effects.

The rate of closure of experimental rooms is a function of the stratigraphy, the depth, the size and geometry of the rooms, and the overall local extraction ratio (the fraction of material mined out in the local vicinity). Rooms in producing mines, where extraction is optimized but long-term stability is not needed, are designed to close quickly. Special purpose openings, such as the planned experimental rooms, are designed for slower closure by minimizing the extraction ratio and optimizing the geometry. Detailed calculations have been performed on examples of experimental room geometries at 1300m. These show that with appropriate design, acceptable creep deformations can be achieved at the deep horizon over an expected design lifetime of 30 years.

### Modest Expansion

For experiments that can be conducted at the existing depth, but requiring space (primarily height) of the same order as Gran Sasso, a new series of drifts and cavities is proposed that uses the existing WIPP excavation as efficiently as possible. Twin drifts would be driven to the east from N460 and N780 for about 500m. These would serve as access drifts to all future experiment cavities. From these east-west “mains”, two additional drifts would be driven several hundred



meters south. The experiment cavities would be excavated between these north-south drifts, and bulkheads installed for ventilation control. Note that this keeps nuisance mine dust from additional future experiment workings from impacting the experiments in these cavities. A drawing for this case (Phase 2) is shown which includes 3 halls of Gran Sasso size. We envision a modest program 20-40 on-site external researchers supporting perhaps 100-200 off-site, and a CUNL staff of 10-20 in this case. The estimated cost for underground mining, including contingency at 25%, is \$5.9M.

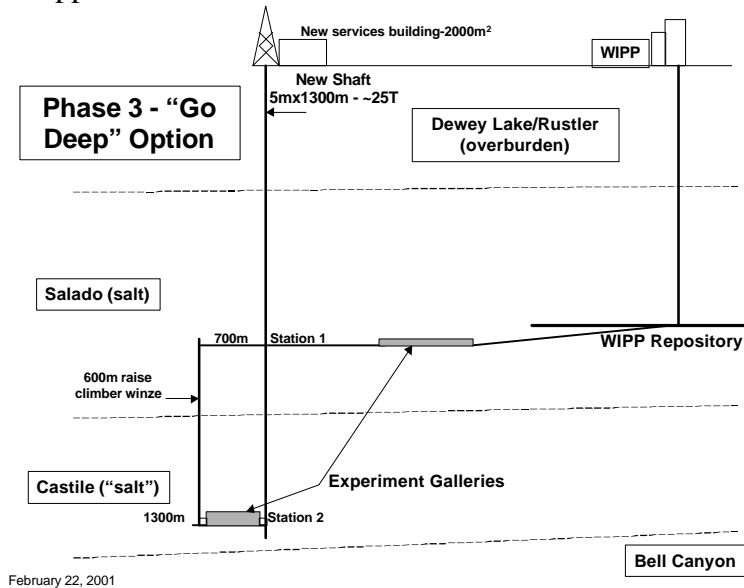
### “Go Deep” Option

The need for more cosmic ray shielding than allowed by the existing depth can be achieved by installation of a new shaft at the easternmost end of the Phase 2 mains; this 50% greater depth results in a cosmic ray reduction of about a factor of 10. This configuration would result in a depth of 1300 meters, or approximately the same depth as Gran Sasso (without the confounding presence



of a complex angle-dependent overburden column), and deeper than at the Kamioka lab. The new shaft would be appropriately sized to accommodate the creation of very large cavities at 1300m, and would provide two stations (one at 700m and one at 1300m). Additionally, a vent and escape raise would be installed from the lower level back up to the Phase 2 mains. With the addition of a fifth shaft at WIPP, new separate surface facilities also make sense. Thus, the Phase 3 configuration includes a change house and other surface support.

This last possibility is sized to accommodate a very large and vigorous research program of the scale of ~200 on-site researchers, as suggested by members of the technical subcommittee. Such a very large physics program likely would require separate access shaft, though access would also be made through the existing infrastructure to save cost. A side-view drawing of this option is shown here. This case would likely represent a world-wide science program of 1,000-2,000 researchers, and require an on-site staff of 50-100.



The cost for this option is broken down into three main pieces: 1) The new shaft from the surface is approximately \$43.6M, 2) miscellaneous access and related equipment is \$14.2M, and 3) the surface building is about \$2M. With a 25% contingency, the total project cost is estimated to be \$74.8M.

## Other facility costs

The cost of any construction project is difficult to estimate without first knowing much more information about the scope of the construction, the schedule it must meet and the manpower available. This is especially true when considering the surface facilities related to CUNL. As a minimum we anticipate the need for a campus building located in Carlsbad that includes sufficient office space, lab space, and high-bay areas. It should have an extensive computing, data collection and archiving, and network system. A scientific library is a necessary component. A candidate location for this campus has been identified on property owned by New Mexico State University. A newly constructed 25,000 square foot laboratory and office building there cost about \$6M. A similar building would support the needs of a scientific community of 25-50 people permanently located there, and a large number of visitors, on a daily basis. With computing resources, electronics equipment, and detector facilities, it is expected that \$10M would be sufficient to provide surface needs over the next 5-7 years.

A need for extensive buildings devoted to the science program of CUNL on the surface at WIPP is not envisioned. In this case, a few modest scale trailers (at least one of which is already available) would be needed to provide on-site space for example for detector operation and monitoring. It may also be useful to have space on the surface to store detector components before they are moved

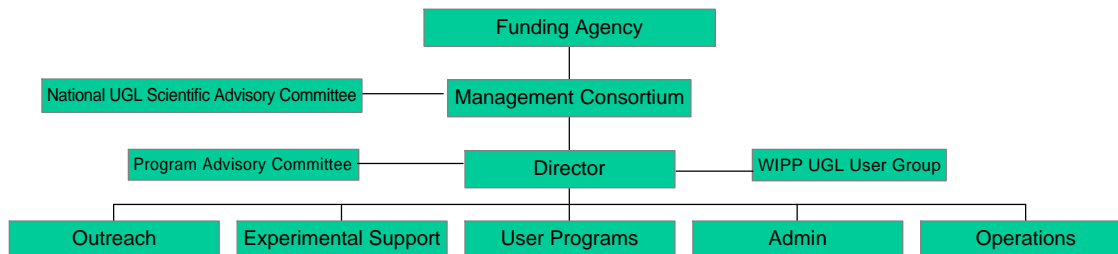
underground, but these kind of needs are very specific to each experiment, and speculation about them is fruitless at this point.

## Personnel Costs

Similar remarks to those above are also true for the personnel costs associated with CUNL. The CUNL consortium (see below) does not now exist in a formal way. The costs depend upon the size of the research program, the level of support required, and the management of said program. A modest program that would develop in the north experimental area would include approximately 10 individuals on the CUNL staff. A more vigorous program would require about double this number, while a program with 200 external researchers underground each day would need about 30-50 people on the CUNL staff. Using a cost of \$100k - \$200k per FTE, about normal in the scientific research community, the personnel costs can be expected to run from \$2M to \$10M annually depending on the size of the research program that is developed.

## V. MANAGEMENT STRUCTURE

The goal of this structure is to allow experimenters to work both efficiently and effectively on their project, and to respond to the needs of the scientific community and funding agencies. We currently envision the overall scientific management structure of CUNL to look similar to that below, although several options could be viable. We believe this provides an efficient and cost-effective structure to provide the kind of management needed for a world-class facility. It can also



be scaled to the effort needed to support the Laboratory as it grows from its current status to the robust program envisioned. This Management Consortium is comprised of a Council of Presidents and a Board of Trustees comprised of its member institutions. This consortium, together with a National UGL Scientific Advisory Committee, would be responsible for the oversight and governance of the WIPP UGL, and would be responsible for the appointment of the Director of the WIPP UGL and setting of the overall scientific policy and direction of the Laboratory. LANL, NMSU, and UC (though INPAC) have expressed great interest in participating in the consortium. We envision a much broader representation in the final makeup of the consortium. We also envision the possibility of this consortium being much broader involving more than one UG site.

The Director is responsible for the leadership and management of the Laboratory and would appoint a Scientific and Technical Advisory Committee to help define the experimental program at the site. A User Group with its Executive Committee would provide feedback to the Director on the User Program at the Laboratory. The Director would also have several Department Heads responsible for the major functions of the Laboratory, such as the User Program, Experimental Support, Operations, and Administration. The primary link of the CUNL to the WIPP Administration and

Maintenance and Operations (M&O) contractor (Westinghouse True Solutions, WTS) would be through the Operations Department.

### **Department Functions:**

The *Outreach* function could include a Visitor Center in Carlsbad that would provide a public forum for the science conducted at CUNL. There are several examples of how this might be setup. One might expect a poster at the Carlsbad Caverns that would advertise the Visitor Center, taking advantage of the large numbers of people that visit the Caverns annually. It would also include outreach programs where scientists from the program would visit schools and other institutions to stimulate interest in the science being conducted at the site. This would also be the coordinating body for student programs, which will form an important part of this Laboratory.

The New Mexico - West Texas region has a large Hispanic population and contains several minority-serving universities with strong scientific research programs including NMSU, the University of New Mexico, University of Texas - El Paso, and Texas Tech University. NMSU is the only land grant university in the US that is both designated minority serving and a Carnegie Level-I research institution, and it is the lead state institution for the AMP and AGEP programs to train undergraduate and graduate students in science, mathematics, engineering and technology. New Mexico is also an NSF EPSCoR state with NMSU taking the lead. Through NMSU and the other regional institutions, CUNL would provide a vigorous program for minority students.

The *User Program* would provide assistance to users and visitors for access to the site, including training. It would coordinate a short-term housing program, and aid experimenters in obtaining long-term housing if needed. It could also facilitate transportation needs for the short-term visitors. It would also be responsible for collection of publications and general records and statistics for the Laboratory.

The *Experimental Support* function relates to the direct support of the experimental program. This would include support for the scientific infrastructure, such as clean rooms, detector labs, cryogenics, computing facilities, and operation of the low-background counting facility. It would aid external researchers with detector construction and operation. These would be primarily scientific staff, engineers and technicians.

The *Operations* team would provide the liaison function of the experimental program to the mine site and infrastructure. It would be responsible for planning and obtaining necessary resources for the experimental program, such as mining, utilities, underground to surface operations, and interface to the CBFO and WTS. It would also provide the Project Management needed for any construction activities related to these infrastructure activities.

The *Administration* function provides basic support in the areas of budgets, human resources, payroll, legal, and similar support services, as required by the funding agencies.

### **Level of Effort and Evolution:**

The management structure must be scalable from the present levels to the anticipated robust program of 200 users on site with 4-5 major experiments. The actual level of effort at any given time must reflect the true needs of the experimental program at the Laboratory.

At the early stages, the basic Funding Agency/Consortium/Lab Director/STAC structure would be established. It may be that some of the Administrative and Operations functions could be provided

through existing resources at the site, similar to what is going on now. A primary function of the Director would be to establish the initial scientific program, working with the scientific community and the funding agencies. Small-scale experiments could run immediately at the North Experimental Area. As new experiments requiring new scientific infrastructure and/or mining activities are identified, construction at varying levels would commence. The ability of WIPP to phase new capabilities as needed allows for a robust scientific program to be established early on and continue to expand as new requirements are established.

## **VI. Summary**

As outlined above, there is a growing community of scientists who are working at the WIPP site near Carlsbad, NM. Based upon this and the nationwide interest in the scientific community, it is now time to develop the Carlsbad Underground National Laboratory to take advantage of the unique opportunity available to the scientific community. We believe that nowhere else in the US can a facility be constructed so cheaply that could effectively contribute to the study of at least four major areas of fundamental physics, namely: neutrino masses and oscillations, proton decay, dark matter, and supernova neutrinos. The site has the ability to respond to the needs of the scientific community on an "as-needed" basis, if so desired, or major Laboratory facilities can be constructed and a large infrastructure established on a very short time period. In either event, we look forward to establishment of the Carlsbad Underground National Laboratory.

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